Lowering our Carbon footprint

Interesting stuff I have learned along the way

Kevin Brown MBE FInstP CPhys

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Overview

- Heat Pumps and their consequences
- Where is our electricity coming from?
- Insulation
- Solar Panels
- Home batteries
- What about Hydrogen for heating?
- Travel

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Our house is a ‘conventional’ 1950’s chalet bungalow

Purchased as 2 bedrooms

Modified to 3 bedrooms

… in Fishbourne

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Heat Pumps

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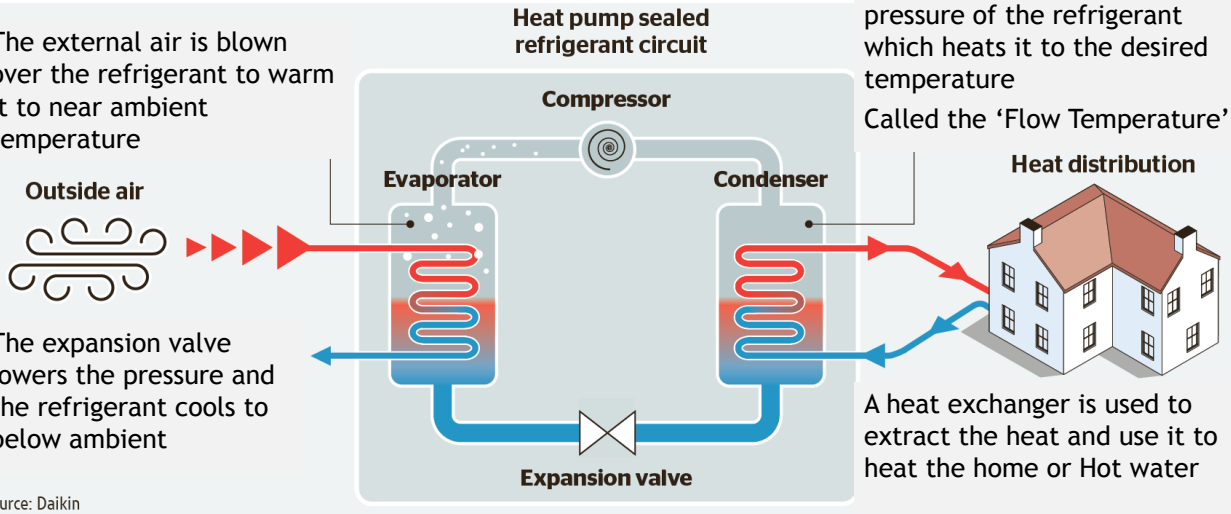
What are heat pumps and how do they work?

The external air is blown over the refrigerant to warm it to near ambient temperature



The expansion valve lowers the pressure and the refrigerant cools to below ambient

The compressor increases the pressure of the refrigerant which heats it to the desired temperature

Called the 'Flow Temperature'

A heat exchanger is used to extract the heat and use it to heat the home or Hot water

Source: Daikin

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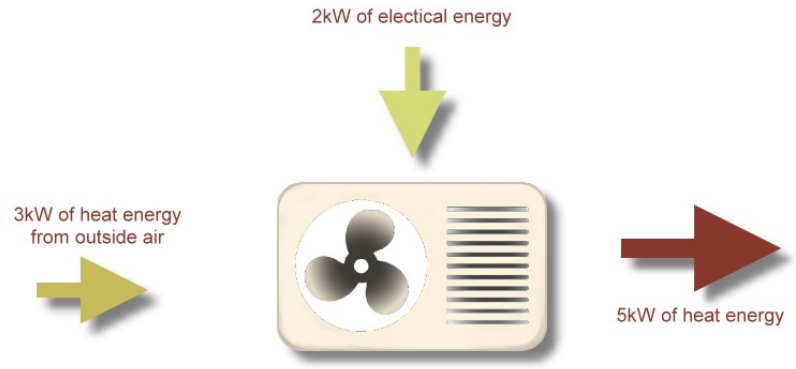
Their efficiency is called the Coefficient of Performance (COP)



Heat energy out / Electrical energy in = Coefficient of performance (COP)

5kW / 2kW = 2.5

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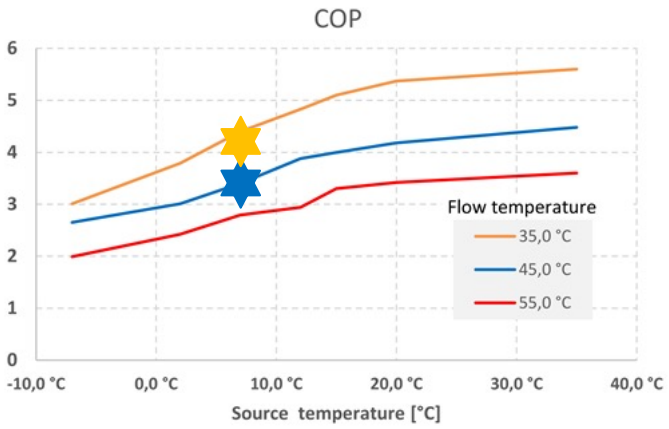
How efficient can a heat pump be?

- More efficient at lower Flow temperatures i.e. can you heat the house with warm rads not hot ones
- Less efficient at lower outdoor temperatures but still efficient

Our actual CoP
1st to 3rd December 2024
Outdoor temp between 6°C and 12°C
Heating (35°C) 4.2
HW (45°C) 3.4
Combined 4.0



https://www.rehva.eu/rehva-journal/chapter/heat-pumps-lost-in-standards

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Seasonal Performance Factor (SPF)

- The CoP will be higher in the Summer than in the Winter
- The SPF of a heat pump is the ratio of **annual** heat generated to the **annual** electricity consumed for the operation of the heat pump.
- SPF = Total heat output per annum / Total electricity consumed per annum
- i.e. the average COP given the variation in demand on the heat pump and the temperature of the medium it is extracting the heat from
- Typical SPF is 3 to 4

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Facts about our Midea Heat Pump

- Can heat water up to 80°C
  - But we use 45°C to improve efficiency
- Can work at outdoor temperatures as low as -20°C
  - Is less efficient the colder the outdoor temperature
- Rated output of 14 kW at outdoor temp -2°C and water temp 50°C
- Quiet – 35 dB (A)
  - 30 dB: Whispering nearby
  - 40 dB: Quiet library sounds
- 10-year warranty
- Installed cost £9,400
- RHI grant of £9,200 paid over 7 years
- Current Boiler Upgrade Scheme is a grant of £7,500

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Goldilocks of Flow Temperature

Remember that the efficiency of the Heat Pump is related to the temperature differential between the outside air and the temperature that the refrigerant is heated to by the compressor – the Flow Temperature

Flow Temperature

Too cool House is cold	Just right House is warm Low energy bills	Too hot Heat Pump less efficient

