Domestic Wood-burning Stoves

*** NOTE IMPORTANT UPDATE ON THE LAW AROUND DOMESTIC WOOD BURNING AT THE END OF THIS DOCUMENT**

- **Is wood a renewable fuel?**
- **Emissions from burning wood**

This report is concerned with domestic wood burning stoves, rather than the use of wood biomass for larger scale heating or electricity generation purposes. However, much of what is discussed below does apply to all scales of wood burning.

Is wood a renewable fuel?

Definitions

It is important to define what is meant by a "renewable" fuel. Solar radiation, wind and tides, for example, are clearly immediately "renewable" but wood, and biomass in general, requires a period of time for new wood to grow in place of harvested wood. The literature has varying definitions of "renewable" and "sustainable", and the two words appear to be becoming almost interchangeable.

For the purposes of this note wood is considered to be a "renewable" fuel if it is not depleted **over a period of five years** and can thus be considered to produce "renewable" energy. As it becomes increasingly important to reduce greenhouse gas emissions over a few years, rather than a few decades, then using a resource that will be replenished in, say, 25 years is not immediately helpful, and is therefore not considered to be renewable here.

The Encyclopaedia Britannica defines "renewable" energy as "*usable energy derived from replenishable sources such as the Sun (solar energy), wind (wind power), rivers (hydroelectric power), hot springs (geothermal energy), tides (tidal power), and biomass (biofuels)*".[1] .

In recent years the UK government has classified the burning of wood to produce energy as a renewable energy source, as are wind, hydro and solar. This has been controversial, particularly in the consideration of burning on an industrial scale, as at Drax power station. There is no doubt that eventually timber regrowth can replace the burnt timber and absorb an amount of carbon dioxide equivalent to that that was emitted during burning. The critical factor, though, is the timeframe over which this occurs; hence the above definition of the use of the word "renewable".

[1] www.britannica.com/science/renewable-energy

Carbon emissions

Harvesting any living timber to burn, even if renewable in the required short timeframe, is releasing carbon into the atmosphere in the same way as burning a fossil fuel. If the timber was left to grow then the carbon would remain out of the atmosphere for longer, and indeed the tree would absorb more carbon as it grows. Eventually, though, when the tree dies and decays the carbon will return to the atmosphere anyway. So it is impossible to get away from the fact that burning wood increases atmospheric carbon dioxide. However, if we organise our harvesting and planting such that the net amount of carbon held in the source of growing wood does not reduce within our five year timeframe, then we can say that it is a renewable energy source. Of course, if we planted at the same rate and did not harvest, then atmospheric carbon dioxide would be reduced further.

For almost any energy source there are additional sources of emissions to consider. For timber there is cutting, processing and transport. This can include kiln drying the timber, which is particularly energy intensive. For other nominally renewable sources there are construction emissions, sometimes very significant, as in barrages or dams. But generally, after construction, emissions are negligible.

Renewable sources

Given the above, what sources of wood can be defined as being renewable energy sources?

One source definitely appears to fit the bill. Because timber has uses other than burning, trees are harvested for construction, furniture, telegraph poles and numerous other uses. Most of these uses result in waste. If this waste cannot usefully remain in its timber form then it will either rot or be burnt, and either way its carbon is released to the atmosphere; so it is probably best, therefore, to burn it in a way that provides energy for our use. This means though that the carbon release occurs far more quickly than if it were left to rot.

Another possible source is the dead wood in a woodland. Left on the ground this would rot naturally and release its carbon to the atmosphere, and so, as with waste, it would seem logical to burn it for our use. However, dead wood is part of a woodland ecosystem, and some must be left as a resource for invertebrates and soil enrichment, amongst other benefits.

The above sources are wood that is already no longer growing.

Another source, though not large, is the result of conservation work. Organisations such as the Hampshire and Isle of Wight Wildlife Trust sometimes remove trees, as has been done over recent years in the extended Winnall Moors Reserve and St Faith's Meadow near St Cross Hospital. The logic for using this timber is the same as for the waste mentioned above, if there is not a practical use that prolongs it in its wood form.

