REDUCING HOUSEHOLD CARBON FOOTPRINTS - WHAT CAN I REALISTICALLY DO? – issue 5c:- 22 February 2022

This issue (no.5) is an update on an article I last revised in 2009. There have been many changes in the last 12 years. When I started drafting this note, I was surprised at how difficult it was to find reliable and consistent information about the current state of play, let alone future predictions. The internet is awash with information from many voices and various vested interests. Deciding what is true, what is informed opinion, and what is misleading propaganda, has been a struggle.

I apologise in advance for the length of this article, which I feel is the minimum in which I can provide meaningful explanation and guidance covering the spectrum.

Green issues, climate change, low-carbon economy, and similar topics are nowadays extensively covered by the media. Unfortunately, apart from the obvious messages of "consume less", "recycle more" etc., the guidance for individuals is scattered widely, and the diversity of views (and sometimes commercial or political bias) causes confusion. As an engineer, I have a good understanding of the technical issues and this is my attempt to share this in a (relatively) non-technical way. This article is written with a UK perspective, and some of the data and assumptions may not fully apply in other countries.

The IPCC (Intergovernmental Panel on Climate Change) now has enough evidence and consensus to state that climate change is happening, and that it is definitely caused by human activity. If we are to avoid excessive temperature changes, and the consequences such as severe weather events, we need to act, NOW!

The actions of one individual will make little difference, but millions of individuals acting together can make a significant impact. And an example set by people in one country acts as a beacon for other countries. We in the UK have no moral or political basis for demanding that other countries emit less CO_2 if we are doing little ourselves.

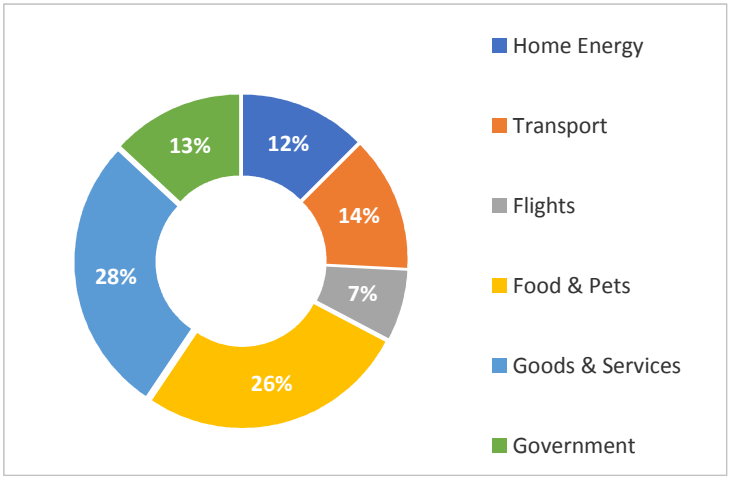
So what can we do? What is affordable, what is the most effective? Some significant improvements can be made which actually save us money. There are others which will cost us money.

THE STARTING POINT:

Although most will know something about CO_2, climate change, carbon footprints etc, I will start by summarising the basic science in a short paragraph. Forgive me if you already know this..

Carbon Dioxide (CO_2) in the atmosphere has been increasing very substantially since the Industrial Revolution, largely due to burning of fossil fuels. Increased CO_2, combined with other effects, causes more of the sun's heat to be trapped in the atmosphere, this is usually called the "greenhouse effect". The scientific view is that we must drastically cut CO_2 emissions (and other damaging emissions) if we are to avoid serious and damaging climate change. The phrase "carbon footprint" refers to the amount of CO_2 emissions associated with each person.

The typical carbon footprint in UK is currently about 10 tonnes per person, including the embedded carbon in imported goods. An average 3 person household has a footprint of roughly 30 tonnes (www.carbonindependent.org). This figure is purely for CO_2 emissions, and does not include other "greenhouse gases" and pollutants which also have a climate warming effect.



Household carbon emissions for an average home with 3 occupants, 2021 estimates. Assumes one holiday trip by plane, and use of two small/medium cars, 7000 miles each.

This article deals with home energy and travel (including air travel), which together make up about 1/3 of our total carbon footprint. For other major areas of food, and goods and services, the basic message is simply "consume less", which doesn't need a long article to explain!

Household annual CO_2 consumption from home energy and travel

	Consumption	Cost	CO_2 emissions
Central Heating (Gas) – average semi-detached house, 3 occupants.	15,000 kWh	£750 (in 2021)	2.7 tonnes (Oil heating 3.6 tonnes)
Electricity – average semi-detached house, 3 occupants	4400 kWh	£900 (in 2021)	1.0 tonnes
Car (small-medium) – 10,000 miles per year, 45 mpg average (petrol)	1000 litres (225 gallons)	£1400	2.2 tonnes
Air travel – 3 people, trips to: • Spain – say 2000 miles • USA – say 7500 miles.	 330 litres 1100 litres		 1.0 tonnes 3.6 tonnes

Note 1. This data has changed since the article was last revised circa 2009. Average home gas consumption is down by 40%, which is a reflection of insulation programmes and more new houses with inherently good insulation. Plus widespread use of condensing boilers which are now standard. Electricity consumption is also down by about 20%. This is largely due to low energy (LED and CFL) lighting, and generally more efficient appliances.
Note 2. Current gas and electricity consumption data is from ONS - Office of National Statistics average household usage. Modern homes are better than this, older homes are worse.. The UK average dwelling is between 2 and 3 bedrooms, and the average occupancy is 2.4 people. The data shown above is for a semi-detached house with 3 occupants. For a 2-bed home with 2 people, take 3/4 of the above data as being representative.
Note 3. The average UK person uses 9000 kWh of energy (= 1.7 tonnes of CO2) for transport of all types. If the transport were only by car, this would represent about 6000 miles for a car with one occupant.

First, we can estimate our approximate household annual CO_2 "footprint" using the table above which includes only the major energy items, i.e. electricity, mains gas (or oil or LPG heating fuel), car fuel, and air travel. The consumption figures above are averages for typical households – you can adjust these to your actual usage from your energy bills.

