The New Winter Peak

Executive Summary

- The shift to renewable energy means that our power supplies will become more intermittent and be unable to scale up in response to demand.
- With electrified (heat pump) heating and electric vehicles, electricity demand will increase.
    - We estimate that by shifting all domestic heating to heat pumps, and all cars to electric vehicles, electricity demand in the EU would increase from 2744 TWh/year to 3946 TWh/year.
    - In addition, because heat pumps are used most on the coldest days, we estimate that the winter peak of electricity demand will increase from 9146 GWh/day to 15849 GWh/day.
- In a renewable grid, generation must be enough to meet this winter peak – meaning that generation will be higher than needed during the rest of the year.
    - **We estimate that we will require 9883 TWh/year to meet the winter peak of demand - 3.6 times higher than the current electricity supply.**
- Smart Retrofit can help reduce this:
    - **If we use Smart Retrofit to reduce overall heat demand by 36%, we reduce the electricity demand of heat pumps by 347 TWh/year.**
    - **However, because this reduces the winter peak of demand – this reduces the total generation required from 9883 TWh/year to 8154 TWh/year – a generation saving of 1729 TWh/year.**
    - **This creates a saving of €3.5 trillion over 20 years - €18000 per household (assuming a levelized cost of energy of 10c/kWh).**
- In short – meeting peak winter demand requires a total generation of 9883 TWh/year – but with Smart Retrofit, this reduces to 8154 TWh/year, saving €3.5 trillion in power generation costs over 20 years.
- These figures assume that existing vehicles in the EU become electric cars, which can be discharged to power the grid at times of high demand.
- We examine the costs associated with using direct electric heating instead of heat pumps. We find that this strategy would result in power generation costs that are much larger than if heat pumps are used.
    - Direct electric heating costs an additional €5.6 to €8.9 trillion over 20 years in power generation costs – equivalent to €28,000 – €45,000 per EU household.
- Our modelling assumptions, caveats, and limitations are detailed in Appendix 1 of this document.

The Challenges

There are a number of energy trends that will result in challenges in balancing the grid:

- The shift to renewable energy means that our power supplies will become more intermittent and be unable to scale 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 – because electricity demand is much higher in winter than in summer.
- The shift towards electric vehicles will result in higher electricity demand – but if managed correctly, these can be used as batteries to help balance the grid.

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 - which will use the most energy during the coldest days of the year.
- **Daily Peak Challenge:** The existing daily peaks in electricity consumption may be made much larger by heat pumps.

This report examines the winter peak challenge.

Demand-side Challenge

- The EU electricity grid currently demands 2744 TWh/year of electricity. [1]
- EU households require 1809 TWh/year of space heating. [2]
    - Of this, 349 TWh is met using direct electric heating, and 195 TWh is met using heat pumps [2].
- If EU domestic heat demand was met entirely through heat pumps, this would result in an additional 605 TWh/year of electricity consumption.
    - This includes the electricity savings met through converting direct electric heating to heat pump heating.
- However, this new demand would not be evenly spread throughout the year – since most heating demand is in winter.
- In addition, changing all current vehicles to electric vehicles would result in additional electricity demand of 598 TWh/year [3].
- Combined – this results in peak demand rising to 15849 GWh/day, from an existing peak of 9146 GWh/day – 1.7x higher.

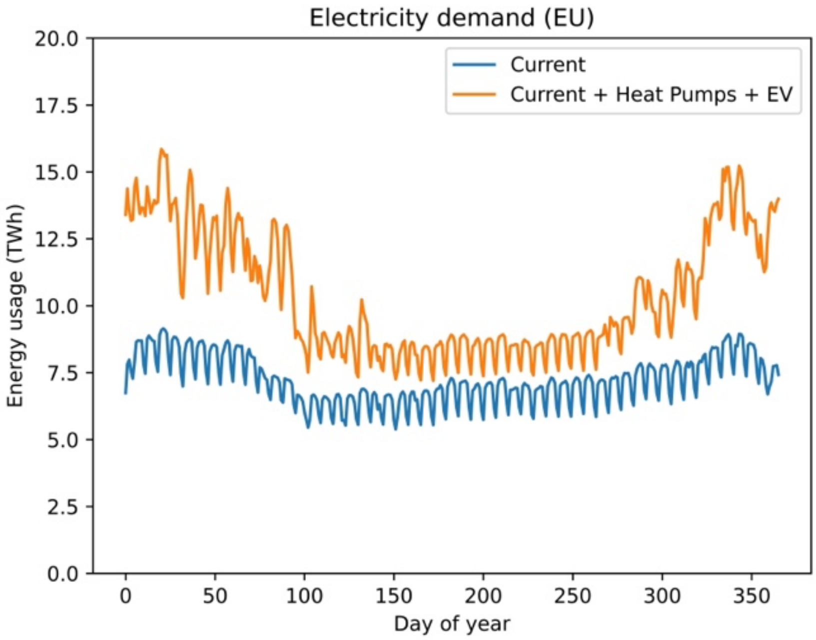

Figure 1: Electricity demand in the EU (2020) (blue), vs estimated electricity demand if all cars were replaced with EVs, and all domestic gas consumption were replaced with heat pumps (orange).