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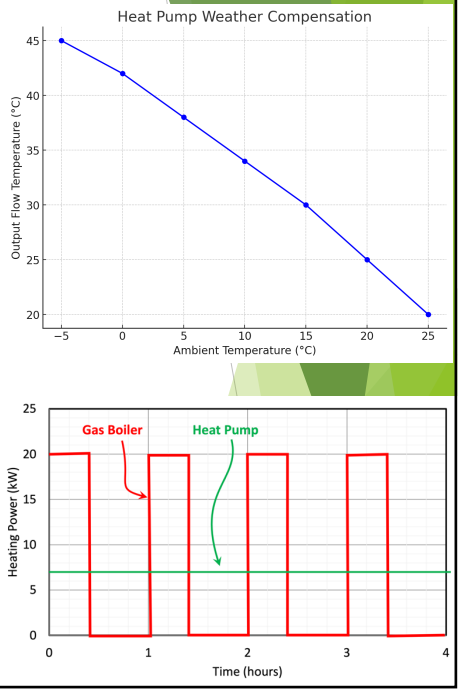
Homely heat pump controller

- Most Heat Pumps have a simple weather compensation to set the Flow temperature of the heat pump as low as possible while still heating your home as you want
- Set by the installation engineer, if it is too cool then your house will not be heated properly.
  - This may be a cause of people thinking heat pumps do not work!
- Homely heat pump controller automatically builds a thermal model of your home from its temperature, the heat pump heating, the outdoor temperature and solar heating
- The controller then continuously adjusts the Flow temperature to
  - maximize COP to minimize the energy used
  - It also considers the electricity price to minimize cost
- As Homely say – a Heat Pump is not a Gas boiler!

https://www.homelyenergy.com/



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- Heat pump is generally running when the electricity is cheapest
- If it needs to run when electricity costs more the set temperature is set low to minimize usage
- House allowed to get a bit warmer to avoid running heat pump at peak time
- **Total** home consumption peaks at 5kW but generally a lot less

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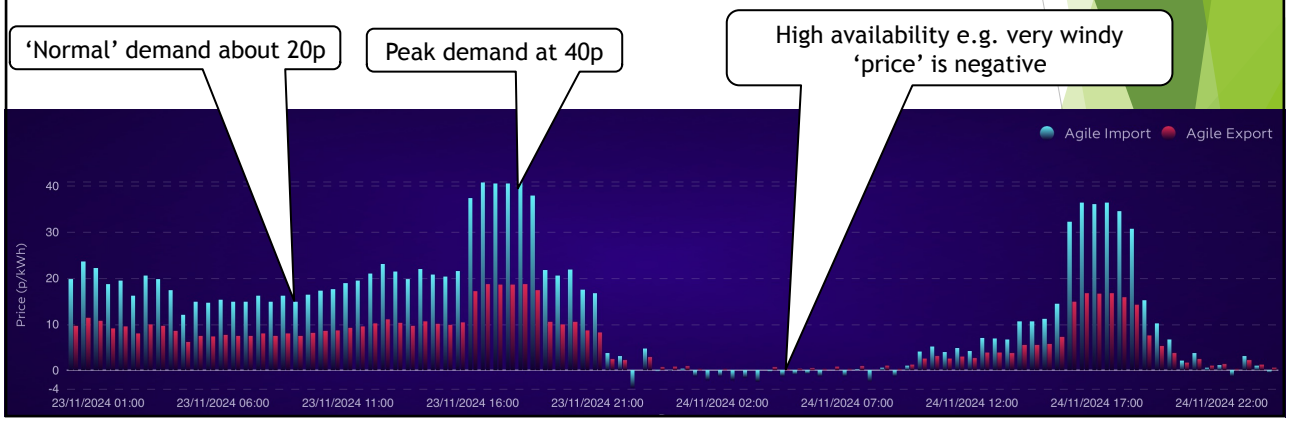
Agile tariffs

- Prices depend on demand and availability
- Published previous day
- Controllers like Homely will optimize the daily usage pattern to save money which has the effect of balancing the grid and avoiding overloads



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Does a heat pump cost more to run?

- Cost of Gas 6.32 p/kWh
- Off peak cost of Electricity 12.32 p/kWh - twice that of gas
- However, electricity usage is reduced by SPF by 3 to 4
- With a smart controller it can cost a lot less to use the heat pump than using gas
- Also, our Solar electricity generation makes it even cheaper

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Consequences of running at a low temperature?

- Radiators often do not feel warm!
- Need more water flow to transfer heat to the radiators
  - We have 'normal' 15 mm pipes which is ok
  - Microbore systems are challenging
- Underfloor heating is ideal as these are low temperature
- Lower heat output for a given radiator size
- Heat pump is on more of the time and house is warm
- Large 250l hot water tank at 45°C to improve efficiency

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Does a Heat Pump need new radiators?

- We ran our Heat Pump for the first Winter to see how it worked and only one room was too cool – so we upsized that radiator
- Then I began to learn more about running the Heat Pump at as low a temperature as possible to minimize power consumption for the same heating
- I figure that the larger the radiators, the lower the temperature for the same heat out
- The heat emitted by radiators is proportional to the difference between the water temperature and the room temperature
- So, I replaced the hall radiator with a 'triple'
- Upstairs radiators are all fine

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Are Heat Pumps new or novel?

- In 2021 there were **190 million** heat pumps installed globally
  - 33% China. 23% North America and 12%. EU
- By 2030, there will be **253 million** heat pumps globally
- Net zero scenarios require 600 million operational units by 2030
- In 2022, the global heat pump market size was **$82 billion**
- 94% of installed base extract heat from the air, 6% use ground or water.
- UK has around **412** heat pumps per 100,000 people, compared to a European average of **3068** heat pumps per 100,000 people
- Households with heat pumps: Norway 60% (1.4 million), Sweden 43%, Finland 41%, and Estonia 34%.
- **55,000** heat pumps were sold in the UK in 2022 - in comparison, more than **620,000** were sold in France.

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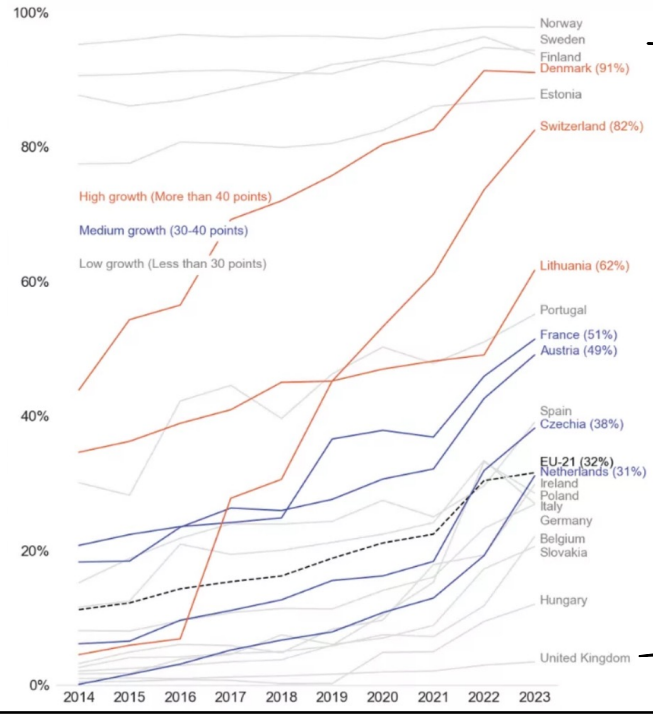