Looking at our "footprint" in this way clearly indicates where there is most potential for improvements.

CONSIDERING THE OPTIONS:

There has been much talk in the press about home eco-improvements, such as solar panels, heat-pumps and the like. These will reduce CO_2, but they are all relatively expensive items, some of which may take a long time to generate enough energy savings to pay for their initial cost, so their financial/investment merits are dubious, unless there are subsidies. More on these later.

There are however a range of relatively simple options which can significantly reduce CO_2 emissions, and actually save you money at the same time. The definition of a "good investment" varies from person to person, but for the purposes of this article, let us say that anything with a payback of the initial cost in 5 years or less is a good investment. (In 2021, bank interest rates are so low, that even a 10 year payback on a "green" investment looks very attractive.)

Some items with longer energy cost payback are included, for example double-glazing, which also adds value to your house when you come to sell, and reduces ongoing maintenance costs too.

CENTRAL HEATING & HOT WATER: (2.7 tonnes CO_2 average)

Improvements are worthwhile in the following areas:

Loft insulation is a high priority. The current recommended figure for loft insulation is 270 to 300mm thickness. If your loft has less than 200 mm (8"), then it's a high priority to top it up to 300mm (or more). If the available space is insufficient, use "loft legs" which raise the loft floor boarding by 175mm. Payback may be from 1 to 5 years, depending on how poor the loft insulation was to start with.

Note that just adding insulation by itself can cause condensation problems, one must ensure that there is adequate ventilation of the loft space to mitigate this risk.

Cavity Wall insulation is also a priority if your property is suitable. If you are past retirement age or in receipt of some government benefits there may be local authority grants making it (and loft insulation) totally free. Houses built prior to 1920 are unlikely to have cavity walls. Other forms of wall insulation are possible but relatively expensive.

Adding cavity insulation to a building constructed between 1970 and mid 1980s will reduce the U-value (a measure of heat loss) from approximately 1.0, to 0.5, i.e. halving the heat loss through the walls. With older buildings, the baseline heat loss is worse, but the same broadly applies, cavity insulation can reduce losses by a factor of 2. If built after 1996 cavity insulation was, or should have been, incorporated at the build. (Source: www.thegreenage.co.uk)

There is a risk of damp problems resulting from cavity insulation on buildings in exposed locations, so make sure that the installer has the expertise and experience to assess this risk.

Double-glazing does save CO_2, but its payback in pure energy terms is likely to be a lot longer than 5 years. However, providing it is good quality, and expected to last a long time, it will enhance the value of the house, and reduce maintenance cost, as well as saving energy.

Note that PVC is not an eco-friendly substance, particularly at the disposal stage. Good quality timber frames or aluminium-clad timber are less polluting and can have a similar lifetime.

Perhaps surprisingly, if you have old double glazing, installed before say 2000, it may be worth upgrading it. Modern double glazing achieves a U value of 1.6 (or better), older double glazing may have a U value of around 3. A single glazed window has a U value of approximately 5.6.

Even with double glazing the heat loss through windows is high, compared to insulated walls and ceilings. Good heavy weight (and close fitting) curtains make a substantial difference to heat loss

at night. A double glazed window loses half as much heat as a single glazed window, but it still loses far more heat (at least 3 times more) than an equivalent area of insulated wall. My temperature measurements on some large double glazed French windows showed that the space between the thermally lined curtains and the windows had a substantially lower temperature when the curtains were closed than when the curtains were opened. The estimated improvement from closing the curtains was approximately 50%, due to the benefits of isolating the room convection currents from the cold window.

On the same subject, if you have a conservatory attached to your house, always close the interconnecting door when the conservatory is not in use (and turn off any heaters in the conservatory!). You will find the conservatory then gets cold at night very quickly - this shows how much heat is lost from the conservatory if the door to the house is open! If it's a glazed interconnecting door, an additional tweak is to fit a curtain on it for use at night.

Draught-sealing is important, particularly in older properties. Draughts are a major loss of heat, though of course one should not eliminate all ventilation. Even if your has good draught sealing already, it's worth going round and checking doors, windows, keyholes etc. on a cold windy day. Air tightness levels are appalling even on many quite new properties.

Open fireplaces with chimneys, unless they are being used frequently, should be stopped up to avoid major heat loss. If the fireplace is used regularly, then fitting a closable "damper" in the flue would be a good idea. Note that if you permanently seal a chimney, it is a requirement to vent the flue to avoid condensation. One product that appears to fit the bill is the "chimney sheep" which stops the main flow while providing some ventilation. <https://www.chimneysheep.co.uk/>. There are also inflatable flue draught stoppers from <https://www.chimneyballoon.co.uk/> and from various DIY stores.

Improving the controls on central heating is easy and very cost-effective. Most houses have a simple dial thermostat. Replace this with a "programmable thermostat", and you can set different temperatures for different times of day. (Cost from about £25 upwards, fit it yourself - payback under 1 year). Typically you will want the house warmest in the evening when sitting down relaxing, less warm during the day. The best ones have an "optimum start" feature which senses how cold the house gets overnight, and adjusts the start time of the heating in the morning to give the desired temperature at the time you want to get up.

Often some rooms in the house are unoccupied much of the time. These should be fitted with a thermostatic radiator valve, and turned down to the minimum acceptable temperature. Failing that, a simple expedient is to drape a thick towel on a radiator to reduce the heat output when not needed. (Still provides some background heating to avoid condensation, and is an obvious visual indicator that the radiator is "turned down".)

An internet connected thermostat ("Nest" is one example) provides a further level of refinement, and can be controlled remotely using a smartphone app. Smart wireless connected radiator valves are also available, whereby one can programme different temperature cycles for each room. An example is "Honeywell Evohome" I have no practical experience of these, but I expect that they can provide significant additional savings.