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 35˚C instead of 45˚C requires 29% less energy input 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. [4]

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.

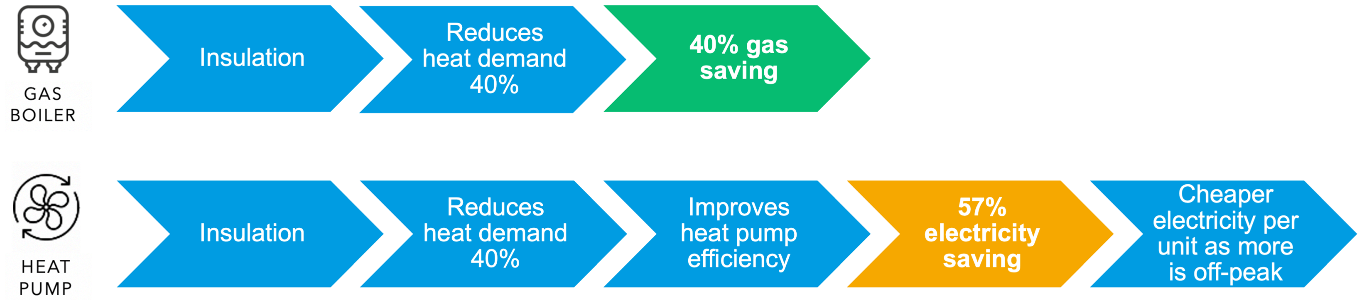

Figure 2: An illustration of how reducing heat demand by 40% can result in improved heat pump efficiency - resulting in a 57% electricity saving.

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.

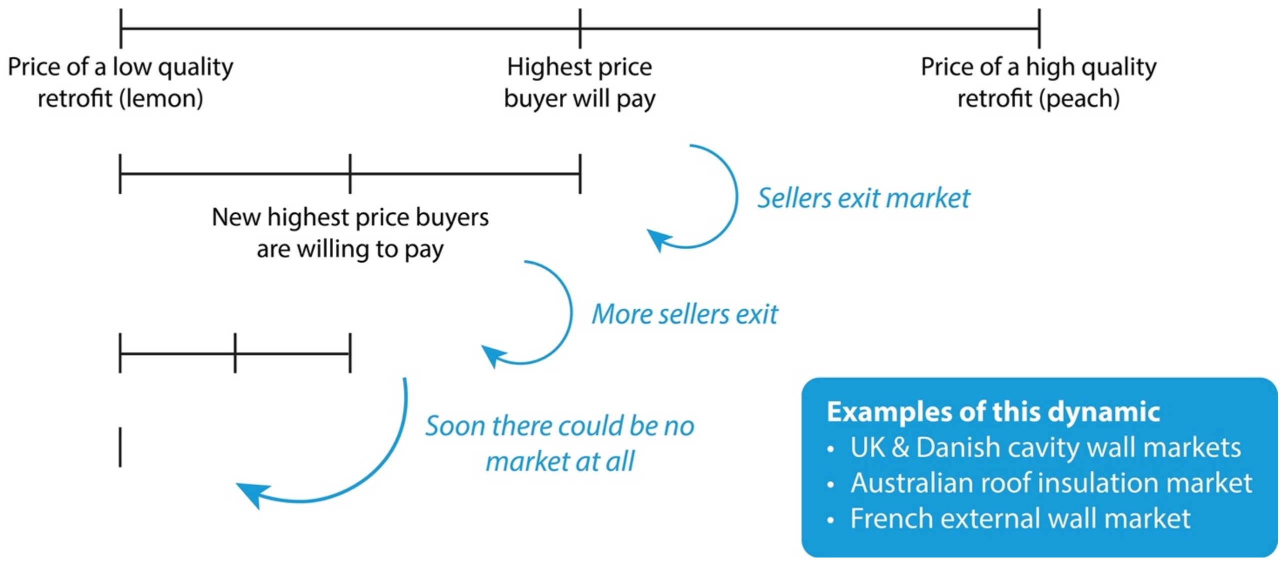

Figure 3: A diagram showing the market dynamics in a "Market for Lemons". Buyers are only willing to pay for the retrofit, they expect to receive – therefore the highest price they are willing to pay is the value of a retrofit in the middle of the market in terms of quality. However, this dynamic then 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 - Practice

In a trial in Eccles in the northwest of the UK, we tested whether a better installation 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 installation.