Nordic countries lead for the last 10 years

Heat Pump share of space heating market

UK is lagging

https://www.ehpa.org/market-data/

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Electricity

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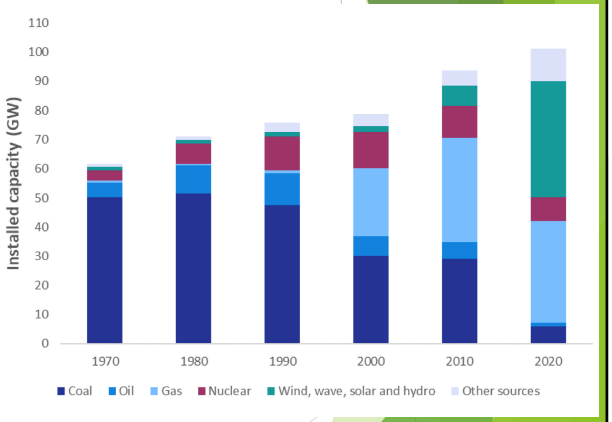
UK generation capacity

- Dramatic increase in renewables
- Labour ambition by 2030:
  - Quadruple offshore wind with an ambition of 55 GW
  - More than triple solar power to 50 GW
  - More than double our onshore wind capacity to 35 GW
  - Develop 10 GW green hydrogen production for flexible power generation, storage, and industry like green steel
- Chris Goodall argues we need
  - 300 GW wind and 260 GW Solar
- We are a long way away from this but not inconceivable



Energy Trends June 2023 Gov.uk, Chris Goodall "What we need to do now" 2020 https://labour.org.uk/wp-content/uploads/2024/03/Make-Britain-a-Clean-Energy-Superpower.pdf

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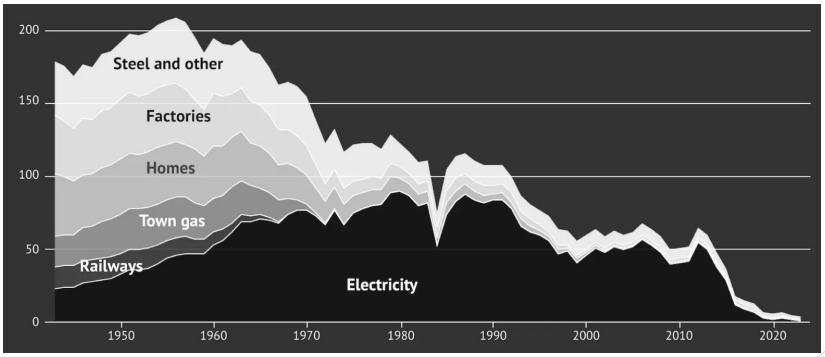
The end of coal for electricity generation

Between 12th January 1882, when the world's first coal-fired power station opened at 57 Holborn Viaduct in London, and 30th September 2024, when Great Britain's last coal-fired power station closed*, the country burnt 4.6 billion tonnes of coal, emitting 10.6 billion tonnes of carbon dioxide.



https://interactive.carbonbrief.org/coal-phaseout-UK/index.html

* Ratcliffe-on-Soar in Nottinghamshire

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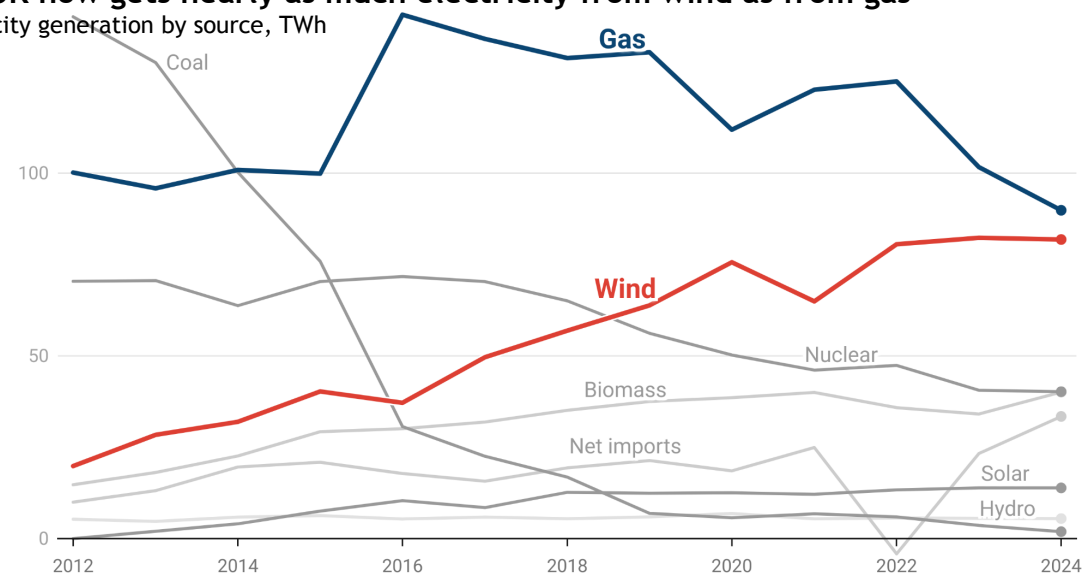
The UK now gets nearly as much electricity from wind as from gas

Electricity generation by source, TWh



https://www.carbonbrief.org/analysis-uks-electricity-was-cleanest-ever-in-2024/

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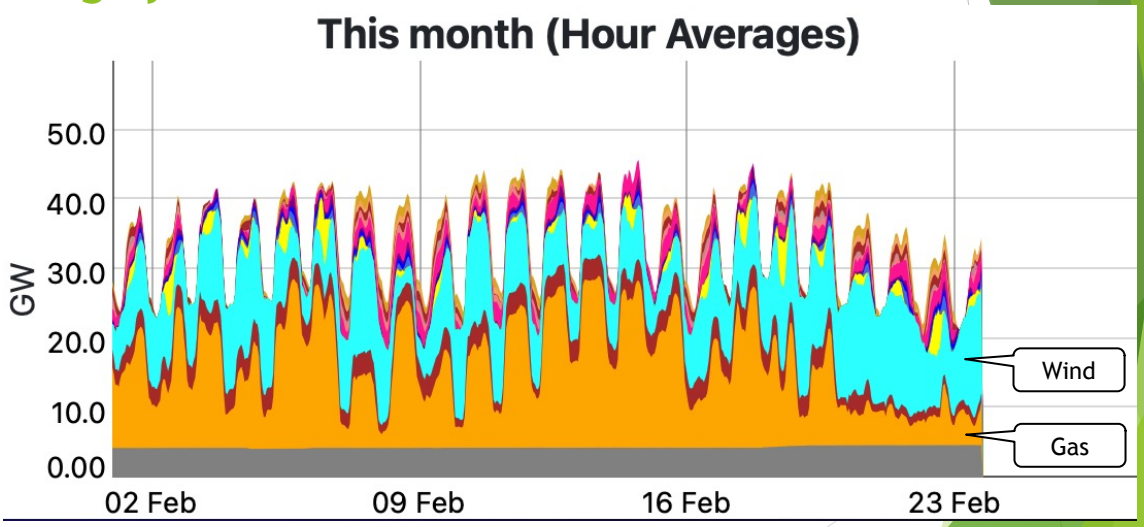
Power consumption and generation is highly variable