The hot-water tank (if you have one) should be insulated to a high standard. Most tanks these days have foam insulation already moulded on at manufacture. But there is no harm in adding a further insulating jacket (cost £10 to £20), and also insulating the hot pipes coming out of the tank. Most new-ish homes now have a "combi" boiler, which provides instant hot water, and therefore there is no hot water tank.

Most hot water tanks have a thermostat mounted near the bottom of the tank to control the heat input. Try turning this down by 5 or 10 degrees, and you will improve the overall efficiency. NB: To avoid the risk of Legionella bacteria growing, the temperature at the top of the tank should be at least 60°C, no less.

(Electric water heating by immersion heater is an interesting example of something that has changed in the last 10 years. In the past, heating the water electrically created vastly more CO_2 than heating the water from a gas boiler. Now, due to the reduced use of fossil fuels in electricity generation (in UK), either method produces about the same CO_2, and in the future electricity will be better than gas. But at present, the cost of the electric heating is 3 to 4 times higher than the cost of heating it from gas. If electric heating is your only option, again the water temperature can be adjusted downwards; usually there is an adjustment screw on the heater, accessible under a removable cover.

Boiler type has an important effect on efficiency. If a boiler is an older type, say 20 years old or more, it will have a much lower efficiency than modern boilers, and also it may have degraded with time. It may be time to replace it, even if it's not at the end of its life. As with double-glazing, a new boiler will enhance the property value.

The new boiler should be the "condensing" type, which has significant efficiency gains particularly when running in condensing mode. Condensing mode is at its most effective with underfloor heating, though it's usually only cost-effective to install underfloor heating during major refurbishment.

The boiler itself has a temperature setting (typically 1 to 5). In winter it may be necessary to have this near maximum, but in spring, summer and autumn this should be turned down to 2 or 3, improving the overall system efficiency.

By fitting a (£5) thermometer to the return flow pipe on the boiler, you can tune the central heating system to maximum efficiency. (Some boilers can display the return flow temperature on their control screen, though the option may be hidden deep in a menu, as it is only generally used by the boiler installer technician.) The return flow temperature should be as low as possible, ideally well below 50 degrees. To achieve this, radiators, in particular those nearest to the boiler may require adjusting, by tweaking the flow control valve (also called the lockshield valve, i.e. the small capped-off valve at the opposite end of the radiator from the main control). This should have been adjusted by the heating installer, when "balancing" the system, but in practice the settings may not be fully optimised.

If you have a chimney, consider installing a **wood-burning stove**. They are much more efficient than open fires, and they use a renewable fuel. Theoretically the CO_2 released when burning wood is reabsorbed by growing new trees, so you can (perhaps) count wood-burning as being very low CO_2. If you have a cheap (or free) source of firewood, then the wood-burner can also reduce your central heating bills.

Ideally the wood stove should be installed in a large fireplace with plenty of space around it, to ensure that room air can circulate around it effectively (natural convection). However, modern "insert" stoves have a convection passage around them which allows them to emit a good flow of hot air, as well as direct radiant heat.

An extra benefit of the wood stove is that even when it is not being used, it greatly reduces the wasteful flow of warm air up the chimney, equivalent to a flue damper or partial restrictor. However , this effect can be achieved far more cheaply by fitting a chimney restrictor!

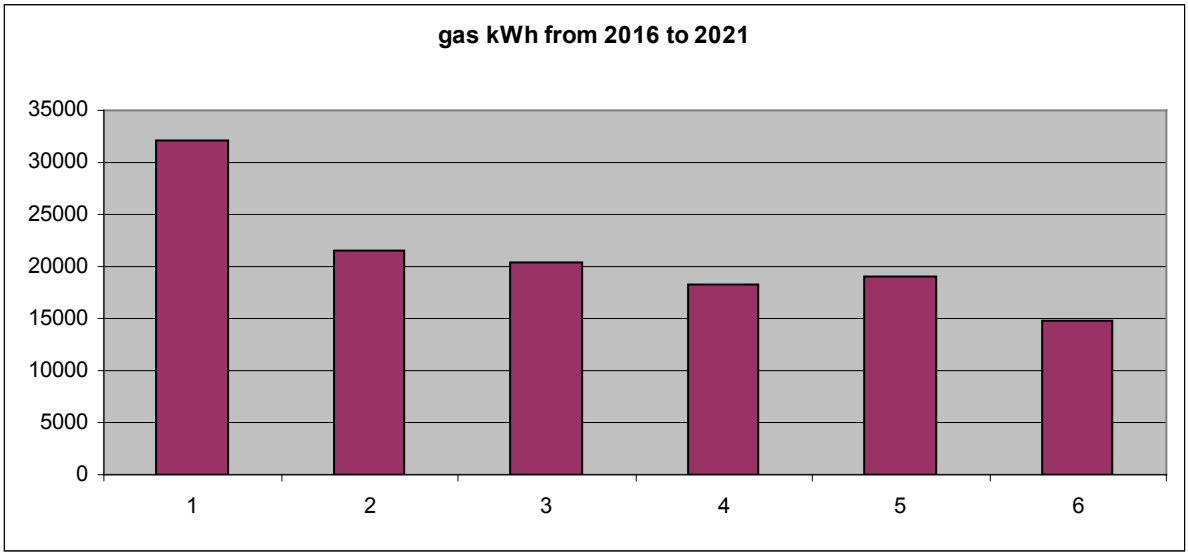
Underfloor Insulation: Some sources suggest that up to 15% of heat is lost through the ground floors, and for suspended wooden floors with a cold ventilated airspace underneath this is plausible. And cold floors are undoubtedly unpleasant to walk on. Unfortunately the cost and disruption of insulating under the floor is usually prohibitive, unless as part of a major house refurbishment.

A lot of small improvements as described above could add up to a substantial saving. Unless your house is unusually poorly insulated at present, the saving is unlikely to reach

50%. But 25% plus may be achievable, and that's a worthwhile gain, particularly as it saves you money as well.