In a similar vein, timber plantations are often thinned in order to allow the stronger trees to grow larger. As with conservation tree removal, these trees are really being cut for another reason, so they might as well be burnt helpfully.

However, it may be that a plantation is being managed purely as a source of fuel. The renewability of such a scheme needs consideration. Whether harvesting live timber produces a renewable fuel depends on how 'renewable' is defined. It may be decided that a woodland can be harvested in such a way that, say, from one year to the next the volume of growing timber (and therefore embedded carbon) remains constant. This volume can be calculated, and it would seem reasonable to define this as being a renewable fuel source, as defined at the start.

Somewhere in between the last two described scenarios is the management of native broadleaved woodland, of which there are approximately 8000 ha in Winchester District, according to the Forestry Commission. These could be managed in such a way that the same volume of wood is extracted as grows, as described in the preceding paragraph. It is important that this is done in a way that does not impact negatively on the ecology of the woodland. It can indeed have a very positive impact on biodiversity.

Sustainable forestry

Sustainable forest management is not quite the same as our definition of renewable. The Forestry Commission uses the following definition (after the Brundtland Commission's definition, 1987):-

"Practising sustainable forestry means managing our forests in a way that meets our needs at present but that does not compromise the ability of future generations to meet their needs. They will rightly expect that their forests and woodlands offer at least the same benefits and opportunities as we enjoy today."

This would appear to be similar to the above defined renewable system, but over a much longer timeframe than five years.

One sustainable forestry model describes an area of land planted with seedlings to replace an area of mature trees just felled. On their own, these two areas could not be described as a renewable resource, because of the time lag between felling and equivalent re-growth. However, if the woodland contains areas of different ages between seedlings and mature trees, such that the volume of timber in the growing trees replaces the felled timber volume within our timescale then this would be renewable for our purposes. If this is then worked on a regular cycle, as some commercial woodlands are, then we have a renewable system, as well as a sustainable forest.

An additional complication is consideration of the possibility of using much of the wood from these various sources for a purpose that locks in the carbon, such as chipboard or

sawn timber. The way that this may or may not impact on the renewability of a source has not been considered here.

According to the Forestry Commission 12% of the UK is forested, compared with 37% of the EU as a whole. If a significant amount of planting were to be carried out in the UK, then this would not only absorb carbon, but would allow there to be more "waste" that could be burnt.

Wood burner demand

According to Ofgem, the "medium" Typical Domestic Consumption Value for gas, for heating and/or cooking, was 12,500 kWh in 2015. This is very approximately equivalent to burning some 2.5 to 3 tonnes (3.5 – 6 cubic metres) of wood. According to the National Energy Foundation, this amount of wood could be produced by planting about a third of a hectare (about 58m by 58m) of poplar which, after the third year, would produce sufficient logs each year. Using these very approximate figures one can get an idea of the size of woodland that would be required to produce logs for a single household in a renewable way. Clearly the area required would depend on the use to which the log burning is put (heating one room, or the whole house, or cooking and/or hot water also), as well as the type of timber planted.

Conclusion

There seems to be no standard definition of wood as a renewable fuel. It would appear therefore to be extremely difficult for a consumer to know how renewable a source of bought wood really is, and for anyone to know what proportion of wood burnt in the home in the UK is from a truly renewable source.

Brian Shorter, May 2017

Emissions from burning wood

Introduction

Wood is part of the natural carbon cycle and consists of cellulose, hemicellulose and lignin; typical percentage figures (dry weight) for European beech are 45, 30 and 24 respectively.[2] Carbon absorbed during photosynthesis is released in equal measure when the wood is burnt (or rots) *in situ* so that there is no net gain of carbon dioxide to the atmosphere.[3] However if the wood supply involves deforestation, especially 'slash and burn', and land disturbance there can be a net gain in CO_2. In many cases carbon emissions from cutting down trees with a chain saw, extracting and transporting the timber, cutting and splitting it into logs, further transport and even artificially drying the wood, are almost unavoidable. It is always better to fell trees close to where they will be burnt, cut and split the logs by hand, and dry them naturally out of doors for 1-2 years. Re-cycled waste wood, other than offcuts from a sawmill, should be avoided as a fuel because it can contain toxic chemicals.

