Heat Pumps: the new Winter Peak

The Challenges

In the future, there are a number of energy trends that will result in big challenges in balancing the grid:

- The shift to renewable energy means that our power supplies will be more intermittent and cannot be scaled up in response to demand.
- The shift of residential heating to heat pumps means that electricity demand will be higher overall, higher at peak times each day, and there will be a new winter peak – where electricity demand is much higher in winter than in summer.

This results in two grid-balancing challenges:

- **Winter peak challenge**: There will be a new winter peak caused by the conversion of domestic heating to electrically powered heat pump heating.
- **Daily peak challenge:** The existing daily peaks in electricity consumption may be made much larger by heat pumps.

This report examines the winter peak problem.

Executive Summary

- With electrified (heat pump) heating and electric vehicles, there will be increased demand for electricity. We estimate that by shifting all heating to heat pumps, and all cars to electric vehicles, electricity demand would increase from 497 TWh/year to 853 TWh/year.
- However, winter peak electricity demand will increase from 1653 GWh/day to 3782 GWh/day.
- In a renewable grid, the amount of generation must be enough to meet this winter peak – meaning that generation must be higher than needed during the rest of the year. We estimate that in order to meet demand during this new winter peak:
    - **With the existing building stock – we must generate 2167 TWh/year in order to meet this demand, 4.4x the current electricity supply.**
- Smart Retrofit can help reduce this:
    - **If we use Smart Retrofit to reduce overall heat demand by 36%, we reduce electricity demand by 111 TWh/year.**
    - **However, because this reduces peak demand - this reduces the total generation required from 2167 TWh/year to 1585 TWh/year – a generation saving of 582 TWh/year.**
    - **This creates a saving of €843 billion over 20 years - €21000 per household (assuming a levelized cost of energy of 7.2c/kWh).**
- These figures assume both that residential heating is converted to heat pumps, and that existing vehicles become electric cars that can be used to actively balance the grid at times of highest demand. This is based on an even mix of wind, solar, and nuclear power generation.

Demand-side challenge

- German domestic consumers currently demand 497 TWh/year of electricity, and 447 TWh/year of heating [1].
- If this heat demand were met through heat pumps, this would result in an additional 215 TWh/year of electricity consumption.
- However, this new demand would not be evenly spread throughout the year – since most heating demand is in winter.
- In addition, converting to electric cars would result in additional electricity demand of 141 TWh. [2]
- Combined – this results in peak demand rising to 3782 GWh/day, from an existing peak of 1653 GWh/day – 2.3x higher.

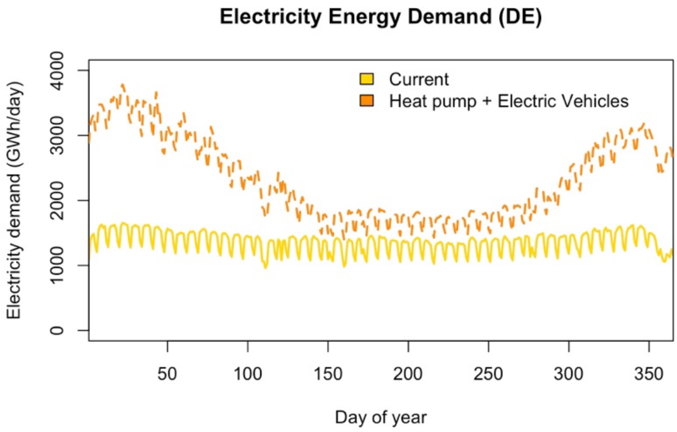

Figure 1: Current electricity demand in Germany (2019) (yellow), vs estimated electricity demand if all cars were replaced with EVs, and all domestic gas consumption were replaced with heat pumps with a COP of 3.0 (orange)

Supply-side challenge

- In periods of low sunlight or wind, these renewable sources produce substantially less energy.
- Around 38% of the time, in Germany, the energy generation of wind and solar are below 20% of their effective capacity (Figure 2).