Our current house, a 1980s 4 bedroom detached house, had some insulation, including wall cavity insulation, when we bought it, but had scope for improvement. Initial changes in the first year reduced the heating usage by about 30%. Further improvements over the following 4 years have also given significant gains, and now the house consumes less than half of the heating energy than it did at the start. These figures have taken into account the weather conditions in each year, by a relatively simple calculation based on "Heating Degree Days" data that is freely available.

Note: For further information, Google "heating degree days" or visit: https://www.degreedays.net



Graph of annual gas consumption of author's house over 6 years, adjusted for weather conditions. 4 bed detached house, 1980 build,

The house is 4 bedrooms, detached, floor area 190 square metres, built in 1980, with (old) double glazing, full wall cavity insulation, and radiator TRVs. The improvements we made were as follows:

- Year 1: close off an open archway between sitting room and hallway, replace open fire by wood burning stove, draught sealing of windows, programmable thermostat.
- Years 2 to 4: upgrade loft insulation (including rectifying some completely uninsulated areas), fit double glazed exterior door, upgrade several double-glazed windows, thermally lined curtains on all large windows, insulate hot water tank.
- Year 5: new condensing gas boiler (this alone saved around 20%).

ELECTRICITY: (1.0 tonnes CO_2 average)

The amount of CO_2 produced per kWh of electricity has reduced dramatically in the UK in the last 10 years. In 2005 the figure was over 0.500 kg CO_2 per kWh. In 2020, it was 0.180 kg. This dramatic 2/3 reduction of the CO_2 was achieved by a combination of phasing out coal fired power stations, reducing usage of gas and oil fired power stations, and increasing the renewable sources of power. This is a substantial achievement, and the UK is currently a world leader in decarbonising its electricity supply.

Also, the average household consumption has reduced substantially over the same period, from 5500 kWh to 4400 kWh, a reduction of around 20%. The reasons for this are varied, including low energy lighting, more efficient appliances, reductions in standby consumption of appliances, and probably also a general awareness of the energy intensive appliances such as tumble dryers and

electric heaters. Further consumption improvements are expected, as old appliances are replaced and all halogen lights are changed to LED.

Note that future use of electric cars, and of heat pumps (air source and ground source) for heating, will probably increase the average electricity consumption.

Low-energy lighting:
The early CFL (compact fluorescent) low energy bulbs did not find favour with a lot of people, due to the quality of the light. However these have largely been superseded by LED lights, which most people find acceptable. LED lights have also become cheaper and adequately powerful.

Beware of some "low energy" bulbs which are available, which are actually halogen incandescent bulbs enclosed inside a conventional looking glass bulb. They do save some energy, but only about 30% compared to a conventional incandescent bulb. A LED bulb saves 85 to 90%!.

Some halogen ceiling downlighters (typically MR16 type) are sold as "Low-Voltage" lighting, which is sometimes misinterpreted as "Low Energy".

A 60 W incandescent bulb used for 1000 hours a year (3 hrs a day) uses 60 kWh of electricity, costing around £12. A halogen bulb of similar light output uses 50 kWh, £10 per year. A LED lamp of 6 W will produce similar light output, and consume 6 kWh, costing £1.20. The LED lamp saves its cost in well under 1 year. Figures for a typical house with say 50 lights, assuming 25 are used daily for 3 hours each, are included in the table below in the "domestic appliances" section.

Note that with Low Voltage (MR16) bulbs, it is not always possible to directly fit a LED bulb replacement. It will fit physically, but it may not work. If so, the usual reason is that the low voltage power supply "transformer" is not suitable for the LED bulbs. The transformer can be changed to a LED compatible one, usually fairly easily, providing it has been installed in an accessible place!

A published report (Climate Change Committee: The Sixth Carbon Budget) showed that in UK in 2019 there were (still) 50% of domestic lightbulbs that were halogen or conventional tungsten filament types. Check your house, any halogen bulbs that are used for more than an hour a day really should be changed to LED. Don't wait for them to expire, change them at the first opportunity, it is cheaper and better to throw them out now! If you are unsure whether a light is halogen or LED, hold your hand close to it (but don't touch it!): halogens emit a lot of heat, LEDs very little.

Domestic appliances:
These have been improving substantially over the last 15 years or so, to the extent that the original energy labelling system had to be changed recently, because nearly all fridges and freezers on the market were achieving A+ or A++ ratings.

For fridges and freezers, you need to not only consider the energy rating, but also the size, as a large unit will consume more electricity than a small unit with the same energy efficiency rating. Luckily, nearly all suppliers publish the annual electricity usage in kWh, and this should be used as the comparator when choosing your appliance.

The information available on the internet is diffuse and over-complicated. Below is a list of my estimates of annual energy consumption of various devices, showing typical new versions and 15 year old versions for comparison. The numbers for the old devices are estimated.

DEVICE	New or current model: kWh/year	15 year old model: kWh/year	Notes
Separate fridge 240 litre and freezer 140 litre	350	500	assumes older units use 50% more.
Medium size fridge-freezer 350 litres	250	375	ditto
Large "American" fridge freezer 600 litres	400	600	ditto
Washing machine 8kg	175	260	used 4 times a week
Tumble dryer 7kg condensing (not heat pump type)	500	700	used 3 times a week
Dishwasher	200	250	used 5 times a week
43 inch TV	180	360	100 W, 5 hours a day
Desktop computer & printer etc	100	150	100 W, 3 hours a day
Kettle	250	250	Boiling 1 litre, 4 times a day.
40 light bulbs, average 40W, half in daily use, 3 hours per day	130 (LED)	870 (halogen)	change halogens to LED
TOTAL OF THE ABOVE	**1800 approx**	**3200 approx**	(Total assumes a medium sized fridge freezer)

The above is obviously not the total consumption for the typical household, as it does not include electric cooking, and a host of small gadgets and electrical devices. Even gas central heating consumes electricity: the circulating pump and the boiler fan together consume around 100 kWh per year. The always-on internet router/modem may consume 50 to 100 kWh per year.