- https://gridwatch.co.uk

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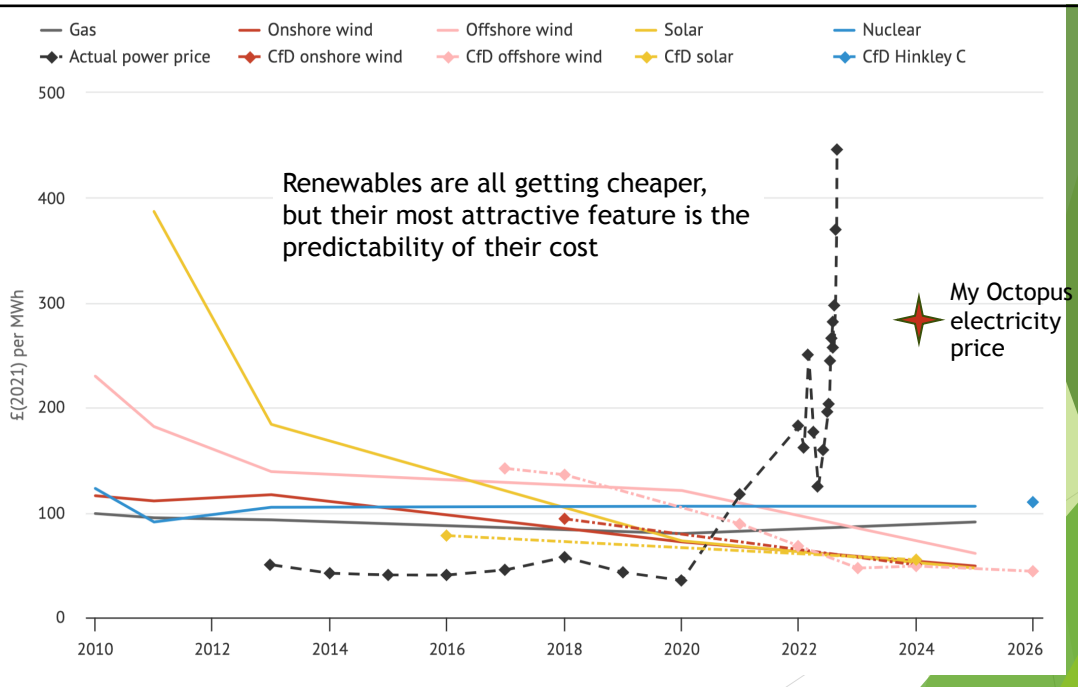

https://www.carbonbrief.org/analysis-record-low-price-for-uk-offshore-wind-is-four-times-cheaper-than-gas/

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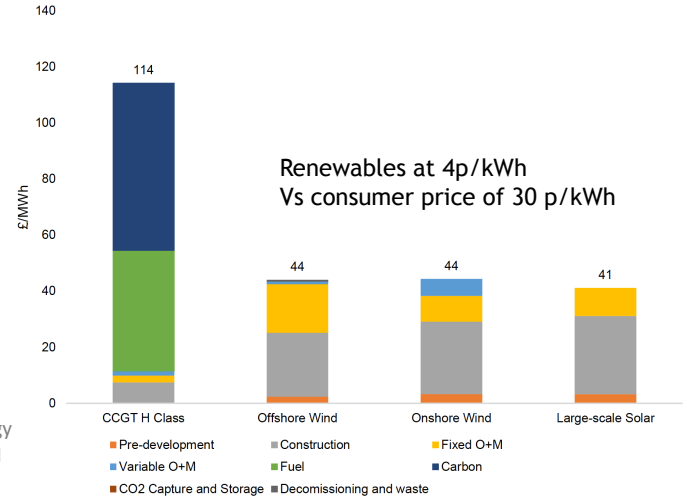
Real cost of generating electricity

- What is baffling is the way that the UK electricity market tracks the gas price when 60% of the generation is not gas
- Electricity should be much cheaper than it is right now
- Hinkley C has a contract prices of £110/MWh (11p/kWh)

Figure 2 – LCOE estimates for projects commissioning in 2025, in real 2021 prices



Electricity Generation Costs Report 2023 Gov.uk

LCOE, Levelized Cost of Energy, the cost of generating energy over its lifetime, divided by the amount of energy produced

CCGT - combined-cycle gas turbine

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Insulation

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Importance of insulation

- Insulation reduces heat loss and therefore reduces heat required to maintain the required internal temperature
- The fuel burnt by a conventional boiler will reduce almost linearly due to the reduction in heat required
- For a heat pump, there is a double win!
  - The quantity of heat required reduced
  - The temperature of the radiators can be reduced which improves the heat pump's efficiency
  - The amount of electricity is reduced by more than the reduction in heat required

People often think that a heat pump needs a well insulated house

This is not true - within reason!

However, good insulation can significantly reduce your fuel consumption

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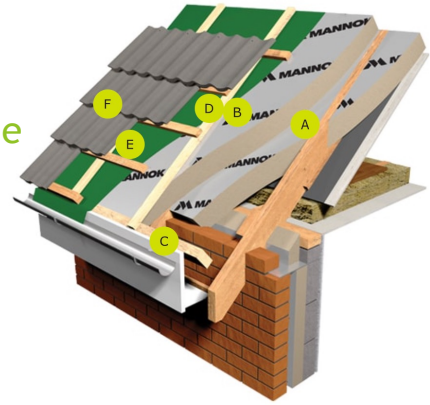
Roof insulation

We had the advantage of remodeling our home



- Roof is insulated between the rafters and then over the rafters.
- Resulted in tiles being 10 cm higher!
- Roof insulation is valuable both in the Winter and in the Summer!

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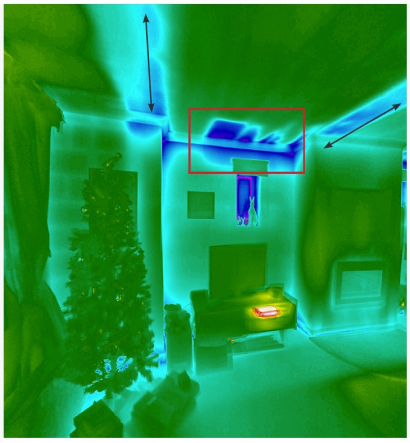
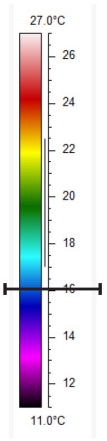
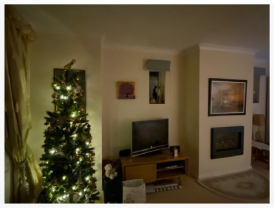
Thermal survey

- The results were not as good as I expected. so commissioned a thermal survey
- Heat house for two hours
- Then look at cooling from the indoors
- Requires cool outdoor temperature
- Revealed a number of cold spots i.e. poor insulation or drafts







Observations

Red box shows area of discontinuous insulation allowing cooler air to flow.