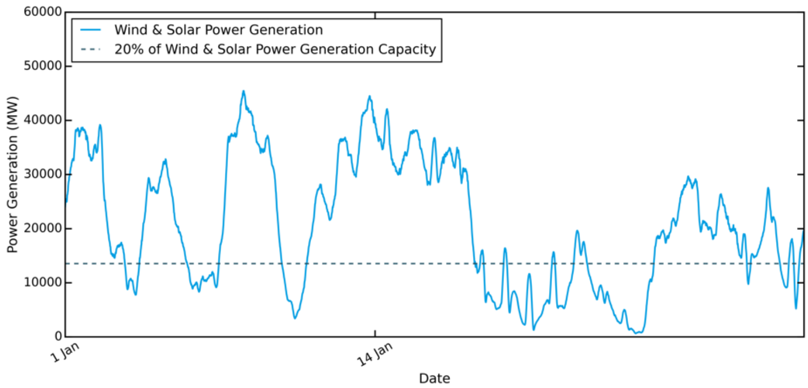

Figure 2: Power generation from solar and wind in Germany, January 2019

The effect of Smart Retrofit in a Heat Pump World

A house with properly installed insulation can be heated with a lower radiator temperature – improving heat pump efficiency

- A heat pump running with a flow temperature of 45˚C instead of 35˚C results in a 41% energy consumption increase for the same heat output
- This reduction in flow temperature can be achieved by reducing heat demand by 40%.
- This means that a 40% reduction in heat demand can lead to a 57% electricity demand reduction – because the remaining heat required can be achieved more efficiently. [3]

A better-insulated house can retain its heat for longer – enabling better energy shifting

- The house, when optimised with an Algorithmically Controlled Smart Thermostat, can do more of its heating during off-peak times – taking advantage of cheaper electricity – as the house will then stay warm during peak times

However, poor quality retrofits that do not reach the level of savings described here will not reach this level of electricity savings.

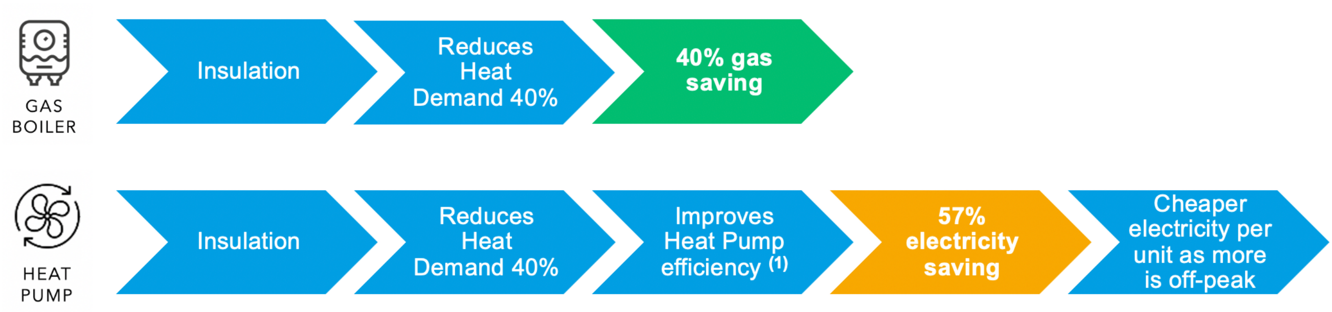

Figure 3: An illustration of how reducing heat demand by 40% can result in improved heat pump efficiency - resulting in a 57% electricity saving

Smart Retrofit and the Market for Lemons - Theory

There is a market failure at the heart of the retrofit market.

The savings attributable to retrofit are determined via "deemed savings" methods. These methods mean that a given insulation measure is always deemed to have made some level of improvement to the house – with no accounting for the actual performance of the retrofit.

This means that a retrofit installed to a low quality - that achieves little savings - is treated exactly the same as a retrofit installed to a high quality that does achieve good savings.

This is because customers (and the governments who encourage or mandate certain levels of insulation) cannot distinguish between high-quality retrofits and low-quality retrofits.

This is known in Economics as a "Market for Lemons". It results in those who perform low-quality retrofits being rewarded – as they can be more competitive on price, but are never held to account for their low quality retrofits.

This occurs until there are no sellers who provide high-quality retrofit – because those who provide low-quality retrofit are more competitive and expand until the whole market is low quality.