There have been messages in the media to switch off (at the mains socket) phone chargers, televisions, computers, and other devices when not in use. Some devices consume significant amounts of power on standby – unfortunately you can't tell which just by looking. However anything sold in the last 10 years should have a tiny (1 or 2 Watts) standby consumption, so there is only a small benefit in switching it off. Older devices might have 10 or 20W consumption. One device at 10 W uses about 80 kWh per year, and at current electricity prices this costs at least £20. Multiply this by 10 or more devices in a family house, and you could save a substantial amount.

One way to tell which devices are wasteful is to feel if they remain warm when in standby mode. If they do, they probably are taking at least 5 W, maybe 10 W or 20 W. (Remember to check not only the device, but also the mains "plug" or the power supply, which may contain a wasteful transformer; this may feel warm even in standby mode.)

For £15 or so on ebay or Amazon.co.uk you can buy a device (search for: "power & energy monitor") to measure the power of each of your devices. Get one and go round your house and find which ones need switching off, or replacing by a lower consumption device. For example, we found to our surprise that our old home telephone system (base-station and 3 handsets with chargers), was consuming nearly 40 W in total. That has now been changed to a better one! Also, much to our surprise, an expensive microwave oven we bought from a reputable manufacturer has a consumption of about 40W when switched off (whereas our old one used only 6W). We are now switching it off at the socket whenever it's not being used.

Modern LCD or OLED large TV's (40+ inches) will consume 100 W or more when running, and some may consume substantial amounts even on standby. An older Plasma Screen large TV can consume 3 times as much as a modern LCD of the same size.

Computers (with their printers, monitors, modems, wireless routers etc.) can add up to hundreds of Watts when running, and 50W or more on standby.

As with home heating, a number of small improvements can add up to a substantial gain. Low energy lighting is a particularly big saver with a very quick payback, so any incandescent bulbs (conventional tungsten filament, or halogen) that run for more than an hour a day need to be chucked out and replaced by LEDs.

CAR TRAVEL: (2.3 tonnes CO_2 per 10,000 miles average)

The figures in the table are for a 45-mpg (petrol) small family car. If you have a Diesel, then a 50-mpg Diesel gives roughly the same CO_2 as a 45-mpg petrol car. If your car is more (or less) thirsty than these baselines, you can adjust your figures accordingly.

Note that Diesel cars often cost more to service and repair than petrol cars, and currently in the UK Diesel fuel is more expensive than petrol. So for a driver doing average mileage (say 8,000 miles per year), a Diesel is unlikely to save much money overall compared to a petrol engine. A Diesel will generally emit slightly less CO_2 than an equivalent petrol car, but the other exhaust pollutants are substantially worse with Diesel.

Before you do a long (or short) journey by car, think whether you could combine two or more journeys to save mileage, or share cars, walk, cycle, or take public transport. Saving 1000 car miles per year represents about 0.25 tonnes of CO_2. Travelling by train or bus (1 person) emits far less CO_2 (see details later in this article).

Reduce motorway cruising speeds – dropping 10 mph from your customary cruising speed will make only a little difference to your total journey time, but can save around 10% of the fuel. (Although there is little point in cruising at less than 60 mph as the gains are insignificant). You may also arrive more relaxed – the benefits of lower noise and vibration!

Hybrid cars using an electric motor in conjunction with an engine (Toyota Prius for example) have impressively improved fuel consumption at low speeds, but currently only limited benefits at high speeds. If much of your fuel is consumed at 70 mph on the motorway, the overall benefits are pretty small. A small Diesel or petrol car with good fuel economy will have similar running costs, as well as being cheaper to buy.

The PHEV (Plug-In Hybrid Electric Vehicle) is an interesting option if you do mostly short journeys, less than 40 miles a day, as you can charge it overnight and run it just on electricity most of the time. But note that it is heavier than a standard car or a normal hybrid car, and so on long journeys it may actually use more fuel than either.

Electric cars (EVs) are getting better and cheaper year by year. And the recharging infrastructure is also improving. This is by far the best car option in terms of CO_2 reduction.

Current models travel around 3 miles per kWh of electricity, so the CO_2 is approximately 0.07 kg/mile, i.e. 70 kg per 1000 miles, less than 1/3 of the CO_2 of a small petrol car.

If the range and capital cost on an available model of electric car meet your needs, then there is no reason to delay. The claimed maximum range will apply only for gentle driving in summer conditions, so its best to look at independent reviews for real-world range in winter conditions. For company car drivers, the taxation position may make an electric car cheaper to own than a standard car.

It has been said that it's greener to keep an old car going than to replace it by a new, more efficient model. There is some truth in this, particularly if your car is only used for a few thousand miles a year. If it does the typical 8,000+ miles, then the picture is not clear-cut. Anyway, most cars are

changed for reasons other than purely "green" ones, so my plea is that you keep green factors in mind next time you change you car.

Public transport, trains and buses
Train travel (in UK) has a very low carbon footprint, 0.05 kg per mile, about 1/5 of a single occupant car. Bus travel is less good, figures around 0.14 kg/mile are quoted, but this partly due to the generally low utilisation of buses in UK. If one considers the marginal cost of each extra passenger on the bus, the number is much lower, probably around 0.08 kg/mile, i.e. about 1/3 that of a single occupant car. Long distance coach travel is claimed to be lower CO_2 than train travel (https://www.statista.com/statistics/1233337)

AIR TRAVEL: (???? tonnes CO_2)

In the last few decades air travel has become cheaper per mile than train or car travel, which seems counter-intuitive. The lack of tax on aviation fuel, and various other factors, distort the "market" in favour of flying.

As the table at the start of this article shows, a trip for 2 to Spain plus a trip for 2 to USA creates about 3 tonnes of CO_2. This figure is purely the CO_2 emissions, and there is a scientific view that the additional effects of the CO_2 being injected directly into the high atmosphere rather than at ground level will magnify the global warming effect of flying by a factor of between 2 and 3. This is referred to as the RFI, radiative forcing index. So the effective figure might be **6 to 9 tonnes** equivalent. Compare that with the energy savings you are likely to be able to make per year in your house!