Black arrows would again indicate a thermal bridge from construction element.

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Remedial works!
Builder had left a few gaps ☹

Gap in insulation

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Remedial works #2
Under the floor

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Solar electricity generation

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Solar technology

- Silicon is doped with Phosphorous to create an n-type semiconductor
- Silicon is doped with Boron to create a p-type semiconductor
- When these layers absorb light photons, they release electrons, and this generates an electrical current
- This is called the photoelectric effect
- The elements are called photovoltaic or PV cells
- A solar panel is made from many PV cells

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Solar

8 in-roof panels facing East and 4 panels facing West

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Solar Edge technology

- Output from each panel individually optimised
- Panel characteristics
- Shade and orientation to the sun
- Lifetime degradation
- Continuously maximises array output

https://www.solaredge.com/uk

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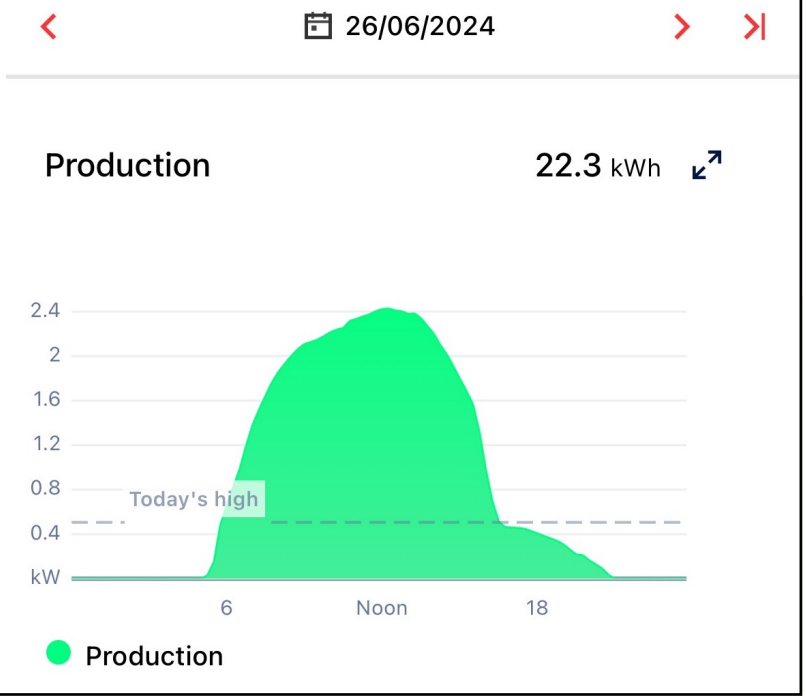
Ideal day



Starts early in morning
Lasts all day
Lower peak than South facing

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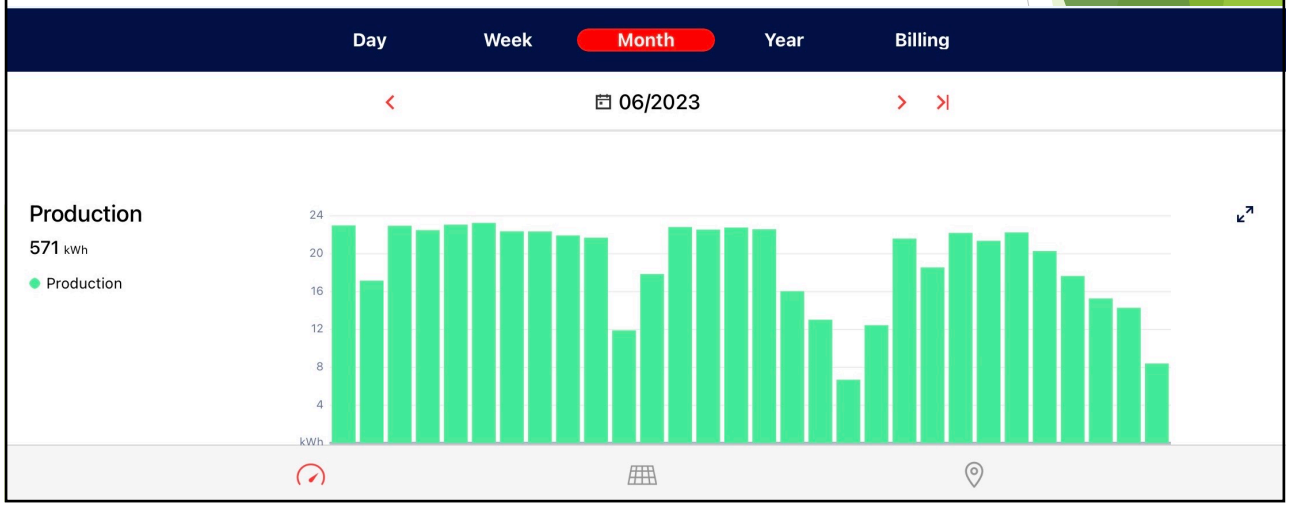
June 2023

Variable due to cloud cover
June 2023 was a very clear month
Average 19 kWh per day