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 help balance supply and demand is to use electric cars. If all 246 million cars in the EU became electric vehicles, and each one had a battery capacity of 40 kWh, then combined they would have a total capacity of 9.8 TWh [3]. 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% to reduce battery degradation.

In our modelling, we have assumed that 50% of the total possible capacity (4.9 TWh) is available for grid balancing at any one time. 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.

Power Interconnectors

Another method which can be used to help balance the grid is by using international power interconnectors, so that a surplus of energy in one country can be used to power a shortage in another country.

In our modelling, we assume these exist so long as the marginal cost saving over 20 years is larger than the capital expenditure.

- These cost around €3 million per km per GW. [7]
- When these interconnectors are used, they lose 3% of energy per 1000 km. [8]

Modelling the Energy System

In this section, we estimate the required renewables generation capacity in order to meet winter demand, according to two scenarios:

- "No retrofit" scenario: The existing building stock is converted to heat pumps. All cars are replaced with electric vehicles, and 50% of their total battery storage (4.9 TWh) can be used for grid balancing without constraint. International power interconnectors exist where their marginal cost saving over 20 years is higher than their required capital expenditure.
- "Retrofit" scenario: As in Scenario 1, except Smart Retrofit has uniformly reduced EU heat demand by 36%.

This modelling works by finding the cost-optimal quantities of wind, solar, and nuclear generation for each European country, and the cost-optimal pattern of international power interconnection to meet demand across the EU between 2016 and 2021, given the weather patterns in those years.

Our assumptions, caveats, and the limitations of this analysis are discussed in Appendix 1 of this document.

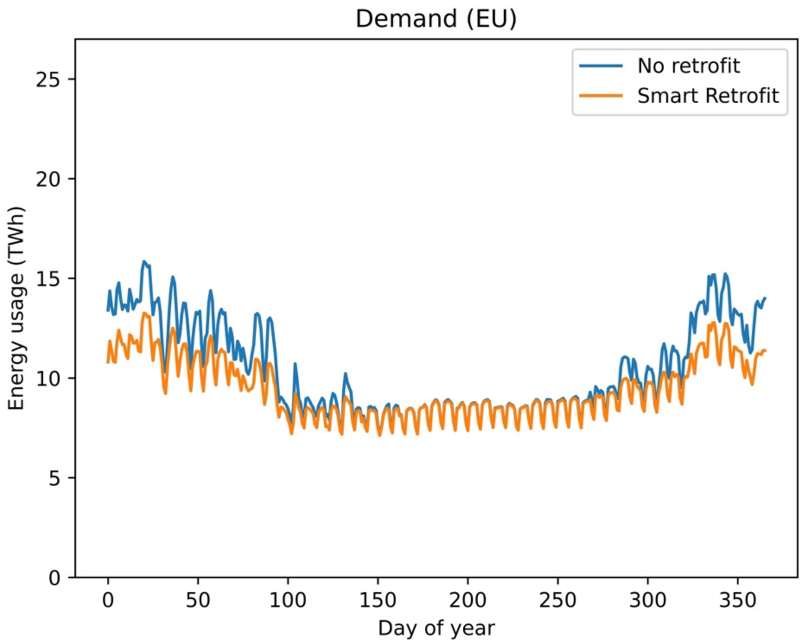

Figure 4: Electricity demand in the EU (2020) in the two scenarios.

Results

To meet demand, the EU requires enough renewable generation to cover both peaks of demand and troughs of supply.

Table 1: Results of energy system analysis

	No Smart Retrofit	Smart Retrofit	**Saving due to Smart Retrofit**
Total electricity demand (TWh/year)	3946	3599	347
Required Generation (TWh/year)	9883	8154	1729
Optimal Energy Mix (Wind, Solar, Nuclear)	51% / 49% / 0%	51% / 49% / 0%	
Generation wasted	60%	56%	
Heat Pump Coefficient of performance (EU-wide average)	2.39	2.85	0.46 improvement
Cost at 10c/kWh of generation (€ billion/year)	988	815	173
Total cost over 20 years (at 10c/kWh) (€ trillion)	19.8	16.3	3.5

Table 1 shows that Smart Retrofit reduces the total electricity demand from 3946 TWh to 3599 TWh – a saving of 347 TWh – but that the total generation required is reduced by 1729 TWh.