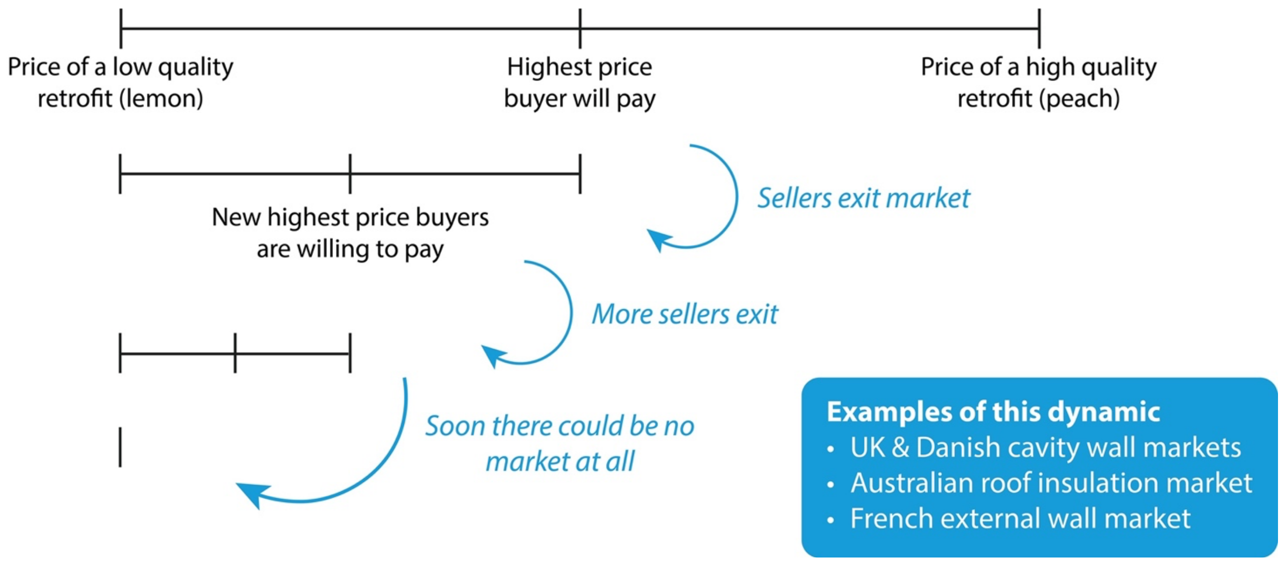

Figure 4: A diagram showing the market dynamics in a "Market for Lemons". Because buyers are only willing to pay for the retrofit they expect to receive – the highest price they are willing to pay is the value of a retrofit in the middle of the market in terms of quality. However, this dynamic then forces the high-quality market participants to exit the market or reduce their quality – otherwise, they would be selling retrofits of a higher value than they will be paid. However, because the highest quality market participants have exited, the average quality reduces – so the next highest quality sellers (who were previously of average quality) are then faced with the same choice. This cycle continues until only the lowest quality sellers remain – and the only market left is one that is the lowest possible quality. This happens regardless of how much extra a high-quality retrofit costs to provide.

Smart Retrofit turns this market dynamic on its head. Smart Retrofit uses real performance monitoring to measure the actual savings attributable to the retrofit, meaning. This means that customers can distinguish between a high-quality and low-quality retrofit.

This means the provider can be held accountable for the quality of the retrofit – ensuring a high-quality retrofit.

Smart Retrofit and the Market for Lemons - Practise

In a trial in Eccles in the northwest of the UK, we tested whether a better install of existing insulation could improve performance in some nearly new housing.

We carried out monitoring of 12 houses that were built in the late 2010s, to determine their real energy performance.

We then replaced their existing insulation to ensure a high-quality install.

Under a “deemed savings” method, this would have made no difference – the houses before and after our improvements would have appeared the exact same to an EPC assessor and received the same EPC certificate.

However – we continued our monitoring in order to find their real energy performance after we had re-installed the roof insulation.

We found an 18% energy saving after we had replaced the existing insulation with well-installed insulation.

This means that the original insulation was installed in a way that made the houses require, on average, 22% more total heat than under a high-quality install.

However, this performance gap is not captured in EPC certificates – because EPC certificates use deemed savings not real performance monitoring. Only real performance monitoring can distinguish between houses with well-installed insulation which perform as they should - and houses with poorly installed insulation that do not perform as they should.