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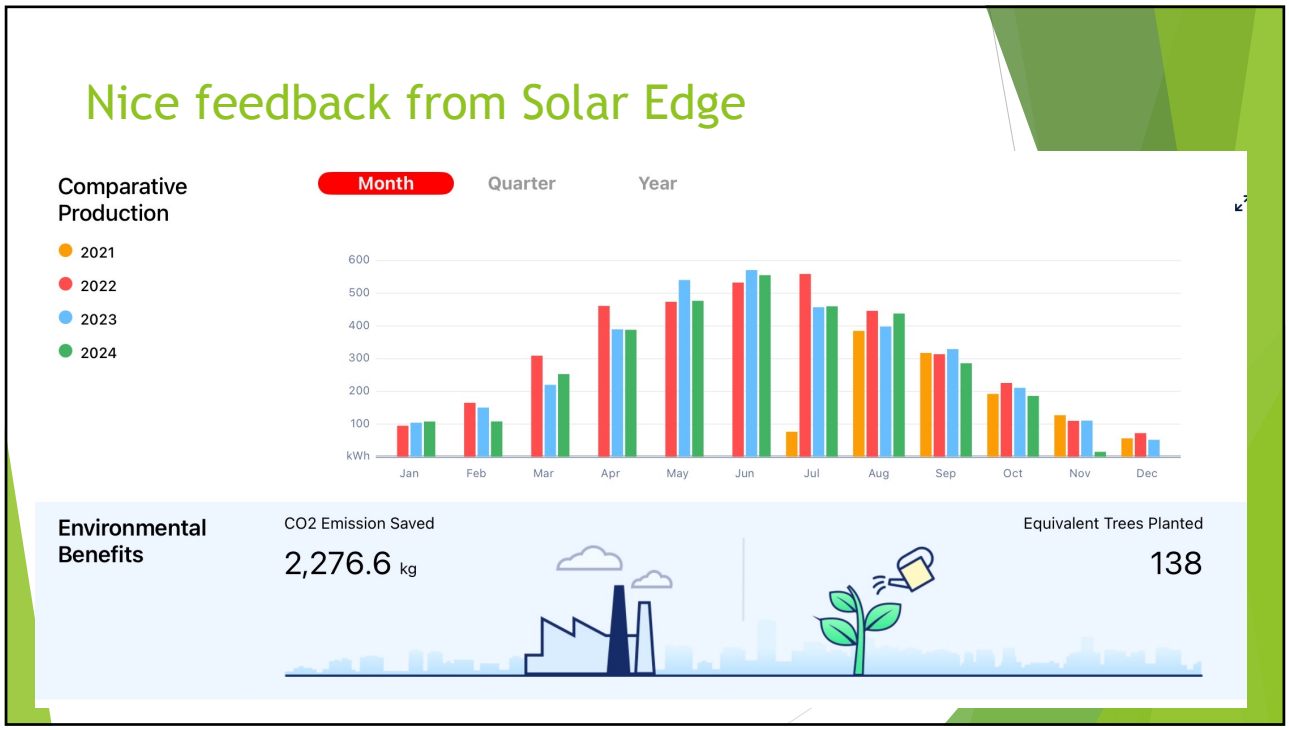
Nice feedback from Solar Edge



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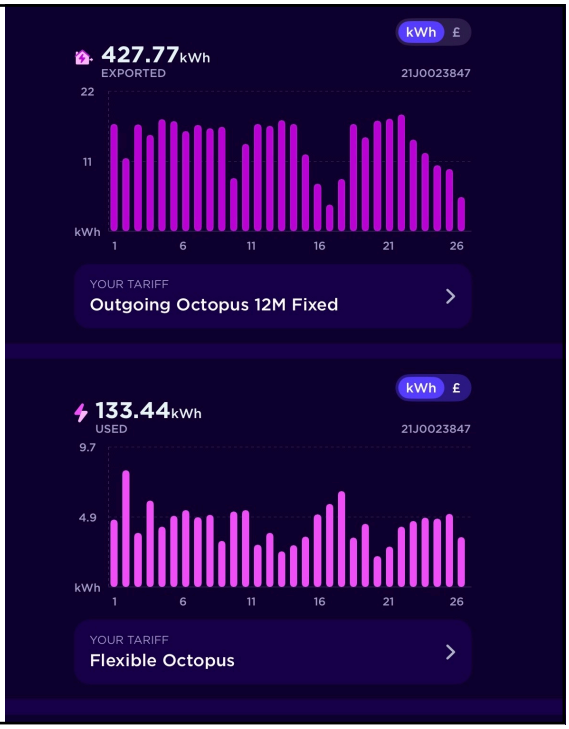
Power exported and used
No home batteries

- June 2023
- Average export 14 kWh per day
- Reported usage 4.4 kWh per day
- Data reported from Smart meter

Solar usage = Solar generated - Energy exported
5 kWh = 19 kWh – 14 kWh

Actual usage = reported usage + Solar usage
9.4 kWh = 4.4 kWh + 5 kWh



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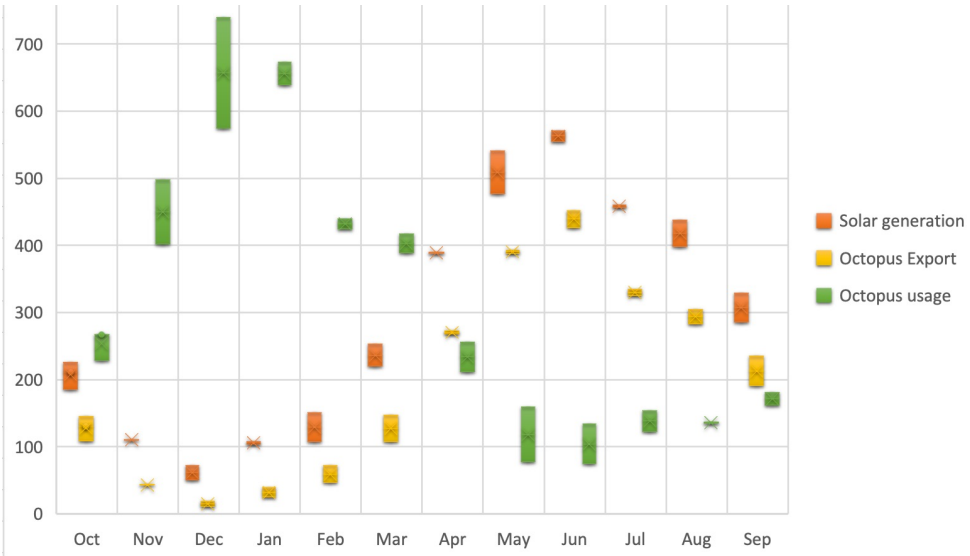
Annual variation - October 2022 to October 2024



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Solar Payback

	Supplier estimate		Current actual	
Annual output	3556 kWh		3600 kWh	
Exported to Grid	711 kWh 20%	5.5 p/kWh	2400 kWh 66%	15 p/kWh
Saving by direct usage	2844 kWh 80%	16 p/kWh	1200 kWh 33%	28.85 p/kWh
Saving	**£494 per year**		**£706 per year**	
Payback	**10 to 11 years**		**7 to 8 years**	

Estimate of direct usage was too high
Redeemed by higher prices
Initial cost £5,175

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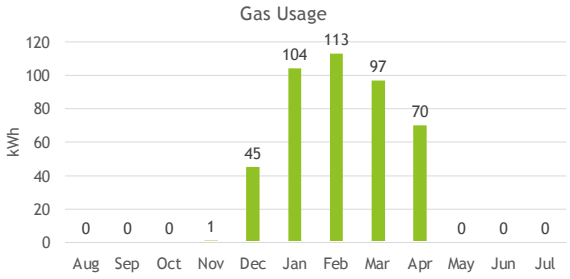
A confession/indulgence …

- We do still have a log-effect gas fire!
- We find it cozy on a winter evening
- It is balanced flue and therefore 99% efficient



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Summary of our home annual performance

kWh	Typical UK home*	Our home before changes
Electricity used	2,700	2,550
Gas used	11,500	13,800
Total usage	14,200	16,350

Brown's home	kWh	% of typical
Solar Generation	3,400	
Electricity used	4,700	
Net Electricity	1,300	48%
Gas used	470	4%
Total usage	**1,770**	**12%**

Average monthly bill £69
Approx £1 per day standing charge
£1.30 day energy consumption

* ofgem.gov.uk (2900 and 12000 until Sep 2023)