Every time you take a plane ride, think whether there is an alternative? For domestic and near-Europe trips take the train instead of the plane and use the longer journey time to relax, read, or contemplate how people like you are helping to make the world a better place! Even car travel (single occupancy) is lower CO_2 than plane travel. Some consider that the train environment can actually be more conducive to effective working or relaxation than the rather oppressive environment of airports and aircraft, so the longer journey time is not wasted. Also when you add in the time to reach airports and the check-in times you may find that train travel times are not so bad! Lastly, consider whether the reason for the travel can be achieved equally effectively by video meetings. These are sometimes clunky and less rewarding than face to face meetings, but when the travel time and cost are included, overall video meetings can sometimes be more effective.

Obviously, visiting relatives or holidaying in distant continents is a bit impractical by train, but why not think about going less frequently, and staying for longer on each trip?

Combining trips to several destinations is usually more expensive than separate out-and-return flights (purely due to airline ticketing policies, there is no fundamental reason for this), but it's definitely better for the planet. In the last few years, ticketing options have become more flexible, making combining trips easier and more economical.

Where possible, choose airlines that have the latest and best aircraft, as these are the most fuel-efficient. For example, for long-haul travel the Airbus A380 is claimed to be 15 to 20% more efficient than a Boeing 747 (CO_2 per passenger-mile).

OTHER ECO-IMPROVEMENTS:

Up to now I have mentioned only things that save money, i.e. have a financial payback as well as reducing CO_2. They are the first priorities, but there are other eco-improvements which can be considered.

Not many people are in a position to build (or have built) a new high efficiency eco-house, which can reduce energy consumption to almost zero and thus reduce one's carbon footprint. However there are various add-on technologies which can be used with existing buildings, which go some way towards this.

Most of these technologies, when applied at the household level, have long financial payback periods. So if we adopt them, we are effectively paying in order to reduce our CO_2 output.

Many people now accept that paying some money to keep our planet liveable is a reasonable thing to do, but we need guidance on how to get the "best bang per buck", i.e. best CO_2 saving per pound (or dollar).

Let's start by looking at some numbers for home energy technologies. I am only including systems that are viable for typical homes. Larger buildings (hospitals, offices etc) may have some other options not included here, such as biomass boilers.

The starting point for most home owners is gas (or oil or LPG) central heating. For all of these, the real efficiency is usually around 80% (80% of the fuel heat goes into the house and hot water). So for a typical gas consumption of 15000 kWh, one is getting approximately 12000 kWh of heat. The CO_2 is 2.7tonnes, corresponding to about 0.23kg CO_2 per kWh of heat delivered. Oil fired central heating generates approximately 30% more CO_2 because of the inherently higher carbon content in oil. Propane (LPG) systems are about half way between gas and oil systems in terms of CO_2.

Most of this heat (approximately 80% in our house) is delivered during the 6 months November to April. If one changes to electric heating (storage heaters or heat pumps) one needs to base calculations on the CO_2 content of the electricity in the winter months. Over last winter 2020-2021, the average CO_2 content of the UK electricity was 0.23kg CO_2 per kW of electricity supply (in summer it was somewhat lower than this). This is a considerable improvement from 10 years ago, when the average was well over 0.40kg, and we can expect further improvement over the next decade as more wind power (and solar and tidal power) comes on stream.

The exact amount of further improvement is difficult to predict, particularly as there are uncertainties regarding the demand side, including charging electric cars, moving to electrically powered heat pumps, and changing working and home life patterns. It is clear however that improvement is likely, and that an average CO_2 content of less than 0.1 kg per kWh is feasible by 2030. See <https://www.icax.co.uk/Grid_Carbon_Factors.html> for example. The costs and CO_2 savings for various technologies shown below are based on this assumption, changing from circa 0.2 kg at present, to less than 0.1 kg within 10 years, i.e. averaging 0.15 kg over the period.

The overnight electricity (used by many homes for off-peak electric storage heaters) has a significantly lower carbon intensity than the daytime average. Currently in winter it can be around 0.16 kg, and in the future may drop to less than 0.08 kg, so over a 10 year period averaging perhaps 0.12 kg. This is very approximate; some people predict that the overnight electricity may drop to zero CO_2, but my view is that while zero CO_2 will occur at times (mainly at windy times!), we are unlikely to experience an <u>average</u> overnight value of zero in this decade, particularly in winter when electricity demand is at its highest.

The cost aspect is even more difficult to predict. At the time of writing this (2021, 2022) there is a UK energy "crisis" caused by various supply side factors, and prices for gas and electricity are unusually high. Whether and when they will settle back to more affordable levels is unclear. The expected default domestic tariff cap level (as at April 2022) is approx 7.5p/kWh for gas and 31p/kWh for electricity. Allowing for the 80% efficiency of gas boilers and central heating systems, the electricity cost is about 3.2x the gas cost. Commercial energy prices are currently even higher than this, and the cap level may rise again in autumn 2022 if commercial prices have not reduced by then.

For evaluating the relative running costs of various central heating options, the main issue is not the absolute price level, but the ratio between gas cost and electricity cost.. The figures below are based on the future electricity cost per kWh being effectively 3.2x the gas cost, which is the current (April 2022) ratio. If the house heating requirement is assumed to be fixed, a ground source heat pump costs 10% less to run than a gas boiler, and an air source heat pump costs 15% **more**. Of course, most people when fitting a heat pump system will also try and improve their house insulation, in order to achieve the same or lower running cost overall. Sources that claim heat pumps have lower running costs than gas boilers, are really referring to the savings from improved insulation, not savings from the heat pump.

The situation may change in the next few years, as the Government has realised that in order to promote electrical heating, the balance of prices needs shifting, and so environmental tariffs currently applied to domestic electricity will probably be transferred to the price of gas, thus shifting the balance in favour of electrical heating.