Electric Vehicles

One method that could be used to balance supply and demand is to use electric cars. If all 48 million cars in Germany became electric vehicles, and each one had a battery capacity of 50 kWh, then combined they would have a total capacity of 2400 GWh. This added capacity could interface with the grid – charging the batteries in times of surplus, and then discharging to power the grid when necessary.

However, there are some constraints:

- These cars are used – and so must always have enough battery power for the user of the car.
- If the entire battery capacity of a car were used every day, it would "age" the battery significantly – equivalent to driving around 100,000 km/year.
- At any given time, not all cars are connected to a charger and so cannot be actively managed.
- Some owners may not wish to participate in such a scheme.
- Electric cars often avoid charging above 80% or below 20% in order to reduce battery wear.

In our modelling, we have assumed that around 75% of this value – 1.8 TWh – is available to the grid for grid balancing. Our modelling shows that we would only need to take advantage of this when both renewable generation is particularly low, and the weather is very cold.

Modelling the Energy System

In this section, we estimate the required grid capacity in order to meet winter demand, according to different scenarios.

All these estimates assume that we meet our energy generation needs from an even mix of wind, solar, and nuclear power. We also assume that we have 1.8 TWh of battery storage connected to the grid.

These are based on Smart Retrofits that achieve an average heat saving of 36% over the housing stock. In addition, we have accounted for the improvement in heat pump efficiency from reduced energy demand.

- Without Smart Retrofit, we have assumed that the heat pump would run at a flow temperature of 55˚C, achieving a COP of 2.08. [3]
- A house that previously required a flow temperature of 55˚C, following a Smart Retrofit which reduced heat demand by 36%, would require a new flow temperature of 42˚C. In this circumstance, the heat pump achieves a COP of 2.75. [3]

Table 1: Results of energy system analysis

Scenario	Today	No retrofit	Smart Retrofit
Heat Demand	447 TWh	447 TWh	286 TWh
Electricity required to meet heat demand	0 TWh	215 TWh	104 TWh
Total electricity demand	497 TWh	853 TWh	742 TWh
Total generation required to meet peak demand	497 TWh	2167 TWh	1585 TWh
Multiple of supply/demand	1.00x	2.54x	2.13x

Table 1 shows that, the total electricity demand reduces from 853 TWh to 742 TWh – a saving of 111 TWh – but that the total generation required is reduced by 582 TWh.

In short, in this scenario, we have found that a retrofit saving of a total of 111 TWh, across the energy system, results in a reduction in necessary generation of 582 TWh.

This is 5.2x the impact that would be expected by the reduction in electricity alone.

This is because the cost of the grid in the future renewable world is largely driven by the level of electricity peak – which disproportionately comes from the seasonal winter heating peak.

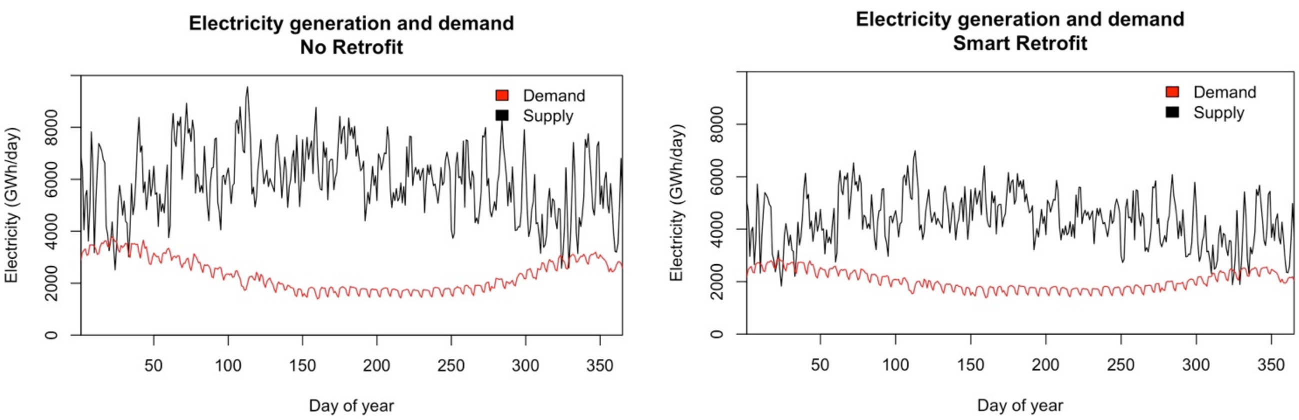

Figure 5: Modelling results - electricity supply and demand throughout the year under no retrofit and Smart Retrofit scenarios

Cost Savings

With Smart Retrofit, we move from required generation capacity of 2167 TWh/year to 1585 TWh/year – a saving of 582 TWh/year.