For the purpose of this discussion a wood stove is defined as a heating device with an enclosed firebox, usually of cast iron or steel, with a means of introducing the fuel (logs or pellets), some means of restricting the air flow and a flue that takes away the exhaust gases. Wood stoves may include a grate and a trap for ash. The best designs of stove allow for two air intakes, one below and one above the solid fuel; the latter assists the complete combustion of gases which reduces air pollution. Pellet stoves operate on this principle and can also control the fuel supply. Some stoves have catalysts or an electrostatic filter, which can even be retrofitted[4], built into the flue, which also reduce atmospheric pollution.

Emissions

In general, wood stoves are more polluting, per unit of heat generated, than larger commercial installations that burn pellets or woodchips for heat and power. Open fires, which share some of the typical emissions of stoves, are generally even more polluting because they may allow smoke to escape into the home, they are thermally more wasteful of fuel and they cause no fewer emissions than stoves. '*There is evidence that good wood-burning stoves produce less air pollution than open fires, because they burn wood more efficiently*'.[5] Open fires are not considered further here.

---

[2] Evtyugina, Margarita, Célia Alves, Ana Calvo, Teresa Nunes, Luís Tarelho, Márcio Duarte, Sónia O. Prozil, Dmitry V. Evtuguin, and Casimiro Pio. "VOC Emissions from Residential Combustion of Southern and Mid-European Woods." *Atmospheric Environment* 83 (February 2014): 90–98. doi:10.1016/j.atmosenv.2013.10.050.

[3] This is not true of a single mature tree replaced by a single sapling because the sapling takes years to replace the CO_2 but it is true if the wood is extracted from a forest of many trees that continue to absorb CO_2 after the mature tree has been felled and replaced, naturally or otherwise, by a sapling.

[4] http://www.poujoulat.co.uk/catalogues/domestic/Leaflet_top_clean_PF_2014.pdf

[5] http://www.dailymail.co.uk/news/article-3972966/Inconvenient-truth-wood-burning-stove-bad-environment-health.html

When wood is burned in a correctly fitted stove various gases are emitted which include nitrogen oxides (NOx), methane, volatile organic compounds (VOCs; which have varying chemical structures with four or more carbon atoms arranged in a ring), toxic dioxins, as well as organic and inorganic particulate matter (PM; both PM_{10} and $PM_{2.5}$[6]) and the greenhouse gas carbon dioxide. Soot, another product, is formed by the incomplete combustion of hydrocarbons. It contains black carbon (BC), which is defined by being highly light-absorbing i.e. black, and is one component of $PM_{2.5}$ particulate matter. At ground level, the gas ozone is an air pollutant harmful to human health and ecosystems and is also a significant greenhouse gas. Ozone is not emitted directly from stoves, but may be generated subsequently from reactions between other emitted gases, such as methane and carbon monoxide (from badly installed or poorly operated stoves).[7]

A study in San Francisco found that oak burnt in a wood stove emitted 9.58 (±21.8%) g of PM per kg of fuel equivalent to 53.5 (±28.3%) mg of PM per cubic metre of flue gas.[8] Another study found that emissions depended on the species of wood (oak, beech or poplar), the type of stove and the operating conditions.[9] These authors stated "*The main disadvantage of biomass burning devices, especially small-scale appliances (woodstoves and fireplaces), is their high level of emissions from incomplete fuel combustion.*" The age and design of the stove is another factor. A Danish study found that $PM_{2.5}$ emissions per unit of thermal energy varied by a factor of six between a pre-1990 stove (3345 mg/kWh) and a new eco-label post-2015 stove (558 mg/kWh).[10] Others have emphasised the additional contribution of combustion conditions, the burn rate, combustion temperature and moisture content of the wood.[11,12] Less pure sources, that contain bark and foliage, can cause more PM emissions than wood alone. It is clear therefore that emissions from wood burning stoves can be highly variable and it is seemingly impossible to agree on typical figures.