Technology	Cost (allowing for grants)	Running cost difference per year	CO_2 saving per year (average 2020 to 2030)	Financial payback period
Solar Photovoltaic (PV) cells 4 kW	£6000	£400 - £500 saving (2022 £0.31/kWh price cap assumed)	0.5 tonnes (see notes)	12+ years
Solar panel water heating	£4000	£100 saving (assuming gas central heating)	0.3 tonnes	40 years
Ground source heat pump 10 kW unit. (Assumes £6000 grant)	£25000 to £30000	Running cost saving approx 10% (without added insulation)	2.2 tonnes	??
Air source heat pump 10 kW unit. (assumes £5000 grant)	£7000 to £13000	Running cost **increases** approx 15% (without added insulation)	2.1 tonnes	??
100 kWh Thermal store using low carbon off-peak electricity	£12000 (no grant)	Cost depends on future overnight electricity tariff, currently not known.	1.1 tonnes	??
Wood burning stove	£3000	No saving (if paying for wood)	0.2 tonnes	??

The last column in the table, the "financial payback period", I have based on an assumption of zero interest on the capital, and also zero inflation in energy prices. In reality both interest rates and energy inflation exist, but they approximately balance each other out. In the past decade energy inflation has been higher than interest rates, currently much higher, and the future trend is unpredictable!

Solar PV Panels: Since 2009 when this article was last revised, rooftop solar panels have become very widespread, and government schemes for providing financial incentives have changed. Also the costs of the panels has reduced substantially. Currently (2020), the majority of the financial benefit comes from the avoided cost of household electricity imported from the grid, and only a small proportion comes from the electricity exported to the grid. New-build properties seem to generally incorporate solar PV, as the added cost for a new build is small, compared to the retrofit cost. When doing calculations on the payback, the standard assumption is that 50% of the electricity generated is used in the home, but in practice most homes will use a lower proportion, maybe in the region of 30%, unless they also incorporate battery storage or thermal storage

systems. The Energy Savings Trust calculator <https://www.pvfitcalculator.energysavingtrust.org.uk/> indicates that annual CO_2 saving for a 4 kW PV system is around 800 kg (0.8 tonnes), but this is based on current electricity carbon intensity. Projecting forwards for an average over the period 2020 to 2030, the CO_2 saving is probably 0.5 tonnes at best, and reduces further in the next decade.

The cost estimate of £6000 includes £5000 for installation, and £1000 for maintenance cost which is mainly replacement of the electronics after about 10 years). At current electricity prices (domestic price cap April 2022 is £0.31/kWh), the payback is around 12 years. If the electricity price increases substantially, the payback period will get shorter.

One needs to have a roof that is south facing and not shaded by trees or buildings, in order to get the full benefit. If not, the payback period may be a lot longer. We note however that the embedded carbon from manufacture and installation of a 4kW set of panels is around 1.5 tonnes, so the panels pay back their carbon debt in around 2 years, based on current electricity carbon intensity.

Solar panels for water heating were heavily promoted, but are not seen much now in UK (though very popular in more sunny countries). They can undoubtedly produce a useful proportion of one's hot water in the summer, but are little use in winter. Their payback period is likely to exceed the lifetime of the equipment, so they are not generally a good investment in UK, for homes heated by gas. However, if your water is all heated by electricity, the solar panel may give a much more worthwhile financial return.

Ground-source heat pumps are expensive, because installation typically involves laying pipes in a deep hole in the ground, or over a large area of shallow excavation. It runs on electricity, and if the system is well designed can achieve an effective COP (coefficient of performance) of around 3.5, which means that it provides 3.5 kWh of heat for every 1 kWh of electricity.

Based on current (2020) electricity supply, the CO_2 saving compared to a gas boiler is 75%, rising to about 88% by 2030.

Note that the articles claiming lower running costs for a heat pump generally include a major insulation upgrade applied at the same time. The insulation delivers the lower running costs, the addition of the heat pump at present does not of itself make much difference to the running costs. At the expected April 2022 electricity and gas prices, the running cost saving from a ground source heat pump will be of the order of 10%.

Air-source heat pumps avoid underground works and are considerably cheaper to install.
The efficiency (COP) is somewhat less than a ground-source heat pump, particularly when outside air temperatures are very low. Measurements on older installed systems have shown COP of around 2.5 average, and a well-designed new system can probably achieve a COP of around 2.8.

Based on current (2020) electricity supply, the CO_2 saving compared to a gas boiler is 69%, rising to about 85% by 2030.

Due to the lower efficiency (compared to a ground source heat pump) the air source heat pump will (at anticipated April 2022 prices) cost about 15% more to run than a gas boiler, for the same amount of heat delivered.

For both ground source and air source heat pumps, the figures I have given above assume that no extra insulation is added to the home, and that therefore the required heat input to the building is the same as for a gas boiler. In practice, most owners will upgrade their insulation as well as changing to a heat pump. Adding substantial insulation improvements and changing over to underfloor heating is a substantial expense. It is very difficult to give any sort of "average" figure, but a nominal range of £5000 to £10000 has been included in the costings shown in the table above. For some houses, the cost could be a lot higher than this.

If your house does not have a mains gas supply, and you are using expensive electricity or oil or propane for heating, then ground-source or air-source heat pumps will be more financially rewarding than the above figures suggest.

Underfloor heating: In order to get high efficiency out of a heat pump system, one requires very large area "radiators". Underfloor heating is the classical way to achieve this, though options such as over-sized wall mounted radiators, or fan-assisted convector radiators are possible alternatives. For most houses this will mean substantial alterations and renovation. Solid concrete floors would require digging out, suspended floors would require lifting and insulating underneath. Even the option of fitting oversize radiators or fan-assisted radiators may be expensive to install, as many homes use small bore piping for radiators, which is inadequately sized for the higher water flow rates associated with a heat pump system.

Although it is difficult to give cost indications, one is unlikely to spend under £5000 on retrofitting underfloor heating (though somewhat less as a part of a major home overhaul project), and this needs to be included in the capital cost of the system.