In Table 2, we show the Levelized Cost of Energy by power source, as determined by Lazard in their most recent analysis.

Table 2: Levelized Cost of Energy (LCOE) (Lazard [4])

Power source	Cost range ($USD/MWh)	Cost midpoint ($USD/MWh)	Cost midpoint (€/MWh)	Weighting in analysis
Solar (utility)	$28 - $41	$34.5	€29.03	0.33
Solar (rooftop)	$59 - $221	$140	€117.81	0
Wind (onshore)	$26 - $50	$38	€31.98	0.16
Wind (offshore)	$83	$83	€69.84	0.16
Nuclear power	$131 - $204	$167.5	€140.95	0.33

Using the mid-point values and applying our existing assumption of 1/3rd solar (all utility), wind (of which half is on-shore and half off-shore), and nuclear, we find an LCOE across the energy system of €72.39/MWh – or 7.2c/kWh.

This means that the Smart Retrofits **reduce grid costs by €843 billion over 20 years – or €21002 per household.**

- **This is based on a LCOE for electricity of 7.2c/kWh**
- **At an energy price of 10c/kWh, this increases to €29000 / household**
- **At an energy price of 15c/kWh, this increases to €44000 / household**

Table 3: Cost savings of Smart Retrofit

(LCOE = 7.2c/kWh)	**Required generation (TWh/year)**	**Cost of energy system (€/year)**	**Cost over 20 years (€)**
No retrofit	2167 TWh	€157 billion/year	€3137 billion
Smart Retrofit	1585 TWh	€115 billion/year	€2295 billion
Saving	582 TWh	€42 billion/year	€842 billion
Saving (per household)	**14506 kWh**	**€1050/year**	**€21002**

Savings due to retrofit in a renewable world – Illustration

Our modelling shows that, with a high quality Smart Retrofit, we can significantly reduce our need to overbuild renewable generation to meet the peak demand in winter. **A 36% heat demand reduction leads to a reduction in electricity demand of 111 TWh – but by reducing peak demand, this translates to a reduction in required electricity generation of 582 TWh.**

This is because the way in which Smart Retrofit affects the energy system is fundamentally different in a renewables world – because energy generation must be large enough to meet the peak demand. Reducing this peak demand allows us to make generation smaller – reducing the amount of energy that is generated year-round – even in summer, when houses are not being heated at all.

With fossil fuels – if we decrease a house's annual energy demand from 20,000 kWh/year to 10,000 kWh/year – the saving is simply 10,000 kWh.

However, consider the same house and the same retrofit with a renewable grid. Before retrofit, the house, which used 20,000 kWh/year, would have used around 4600 kWh in the month of January. After retrofit, it would use only 2300 kWh in the month of January.

In a renewable grid, the 4600 kWh that the pre-retrofit house needed in January had to be generated year-round – because there is no way to scale up or down production. This is a total saving of 55,200 kWh/year.

But now, the house has been retrofitted – and it only needs 2300 kWh in January. This 2300kWh/month must still be generated year-round – which is still a total of 27,600 kWh. But this has been reduced from 55,200 kWh.

So, the retrofit – which reduced total energy demand from 20,000 kWh to 10,000 kWh, allows us to reduce energy generation for that house from 55,200 kWh to 27,600 kWh – a saving of 28,000 kWh.

This simple illustration does not account for peaks within January, or troughs in renewables generation – but illustrates how retrofit savings can cause much higher savings in required generation.