This is 5.0x the impact that would be expected by the reduction in electricity usage alone.

In short – saving just 347 TWh/year of electricity for heating has led to saving the need for 1729 TWh/year of generation.

This means that every 1 kWh of energy saved by retrofit saves 5 kWh of required generation.

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

This large generation saving results in significant cost savings:

- Based on a Levelized Cost of Energy (LCOE) of 10c/kWh, this saves €3.5 trillion over 20 years – or €18,000 per household in the EU.
- Based on a higher LCOE of 20c/kWh, the saving is €35,000 per household in the EU.

This is an average figure – savings would be higher in countries with higher heat demand, and lower in countries with lower heat demand.

Results: Direct Electric Heating

This scenario checks the power generation costs of using direct electric heating across Europe, instead of Heat Pumps. We find that this results in an additional €8.9 trillion in power generation costs without Smart Retrofit, and €5.6 trillion with Smart Retrofit.

Table 2: Results of energy system analysis

Scenario: **Direct Electric heating** **(Build more renewables)**	No Smart Retrofit	Smart Retrofit	**Saving due to Smart Retrofit**
Total electricity demand (TWh)	4969	4340	628
Required Generation (TWh)	14364	10940	3424
Optimal Energy Mix (Wind, Solar, Nuclear)	51% / 49% / 0%	50% / 50% / 0%	
Generation wasted	65%	60%	
Cost at 10c/kWh of generation (€billion/year)	1436	1094	342
Total cost over 20 years (at 10c/kWh) (€ trillion)	28.7	21.9	6.8

Table 2 shows that, in the direct electric heating scenario, the costs are significantly higher.

The power generation costs over 20 years are significantly higher than with heat pumps:

- **Without Smart Retrofit** – The power generation when using direct electric heating costs €8.9 trillion more than heat pumps over 20 years (45% more).
    - This is equivalent to an extra cost of €45000 per household over 20 years.
- **With Smart Retrofit** - The power generation when using direct electric heating costs €5.6 trillion more than heat pumps over 20 years (34% more).
    - This is equivalent to an extra cost of €28000 per household over 20 years.

These cost differences are due to direct electric heating being significantly less efficient than heat pumps. Heat pumps typically have an effective coefficient of performance of 2-4, whereas direct electric heating can never be more than 100% efficient.

If the EU did use direct electric heating instead of heat pumps, the power generation cost savings due to Smart Retrofit would be very large, at €6.8 trillion over 20 years (€35000 per household).

These figures are calculated for the EU as a whole, and so the cost differences for individual countries may vary significantly from these figures. In particular, countries in warmer areas of Europe that have lower than average heat demand may see a smaller cost difference between heat pump and direct electric heating than the average reported here.

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 347 TWh – but because this reduces peak demand, this translates to a reduction in required electricity generation of 1729 TWh – 5.0x higher.

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 reduce the necessary supply accordingly – 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 is generated year-round – because running costs cannot be reduced in line with decreasing demand, unlike with fossil fuels. This leads to a total generation 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 27,600 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.

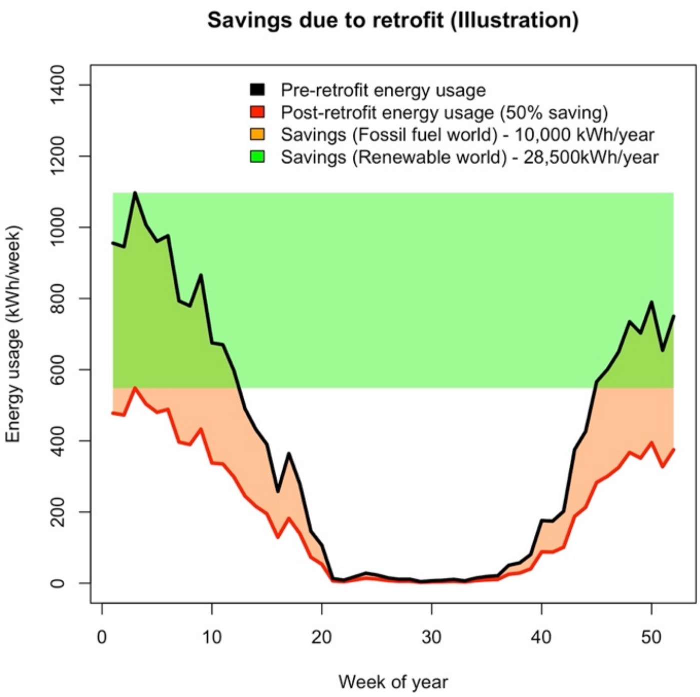

Figure 5: We examine a saving due to retrofit of 10,000 kWh/year. In a fossil fuel world, this would save us 10,000 kWh/year. But in a renewable world, our saving is much larger. This is because our 10,000 kWh/year saving corresponds to a January saving of circa 2300 kWh – but to meet the January demand, this 2300 kWh must be generated in every month – a total of 27,600 kWh.