In the UK, Defra have noted that pollution from domestic wood burning is increasing; it caused 17% of $PM_{2.5}$ emissions in 2013, similar to that from road transport. Since 1990 there has been a steady reduction in emissions of many polluting gases (NOx, non-methane VOCs, $PM_{2.5}$, PM_{10}, sulphur dioxide) although PMs have levelled out since 2010 (Fig. 1 in ref.[13]).

---

[6] PM10 and PM2.5 are defined as all particulates less than 10 and 2.5 microns in aerodynamic diameter (size), respectively.
[7] Anon (UNEP). "Integrated Assessment of Black Carbon and Tropospheric Ozone Summary for Decision Makers." UNEP, WMO, 2011.
[8] Gullett, Brian K., Abderrahmane Touati, and Michael D. Hays. "PCDD/F, PCB, HxCBz, PAH, and PM Emission Factors for Fireplace and Woodstove Combustion in the San Francisco Bay Region." *Environmental Science & Technology* 37, no. 9 (May 2003): 1758–65. doi:10.1021/es026373c.
[9] Evtyugina, Margarita, Célia Alves, Ana Calvo, Teresa Nunes, Luís Tarelho, Márcio Duarte, Sónia O. Prozil, Dmitry V. Evtuguin, and Casimiro Pio. "VOC Emissions from Residential Combustion of Southern and Mid-European Woods." *Atmospheric Environment* 83 (February 2014): 90–98. doi:10.1016/j.atmosenv.2013.10.050.
[10] Press-Kristensen, Kåre. "POLLUTION FROM RESIDENTIAL BURNING: Danish Experience in an International Perspective." Copenhagen: The Danish Ecological Council, 2016.
[11] http://www.biomasscenter.org/images/stories/FSE_PM_Emissions.pdf
[12] For best results firewood should have a moisture content of less than 20% (https://en.wikipedia.org/wiki/Wood-burning_stove).
[13] Defra National Statistics Release: Emissions of air pollutants in the UK, 1970 to 2015. 21 December 2016

However Defra note that the contribution from the category covering combustion in the residential, public, commercial and agricultural sectors has increased over recent years and peaked in 2013 at 51 kilotonnes PM_{10} and 50 kilotonnes $PM_{2.5}$. Because $PM_{2.5}$ is a sub-set of PM_{10} these figures suggest that almost all pollution (around 98%) comes from particles less than 2.5 microns in diameter. Another source estimates that 65% of wood smoke is fine particles.[14] In 2014 fuel demand in the UK domestic sector was down but consumption increased again in 2015 and estimated emissions of $PM_{2.5}$ from residential, public and commercial combustion were only slightly less than in 2013. 79% of the emissions from residential, public and commercial combustion in 2013-2015 were from the use of wood as a domestic fuel, presumably both in wood stoves and open fires.

Wood burning is said not to emit harmful-to-health nitrogen dioxide directly.[15] Only nitric oxide is normally emitted[16] however subsequently NO may react chemically with ozone to produce secondary NO_2 and oxygen.[17]

The effects of wood burning stoves on human health and climate are now discussed separately. Note that although the adverse impacts of several emissions products are well known there seems to be little information on the quantity of emissions produced and how these impacts depend on the actual quantity of emitted material.

Health impacts

The health impact of air pollution from stoves is well known. It occurs indoors and out of doors and affects everyone. Children are particularly affected because of their small bodies and growing organs.[18]

Here just the impacts on human health of wood burning stoves are considered. The impacts of cooking stoves, widely used in developing countries, are not included.

The health impact of a domestic wood burning stove, relative to other forms of heating, depends on how it is used. If the stove is used to provide heat in place of a central heating boiler then we must compare the stove's emissions to the boiler's emissions (see later). If the stove is simply used to provide a cosy atmosphere or to provide heat, **in addition** to central heating, then we must consider the impact of the **additional** emissions from the stove.