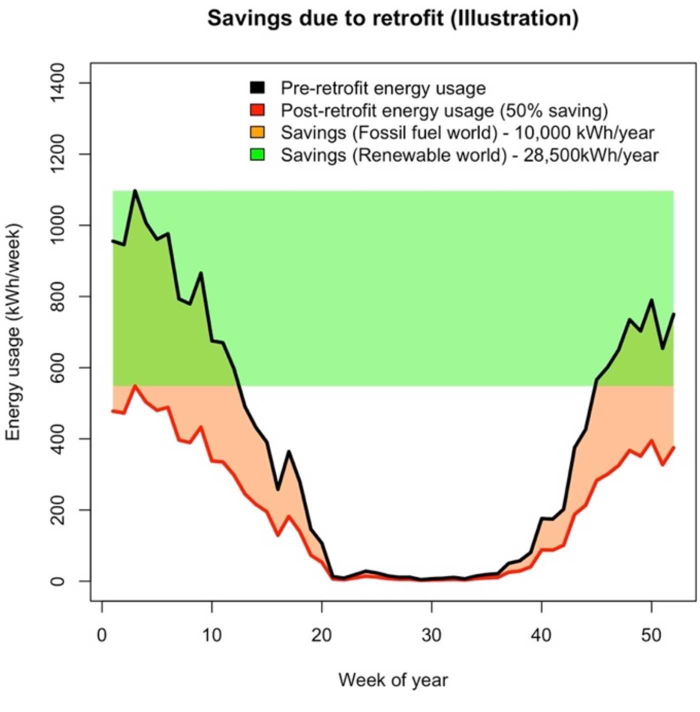

Figure 6:We examine a saving due to retrofit of 10,000 kWh/year. In a fossil fuel world, this would save us 10,000 kWh/year. But in a renewable world, our saving is much larger. This is because our 10,000 kWh/year saving corresponds to a January saving of circa 2300 kWh – but to meet the January demand, this extra 2000 kWh must be generated in every month – a total of 28,000 kWh.

Caveats

There are several caveats to this analysis:

- We do not have data showing how much gas is used domestically each day in Germany. So, we have approximated it using the total amount used in a year, and then distributed this across each day of the year based on a typical profile – as determined via an analysis on our own dataset based on houses in Belgium.
- Heat pumps have been assumed to have a constant coefficient of performance (COP) over the year. In practise, this may be lower during the coldest days of winter – increasing energy demand even further in winter. In addition, if heat pumps are installed in houses that are unsuitable for them, this may decrease even further. Smart Retrofit can measure the energy performance of the house to understand what heat pump is required and what intervention may be necessary to ensure good heat pump performance.
- This analysis works from the basis that the hourly peak problem has been solved, and the only challenge remaining is to ensure that enough electricity is generated each day. In practise, we may have to consider both problems (and their interactions) at once.
- In Germany, around 1.7% of heating demand is met electrically. This has not been included in this analysis.

Sources

[1] "Disaggregated final energy consumption in households – quantities" – Eurostat (online data code - NRG_D_HHQ)

[2] If all of Germany were to switch to electric vehicles, it is estimated that this change would increase the country's electricity usage by an additional 141 TWh. This estimation was generated based on a 2021 finding that there was a total of 48,248,584 cars in Germany [A] and that average yearly distance travelled is 13,602 km (8451.89 miles) [B]. A study of electric vehicle battery usages across multiple car manufactures found that the average energy required to drive one mile is 0.346 kWh [C].
[A] https://www.best-selling-cars.com/germany/2021-germany-total-number-of-registered-cars-by-brand/
[B] https://www.odyssee-mure.eu/publications/efficiency-by-sector/transport/distance-travelled-by-car.html
[C] https://ecocostsavings.com/average-electric-car-kwh-per-mile/

[3] Based on an external temperature of 2˚C, data taken from the technical guide for the Veissmann Vitocal 200-A heat pump, unit type AWO-M 201.A04.

https://viessmanndirect.co.uk/files//ea6a61ab-9c44-4985-948f-abd901688277/1905%20Vitocal%20200-222-A%20%20Download%20-%20Technical%20Guide.PDF

[4]" Lazard's Levelized Cost of Energy Analysis – version 15.0" – Lazard, 2021.
https://www.lazard.com/media/451881/lazards-levelized-cost-of-energy-version-150-vf.pdf
Exchange rate of £0.7259/USD used (average exchange rate 2021, HMRC)
Exchange rate of €0.8415/USD used (average exchange rate 2021, HMRC)

[5] "Energy consumption in households" – Eurostat
https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households#Energy_products_used_in_the_residential_sector