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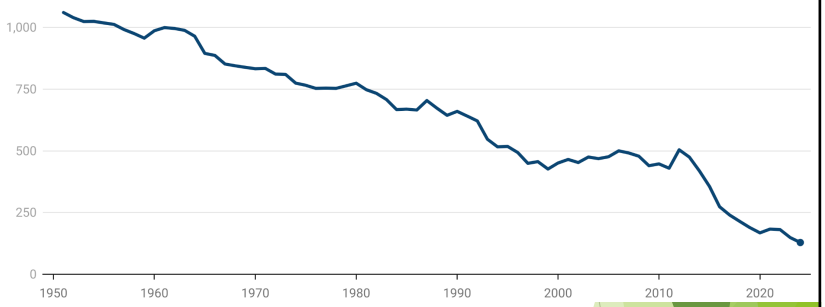
Carbon intensity

- Natural gas 203g/kWh (ref 1)
- In 2024 the carbon intensity of UK electricity was its lowest ever at 124 g/kWh (ref 2)

The UK's electricity was the cleanest ever in 2024, with emissions per unit down by two-thirds in a decade

Carbon intensity of electricity generation, gCO2/kWh



Brown's home	kWh	Carbon footprint kg	Typical kg
Net Electricity	1,300	161	334
Gas used	470	95	2,334
Total usage	**1,770**	**256 (9% of typical)**	**2,668**

- 1) https://www.carbonindependent.org/15.html
- 2) Carbonbrief.org 2 Jan 2025

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Home batteries

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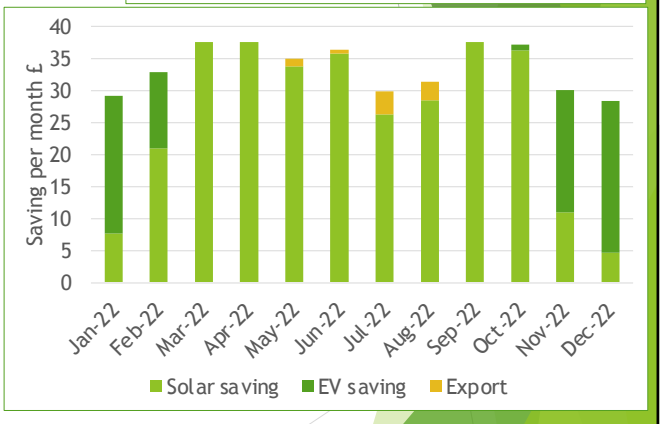
Are home batteries a good idea? Financial impact - with EV tariff

- **Can save money by shifting energy usage**
  - **Use Solar to charge when possible**
  - **Use cheap EV tariff to charge remainder**
  - **Use battery instead of buying electricity**
  - **Export what is left**
- Modelled battery capacity of 5 kWh
- Annual saving about £400
- Installation cost of £3,000 to £4,000
- Payback of 7 to 10 years
- Guaranteed lifetime of battery is 10 years

Solar saving is typical tariff 25 p kWh
EV tariff saving is EV minus typical tariff 25 - 7 = 18 p/kWh
Export revenue is EV minus export tariff 15 - 7 = 8 p/kWh



Currently home batteries are marginal financially

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Are batteries a good idea? Environmental impact

- We do not have a battery and therefore in the Summer when we export more energy, and the grid uses less gas
- In Winter we use more energy, and the grid uses more gas
- The grid is currently averaging at around 40% gas for electricity generation
- Therefore, over the year the grid only uses the amount of gas that corresponds to 40% of our annual net electricity usage
  - This is unaffected by having a home battery or not
- Not using a battery also avoids the environmental impact of making it
- Using the grid as storage is currently better for the environment

Currently home batteries do not make environmental sense

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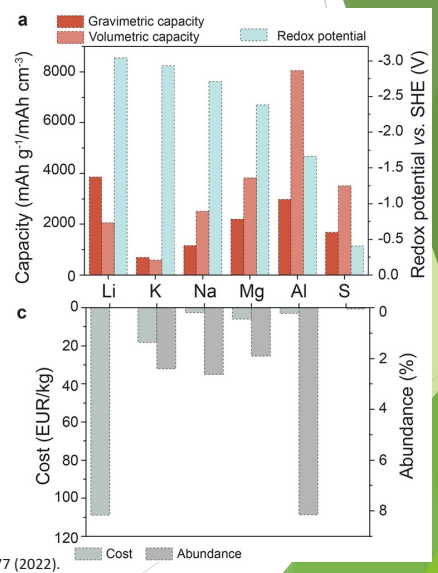
What would make batteries a good idea?

- They need to be much cheaper, and their manufacture must have much less impact on the environment
- **Sodium Ion** Batteries look promising
  - Comparable capacity
  - High abundance
  - Low cost of materials
- This would transform electric vehicles and home battery storage
- Not there yet!



Klimpel, M. et al. Advances and challenges of aluminum–sulfur batteries. *Commun Chem* **5**, 77 (2022).

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Sodium Ion technology developed by a British start up - Faradion

- "Providing lithium-ion performance at lead-acid prices."
- Doesn't use any Lithium, Cobalt, Copper or Graphite
  - Lithium and Cobalt are rare, polluting and sourced from politically insecure countries
- Improved safety as they can be shipped fully discharged
- They are also produced on existing Li-ion battery manufacturing lines, requiring no additional asset investment.
- Pilot scale production investment occurred in Sheffield
- First batteries installed in 2022

https://faradion.co.uk/technology-benefits/

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Acquired by Reliance New Energy Limited (India)

- "RNEL acquired leading global sodium-ion battery technology company Faradion Ltd. for an enterprise value of GBP 100 million. RNEL is also investing GBP 25 million as growth capital to accelerate commercial roll out."
- Investing 10 Billion USD in 5 Giga factories for renewable technologies
- One of which is a battery giga factory by 2026
- Will produce Lithium Iron Phosphate (LFP) solutions at world beating lifecycle costs
- "Fast-tracking commercialisation of our sodium ion battery technology."
- Parent company (money) is Oil and Gas

https://www.ril.com/businesses/new-energy-materials

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I conclude Home batteries do not make sense right now …

unless you have one anyway
e.g. in your electric car!

There are lots of schemes about using car batteries to smooth our load on the network

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Hydrogen for home heating?

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What about Hydrogen

- Often touted as an alternative to Heat Pumps for home heating by the media
- It is just Hydrogen, but it is labelled by its production method
- 'Blue Hydrogen' is created from natural gas and generates large amounts of CO_2
  - If the CO_2 is captured this is called 'low Carbon'. This is 'relatively easy' to capture as it is generated where the Hydrogen is generated as opposed to Natural gas where the CO_2 is created at point of use and difficult to capture
  - Currently the CO_2 is not captured, and this is 'high Carbon'
- Ideally Hydrogen is generated by renewables which is called 'Green Hydrogen'
- Low Carbon Blue Hydrogen is 'relatively' easy to achieve and can be considered a 'bridging strategy' to get us to Green Hydrogen as it will take many years to establish enough renewable capacity
  - Although the costs of the Carbon Capture are unclear

https://www.gov.uk/government/publications/uk-hydrogen-strategy

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What about Hydrogen heating? In home costs

- Hydrogen 'boilers' are very similar to Natural gas boilers so we can assume that the installation costs are about £5,000
- We have data to suggest that the average heat pump installation is about £13,000[1]
- On a National scale assuming about 30 million home need to be upgraded
  - Hydrogen boilers £150 billion
  - Heat pumps £390 billion

Looking good for Hydrogen!