[14] Press-Kristensen, Kåre. "POLLUTION FROM RESIDENTIAL BURNING: Danish Experience in an International Perspective." Copenhagen: The Danish Ecological Council, 2016.

[15] https://tallbloke.wordpress.com/2017/01/29/wood-burners-or-diesel-vehicles-whats-behind-londons-air-pollution/

[16] Petrocelli, D, and A M Lezzi. "CO and NO Emissions from Pellet Stoves: An Experimental Study." *Journal of Physics: Conference Series* 501 (April 10, 2014): 012036. doi:10.1088/1742-6596/501/1/012036.

[17] https://uk-air.defra.gov.uk/assets/documents/reports/aqeg/nd-summary.pdf

[18] Anon (WHO). "Don't Pollute My Future! THE IMPACT OF THE ENVIRONMENT ON CHILDREN'S HEALTH." Geneva: World Health Organisation, March 2017.

The products of wood burning which are potentially unhealthy include nitrogen dioxide (NO_2), VOCs (benzene), dioxins, polycyclic aromatic hydrocarbons (PAHs), PM_{10} and $PM_{2.5}$. Highly dangerous carbon monoxide may be emitted if the stove is not installed or operated correctly, allowing incomplete combustion, but this is not considered further here.

Evidence of the damage done by $PM_{2.5}$, including black carbon and soot, when inhaled into the lungs is clear. For example, in the USA exposure to $PM_{2.5}$ was positively associated with increased costs of childhood asthma hospitalizations. A World Health Organisation (WHO) report, published in 2013 and quoted next, states that *"PM_{10} and $PM_{2.5}$ include inhalable particles that are small enough to penetrate the thoracic region of the respiratory system. The health effects of inhalable PM are well documented. They are due to exposure over both the short term (hours, days) and long term (months, years) and include:*
• respiratory and cardiovascular morbidity, such as aggravation of asthma, respiratory symptoms and an increase in hospital admissions;
• mortality from cardiovascular and respiratory diseases and from lung cancer.

… for mortality, and especially as a consequence of long-term exposure, $PM_{2.5}$ is a stronger risk factor than the coarse part of PM_{10} (particles in the 2.5–10 µm range)." It has been estimated that *"… Long-term exposure to $PM_{2.5}$ is associated with an increase in the long-term risk of cardiopulmonary mortality by 6–13% for every extra 10 µg/m3 of $PM_{2.5}$.*

***There is no evidence of a safe level of exposure to PM or a threshold below which no adverse health effects occur**. The exposure is ubiquitous and involuntary, increasing the significance of this determinant of health*."[19] The WHO report also says that the evidence for the hazardous nature of combustion-related PM (from both mobile and stationary sources) is more consistent than that for PM from other sources such as dust and soil. Many components of PM attached to black carbon are currently seen as responsible for causing ill-health, for instance organic compounds such as PAHs (polycyclic aromatic hydrocarbons) that are known carcinogens and directly toxic to the cells, as well as metals and inorganic salts.

NO_2 acts mainly as an irritant affecting the mucosa of the eyes, nose, throat and respiratory tract. Low level NO_2 exposure may cause increased bronchial reactivity in some asthmatics, decreased lung function in patients with chronic obstructive pulmonary disease and increased risk of respiratory infections, especially in young children.[20] Lung oedema, or accumulation of fluid in the lungs has been observed in humans after short-term exposure to concentrations of as little as 20 mg/m^3 or more. It has also been found that NO_2 effects tend to occur many hours after exposures have ceased, so that persons exposed to NO_2 are often unaware of the severity of their exposure for some time after. The current WHO

[19] Anon (WHO). "Health Effects of Particulate Matter: Policy Implications for Countries in Eastern Europe, Caucasus and Central Asia." Copenhagen: World Health Organisation, March 2013.
[20] https://www.epa.gov/indoor-air-quality-iaq/nitrogen-dioxides-impact-indoor-air-quality

guideline values for NO_2 are a one-hour level of 200 µg/m3 and an annual average of 40 µg/m3. Some European studies have shown that mortality rates increased by 2.0-7.6% for a 100 µg/m3 increase in atmospheric NO_2 levels .[21]