Appendix 1: Modelling Assumptions, Caveats and Limitations

- To estimate the distribution of heating demand over the year for each EU region, we have used a Heating Degree Days (HDD) and Cooling Degree Days (CDD) calculation based on weather data for the period (2015-2021).
  - We use a set point of 18˚C for heating and 21˚C for cooling but ignore any temperature differences less than 3˚C [6].
- Wind and Solar generation are distributed over a year according to the distribution of generation from those power sources in each EU country during the period [1]. Nuclear is assumed to produce power at a constant rate.
- As discussed in the Electric Vehicles section, there are 4.9 TWh of battery storage available from electric vehicles. This analysis does not consider whether it is cost-effective to build additional battery storage capacity.
- As discussed in the Power Interconnectors section, international interconnectors exist if it is cost-effective to do so given a power interconnector lifetime of 20 years.
  - A power interconnector costs a capital expenditure of €3 million per GW per km [7], and losses are 3% of energy per 1000km [8].
  - The distance used for the cost and energy loss rate of a power interconnector between two countries is the distance between the geometric centroids of the two countries.
- The Coefficient of Performance (COP) for each region for each day is estimated based on a number of assumptions.
  - The required flow temperature of 21˚C plus three times the Heating Degree Days value for that day.
  - The external temperature is from weather data for that day for that region in 2015-2021.
  - We then use these external and required flow temperatures to find a COP based on the technical guide for the Viessmann Vitocal 200-A heat pump, unit type AWO-M 201.A04 [4].
  - For reference, this resulted in an EU-wide average COP of 2.38 without Smart Retrofit, and 2.85 with Smart Retrofit.
  - Heat pumps are assumed to have a COP of 3.0 while cooling.
- In some countries, heat pumps or direct electric heating are in wide use. Existing heat pumps are assumed to have the same COP as in our assumptions, and direct electric heating was assumed to have an efficiency of 1.
- To find the cost-optimal mix of wind, solar, and nuclear energy capacity in each EU country, we used a price of 2.9c/kWh for solar, 5.1c/kWh for wind, and 14.1c/kWh for nuclear [5]. Different prices may result in a different energy mix – in particular, we used a cost for nuclear power which is much higher than solar or wind – resulting in 0% nuclear in the energy mix across the EU. This does not account for differences between the cost per kWh of different sources of energy in different EU countries.
- The 36% saving due to Smart Retrofit is applied directly to both heat and cooling demand – assuming that heating and cooling demand are reduced by 36% in every region and on every day.
- The results are based on a non-convex optimisation procedure and may not be exact, in particular around the optimal usage of international power interconnectors.

Sources

[1] ENTSOE Transparency platform, 2020 data.

[2] "Disaggregated final energy consumption in households – quantities" – Eurostat (online data code – FC_OTH_HH_E_SH), 2020 data

[3] There are 246 million cars in the EU [A], and average miles driven is 11,300 km/year [B]. The average energy consumption is 0.346 kWh/mile [C], leading to a value of 598 TWh/year to power electric cars across the EU.

[A] https://www.acea.auto/files/ACEA-report-vehicles-in-use-europe-2022.pdf#page=4

[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/

[4] Data taken from the technical guide for the Viessmann 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

[5] "Lazard's Levelized Cost of Energy Analysis – version 15.0" – Lazard, 2021. Midpoint of estimate range taken where appropriate.

https://www.lazard.com/media/451881/lazards-levelized-cost-of-energy-version-150-vf.pdf

Exchange rate of €0.8415/USD used (average exchange rate 2021, HMRC)

[6] Eurostat – Heating and Cooling degree days - statistics

https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Heating_and_cooling_degree_days_-_statistics#Heating_and_cooling_degree_days_at_EU_level

[7] Pöyry, report to the (UK) National Infrastructure Commission, finds a cost between €2-4m per GW per km. Average value of €3m/GW/km taken

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/505222/080_Poyry_CostsAndBenefitsOfGBInterconnection_v500.pdf

[8] IEA ETSAP, 3% loss per 1000km for HVDC power interconnectors

https://iea-etsap.org/E-TechDS/PDF/E12_el-t&d_KV_Apr2014_GSOK.pdf