Thermal storage systems: Various options exist or are under development. One interesting new device is the "Warmstone" which is in effect a whole-house electrical storage heater with 100 kWh capacity, enough to provide a full day's winter heating in many homes. See <www.caldera.co.uk>. If the device is heated up at night using low-carbon off-peak electricity, the future CO_2 savings will be substantial. At present (2020) the CO_2 saving would only be around 20% compared to a gas boiler (but 40% compared to an oil fired boiler), and by 2030 the saving is expected to be around 60%. Averaging over 2022 to 2030, the savings should be around 40% compared to gas, or 55% compared to an oil fired heating system.

This system has several advantages. Firstly it is moderate cost (installed cost is predicted to be £12000 total), secondly it requires no changes to the central heating system, it just replaces (or works together with) the current gas or oil fired boiler, and thirdly no changes to house insulation etc are required. With a heat pump system, house insulation improvements, and underfloor heating are both needed to keep running costs at or below the cost of conventional gas central heating.).

Costings from the company that supplies this system suggest that for an oil-fired or LPG fired heating system, the running costs with the thermal store will be less. This calculation relies on the availability of cheap overnight off-peak electricity at circa 5p/ kWh, and it is not clear whether such attractive rates will be generally available, particularly during the current energy "crisis", and currently rates offered for new customers appear to be much higher than 5p/kWh. If this situation continues then it could be a substantial barrier to uptake of this otherwise attractive technology. The "break even" on running cost occurs when the price of off-peak electricity is around the same as gas, currently (from April 2022 onwards) gas is around 7.5p/kWh

The "Warmstone" device described above is large enough for a detached house. Smaller thermal storage units are available from Tepeo.com (currently 40 kWh capacity), and from Sunamp (12 kWh capacity).

Wood Burning Stoves were discussed earlier in this article. The CO_2 reduction is a bit controversial, in that it assumes the wood burned is replaced by new trees, which of course take years to grow. Even burning "waste" wood is possibly controversial. If the waste wood goes to a recycling centre, it will either be recycled into other products, or incinerated to produce energy, so it is arguable whether a wood burning stove really saves much CO_2. Plus, it will only generally be used in evenings and will not heat the whole house, so its impact on the house heating requirement will be low, maybe 10%, at best 20%, for most households.

Summarising all of the above, it appears that at current energy prices, none of the alternative heating/energy options listed will substantially reduce operating costs (compared to gas central heating). Future energy prices are difficult to predict, but if one assumes that fossil fuels will in general increase more than electricity prices (either by natural market forces or by government incentives, green taxes etc), then changing your heating system may yield a good financial return.

If you are prepared to spend money to reduce your carbon footprint, then the options above are worthwhile. If not, then you are left with improved insulation and reducing house heat loss as the approach which has a financial payback.

One approach therefore is to start by upgrading insulation and reducing heat loss, and whenever you are doing a major project such as an extension, or renewal of flooring, incorporate efficiency enhancers such as underfloor heating and underfloor insulation. And wait until energy pricing, grants, etc are such that changing the heating system to a heat pump or a thermal store will be financially beneficial.

ALTERNATIVE OPTIONS:

I am a strong believer that while sometimes "small is beautiful", for carbon reducing technologies "big is better". Economies of scale means that small wind turbines give a negligible energy return, but large wind farms work extremely well, repaying all their embedded CO_2 of construction in under a year. Likewise, large scale solar PV schemes are far more cost-effective and efficient than individual rooftop panels. While large scale schemes are subject to grid distribution losses, they are still usually far better than small systems.

Therefore rather than fitting a small solar PV panel or water heating panel to your house, you could consider another approach, which is to put your money into larger schemes, which will have better payback and also more CO_2 impact per pound invested.

One example is **investing (buying shares) in windfarms**. Obviously, some will consider investment in windfarms as risky, being at the whims of the weather, technical risks etc. I guess it's wise not to put your entire life savings into this.....

There are currently (in the UK) only a small number of opportunities to invest in pure renewable energy companies, e.g. Renewable Energy Generation Ltd <https://www.renewableenergygeneration.co.uk/>, also Thrive Renewables <https://www.thriverenewables.co.uk/> although windfarm schemes are sometimes run as co-operatives giving local (and other) people an opportunity to invest directly. Examples – see: **www.energy4all.co.uk** , which covers a number of small wind farms. If you register your interest with them they will notify you of future share offers.

A recent arrival in this field is Ripple Energy <**rippleenergy.com**>, a company that supplies green electricity and additionally enables subscribers to buy shares in the wind farm(s) that they are constructing. Share dividends, and a slow (5% p.a.) capital repayment will be applied as discounts on your electricity bills.

There may also be local direct investment schemes into solar power from time to time, e.g. rooftop solar panels on schools as a community co-operative scheme. Google "community energy" and find out what exists in your area.

One option is to **purchase your electricity from a renewable energy supplier**, and pay the slight premium that such tariffs usually have. There will be no financial payback, but the small amount extra of money you pay may contribute to reducing CO_2 emissions. (But note that this is debateable, as all electricity in UK is distributed down the same wires, so it is impossible to claim that one supplier is delivering to your home more renewable energy than another. If the supplier

can show that they are using your extra money to invest in increased renewable energy production (wind farms, solar) etc, then that is fine. If not, it's probably "greenwash".)
See www.greenelectricity.org/domestic.php for useful information, including costs and green ratings. Also see this recent article: <https://www.which.co.uk/news/2021/10/which-reveals-new-eco-providers-for-energy/>

SUMMARY CHECKLIST

- Loft insulation
- Cavity wall insulation
- Double glazing
- Draught sealing
- Chimneys
- Programmable thermostat
- Thermostatic radiator valves
- Hot water tank insulation
- Condensing boiler
- Boiler temperature setting
- Wood burning stove
- Low energy LED light bulbs
- Efficient domestic appliances
- Standby power consumption
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- Hybrid cars
- Battery electric cars
- Air travel – train alternative
- Combining trips
- Choosing airlines

- Photovoltaic cells
- Solar water heating
- Ground source heat pumps
- Air source heat pumps
- Thermal stores

- Investing in renewable energy schemes

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