VOCs include are a wide range of compounds that usually have no colour, taste or smell. Some cause direct health effects, while others contribute to smog.[22]

PAHs are a health concern because they can cause cancer.[22]

On the basis of the above evidence it is clear that wood burning stoves pose a serious health risk from their emissions of $PM_{2.5}$ and secondary NO_2 and their use, particularly in more densely populated areas, should be minimised. For example, they might be used as a back-up or emergency source of heat when the main heating system, for whatever reason, is not available.

Climate impacts

Wood stoves emit a variety of products into the atmosphere which can demonstrably affect climate. These include the greenhouse gas carbon dioxide and black carbon, a form of soot. The climate impact of a domestic wood burning stove, relative to other forms of heating, depends on how it is used. If the stove is used to provide heat in place of a central heating boiler that burns a fossil fuel then it is genuinely saving CO_2 emissions but if it is simply used to provide a cosy atmosphere or heat, **in addition** to central heating, then there is no net climate benefit.

Regarding CO_2, one source suggests that a wood stove burning logs emits less than 6 g CO_2 per kWh whereas a boiler burning natural gas emits 216 g CO_2 per kWh (for comparison, UK government figures for 2016 are 13 and 184 g CO_2 per kWh, respectively).[23, 24] In other words a wood stove is said to have at least 14 times less effect on radiative forcing (RF) from its emissions of CO_2 than a gas boiler. This surprising statement conflicts with information from Forestry Research who point out that CO_2 emissions per kWh of heat from burning wood fuels are relatively high because of the relatively low calorific value of wood compared to fossil fuels.[25] Similarly Defra suggests that the 'out-of-scope' emissions, neither scopes 1, 2 or 3,[26] from burning logs should be calculated using a factor of 352 g

[21] Based on research cited in Morrin, Stephen, Smith, William J., and Timoney, David J. "Improved Emissions Inventories for NOx and Particulate Matter from Transport and Small-Scale Combustion Installations in Ireland (ETASCI), Part 2 of 2." Johnstown Castle, Ireland: EPA Research, 2015.

[22] https://www.canada.ca/en/health-canada/services/air-quality/indoor-air-contaminants/avoid-wood-smoke.html

[23] http://www.stovesonline.co.uk/fuel-CO2-emissions.html

[24] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2016

[25] https://www.forestry.gov.uk/fr/beeh-9urng3

[26] Scope 1 covers direct emissions that come from company-owned or -controlled sources, and scope 2 covers indirect emissions that come from the generation of purchased electricity, steam, heating and cooling consumed by the reporting company. Scope 3 includes all other indirect emissions that occur in a company's value chain.

CO_2/kWh.[27] The explanation appears to be that the low figures for wood assume that it comes from a renewable low-carbon source. This means that the carbon dioxide released when such wood is burnt is simply being returned to the atmosphere as part of the contemporary natural carbon cycle and will 'soon' be re-absorbed by fresh biomass growth so that there is no net increase of CO_2 in the atmosphere. The wood fuel is described as being carbon neutral.[28] The quoted figures of 6 and 13 g CO_2/kWh refer to the **additional** carbon emissions noted earlier for wood processing, transport etc.

Black carbon (BC) is a climate forcing agent.[29] BC warms the Earth by absorbing sunlight and heating the atmosphere and by reducing albedo (reflectivity) when deposited on snow and ice (direct effects) and indirectly by interaction with clouds, with an RF from all sources of 1.1 W/m^2.[30] The latest IPCC Working Group 1 report in 2013 suggests that black carbon has a smaller average RF of 0.64 W/m^2 with an upper uncertainty limit of 1.1 W/m^2.[31] IPCC Working Group 1 shows that since 1750 the contributions from all forms of black carbon have had a combined RF only exceeded by carbon dioxide and methane (and its derivative gases, principally ozone). However, the IPCC Working Group 1 estimate that the RF of black carbon alone on snow is only 0.04 W/m2 (range 0.02 to 0.09) and Bond et al. (2016) give an average of 0.13 W/m2 (range 0.04 to 0.33; Table 1) for black carbon on just snow and sea-ice. These are smaller averages than almost any other RF components that these authors tabulate.