1 https://www.gov.uk/government/statistics/boiler-upgrade-scheme-statistics-june-2023
Logic courtesy of Protonsforbreakfast blog 6 August 2023

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How much power capacity do we need to heat all UK homes?

- Study by Watson U of Loughborough
- Collected half hourly data from 6000 homes
- Did a model fit against daily external temperature
- Average UK annual heat requirement 70 GW
  - 2.3 kW heat per home
- Peak heat requirement is 170 GW
  - 6.2 kW heat per home

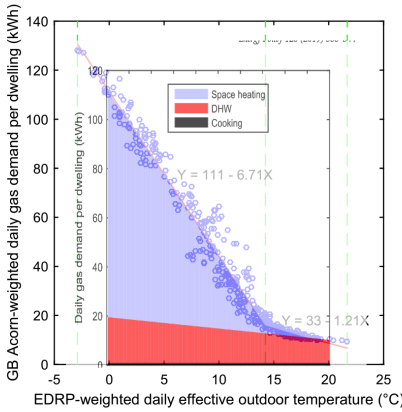

Fig. 5. Broken-stick regression of the Acorn-weighted daily gas demand per dwelling (EG) against the EDRP-weighted effective outdoor air temperature (ET_{EDRP}). The break-point is 14.2 °C and adjusted R^2 0.97.

S D Watson et al Energy Policy 126 (2019) 533-544

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Installation costs for 170 GW of heat capacity using heat pumps

- A CoP of 3 reduces this to 57 GW of electricity
- 10% loss in transmission increases to 63 GW
- Assume offshore wind with a load factor of 40%, need 157 GW capacity
  - Not that much greater than Labour's ambition
- Installation cost of offshore wind £3M per MW
- Therefore £472 Billion
- Roughly £15,700 per household, maybe £1,500 per year for 10 years

we currently have around 26 GW of Off-Shore Wind and there is about 100 GW 'in the pipeline' over coming decades.

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Installation costs for 170 GW of heat capacity using Hydrogen

- Hydrogen generation efficiency of 46% increases this to 340 GW of electricity
- Using the same assumptions as Heat Pumps implies 920 GW of offshore wind
  - About ten times Labour's ambition
- Therefore £2,760 Billion (roughly the GDP of the UK)
- Roughly £92,000 per household

Process	*Efficiency*	*Cumulative Combined Efficiency*
Electrolysis	***75%***	***75.0%***
AC/DC Conversion	***95%***	***71.3%***
Compression	***90%***	***64.1%***
Transmission	***80%***	***51.3%***
Combustion	***90%***	***46.2%***

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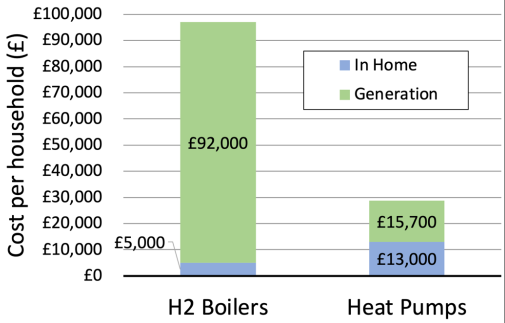
Hydrogen in summary

- Heat Pumps cost more to install, however,
- Hydrogen would have running costs **6 times higher** than heat pumps
  - Amazing that this is rarely mentioned in the comparison*
- Hydrogen technology is still immature compared to a massive global Heat Pump market
- However, Hydrogen does make sense to store excess renewable generation
  - When we get to a situation when we have excess!

Costs per Household		
	H_2 Boilers	Heat Pumps
In Home	£5,000	£13,000
Generation	£92,000	£15,700
	£97,000	£28,700



https://www.bbc.co.uk/news/

*The neighbourhood leading a green energy revolution March 2022

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A few words on Transport

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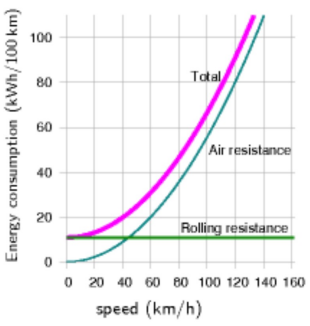
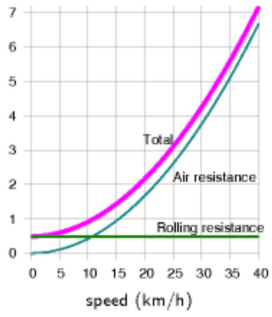
What about transport?

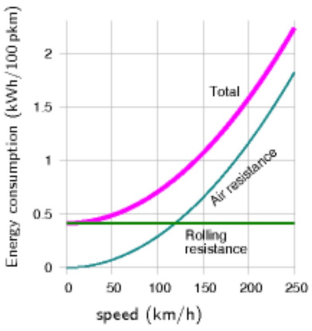
Car
30 kWh/100 km @ 60 km/h



Bike
2 kWh/100 km @ 20 km/h



Train
0.7 kWh/100 pkm @ 100 km/h



https://www.withouthotair.com/cA/page_259.shtml

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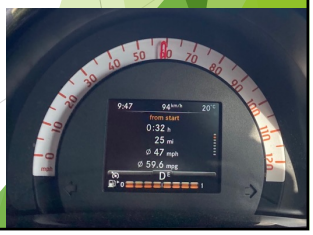
Our travel

- Shopping etc in Chichester
  - Electric bikes and panniers
- Moving moderate sized things
  - Electric bike and trailer!
- Occasional commute to Crawley office
  - Brompton fold up bicycle and train
- Holidays
  - Train and Electric bikes
- If all else fails
  - ~~Fuel~~ Car

Electric Car



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Why buy an electric car?

- For years we had been undecided on this issue
- We don't use our Car that much
  - About 3000 miles per year
  - Our Smart Car gave about 50 miles per gallon
  - Carbon footprint 60 gallons/year or 650 Kg of CO_2
- It takes a lot of resources to build an electric car which then must be offset by the lower carbon production during its use.
- Therefore, there electric cars make more sense for higher mileage users
- However, I finally got fed up with burning a finite resource every time I used the car, so we took the plunge!

Reminder

Smart car fuel	650 kg
Our home	256 kg
Typical home	2,668 kg

10.9 kg/gallon https://www.carbonindependent.org/17.html

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Summary

- Heat Pumps – wherever possible
- Electricity should be cheaper
- Insulation – as much as you can
- Solar Panels – as much as you can
- Home batteries – maybe later?
- Hydrogen – only when we have surplus renewables
- Travel – do what you can

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