BC is not well mixed in the atmosphere because of its short lifetime. It stays in the atmosphere for only a few days to weeks, before it is removed by the precipitation of rain or snow.[32] In comparison, carbon dioxide (CO_2) has an atmospheric lifetime of more than 100 year.[33]

However, Bond et al. (2103) estimate that the global warming potentials[34] of BC, when all associated forcing mechanisms (including cloud effects) are included, are 920 and 3,200 times worse than CO_2 over 100 and 20 years, respectively. These figures have large uncertainties and can vary by ±30% depending on where the BC is emitted. Nevertheless, this explains why BC is considered to have such a potentially important impact on climate change.

---

[27] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2016
[28] Press-Kristensen, Kåre. "POLLUTION FROM RESIDENTIAL BURNING: Danish Experience in an International Perspective." Copenhagen: The Danish Ecological Council, 2016.
[29] https://en.wikipedia.org/wiki/Black_carbon
[30] Bond, T.C., and 30_co-authors. "Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment." *Journal of Geophysical Research: Atmospheres*, no. online jgrd.50171 (2013).
[31] IPCC_AR5_WG1. "Climate Change 2013: The Physical Science Basis." Technical Summary Fig.TS.7. IPCC, 2013.
[32] Bond, T.C., and and_30_co-authors. "Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment." *Journal of Geophysical Research: Atmospheres*, no. online jgrd.50171 (2013).
[33] V. Ramanathan and G. Carmichael, *Global and regional climate changes due to black carbon*, 1 Nature Geoscience 221-22 (23 March 2008)
[34] Global warming potential means the integrated warming effect of radiative forcing, relative to carbon dioxide, over the given time interval and factors in how long the gas or other product resides in the atmosphere.

Modelling suggests that in the UK the contribution of heating stoves and fireplaces to RF will increase by 23% between 2010 and 2030 with BC being responsible for more than three-quarters of this.[35] The study predicts that, on current trends, by 2030 burning biomass will have a larger warming impact than fossil fuel combustion.

Even so, it is interesting to consider whether black carbon emitted in Winchester can have any impact on Arctic snow or ice. It has been said by the co-author of one study that "*High-latitude sources are especially important. Even though China* [which lies almost entirely at a lower latitude than Winchester], *for example, releases much more black carbon than Arctic regions, reductions there have less impact per kilogram than reductions in the Arctic*."[36] The closest land to Winchester on the Arctic Circle is around 1900 km away implying the need for an average wind speed, consistently in the right direction, of 11.3 km/h for a week if snow or ice on the Arctic Circle is to be affected. Most Arctic ice or snow, on land or sea, is much further away from Winchester and so it seems unlikely that black carbon released in Winchester is going to affect Arctic snow or ice although it could conceivably affect closer mountain glaciers in Scandinavia or the Alps. It seems reasonable to conclude that BC emitted in Winchester will have only a minimal effect on Arctic snow and ice.

Wood burning stoves and central heating boilers

Table comparing emissions from wood stoves and gas and oil boilers

g/kWh (gross Calorific Value)	CO_2 (net)	PM	$PM_{2.5}$ ratio^^	NO_2^	N_2O	CH4
Wood from a low-carbon source (logs)	13 <6^^^	++0.56	1000	very small	unknown	unknown
Wood from a non-renewable source	352	++0.56	1000	very small	unknown	unknown
Gas CH boiler	184 216	<0.017 +0.011 ++0.072	0.323	NOx <0.084”	0.0001	0.00025
Oil CH boiler	245	???	35.7	NOx <0.120””	0.00061	0.00061

Values from DBEIS for Scope 1 emissions in 2016 unless otherwise indicated
^ actually NO + NO_2 (Defra)
^^ ratios of emissions from wood and boilers relative to logs (set to 1000). Press-Kristensen, 2016, ref. 27
^^^ ref. 22
+ National Atmospheric Emissions Inventory, ref. 36
++ Austrian database, ref. 37
“ for Worcester Bosch gas boilers

[35] Mitchell, E.J.S., G. Coulson, E.W. Butt, P.M. Forster, J.M. Jones, and A. Williams. “Heating with Biomass in the United Kingdom: Lessons from New Zealand.” *Atmospheric Environment* 152 (March 2017): 431–54. doi:10.1016/j.atmosenv.2016.12.042.
[36] https://www.sciencedaily.com/releases/2017/02/170203101531.htm

Having considered the absolute emissions from wood stoves it is interesting to consider in more detail the relative emissions from stoves and gas or oil central heating boilers. This is because in many instances a stove will be used to provide heat in place of a boiler. A stove may also consume less fuel than a boiler simply because it is used to heat a smaller space, even a single room, and not a whole home or a large part of a home. It is useful to know whether or not stoves are an improvement from the health and climate change perspectives. The table summarises information presented earlier, and later in this section.

Defra notes that emissions factors for PM_{10} from domestic boilers are less than 500 mg/therm (17 mg/kWh) whereas the National Atmospheric Emissions Inventory assumes 326 mg/therm (11 mg/kWh).[37] An Austrian source quotes 0.0002 kt/PJ (72 mg/kWh) for PM_{10} from domestic boilers in 2001.[38] Even the Austrian estimate for a gas boiler is almost eight times less than the figure of 558 mg/kWh for the best Danish wood stove quoted earlier. Press-Kristensen (2016; Fig. 2) quotes astonishing but unattributed figures that suggest that a 'new eco-label stove' emits 3,100 times more $PM_{2.5}$ than a gas boiler and is 28 times worse than an oil-burning boiler. Older wood stoves are even worse.

There are also concerns that ultrafine particles, those less than 0.1 microns in diameter ($PM_{0.1}$), may be more hazardous to health than larger particles, especially since the number of smaller particles in the air increases exponentially as particle size decreases. However most ultrafine particles come from road vehicles and the evidence regarding emissions from biofuels and boilers is limited.[39,40,41]

Bond et al. (2013) conclude that conventional wood stoves offer little or no potential for reducing global climate forcing by targeting their BC emissions alone.[42]

The conclusion must be that, with current evidence, the PM emissions from a wood burning stove are considerably greater than from a gas boiler even if the precise figures are in doubt.

[37] https://uk-air.defra.gov.uk/assets/documents/reports/cat08/0407081208_Task7_cumbustion_report_issue1.pdf
[38] BUWAL (Bundesamt für Umwelt, Wald und Landschaft) (2001) *Massnahmen zur Reduktion von PM10-Emissionnen.* Schlussbericht. BUWAL Abteilung Luftreinhaltung und NIS, January, 2001 quoted in http://www.iiasa.ac.at/~rains/PM/docs/documentation.html#BUWAL_2001
[39] Oberdörster, Günter, Eva Oberdörster, and Jan Oberdörster. "Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles." *Environmental Health Perspectives* 113, no. 7 (March 22, 2005): 823–39. doi:10.1289/ehp.7339.
[40] http://burningissues.org/car-www/medical_effects/pre-conference_2_froines.pdf
[41] http://www.aidic.it/aaas10/webpapers/47Minutolo.pdf
[42] Bond, T.C., and 30_co-authors. "Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment." *Journal of Geophysical Research: Atmospheres*, no. online jgrd.50171 (2013).

Regarding CO_2, emissions, figures that were presented earlier are shown in the table. It is clear that a wood stove which burns logs from a sustainable supply has at least 14 times less effect on RF from its emissions of CO_2 than a gas boiler.

One source of the greenhouse gas N_2O is incomplete combustion of biomass. Gas and oil burning boilers emit very small quantities of N_2O and methane. Defra states that the emissions of N_2O and methane from a wood stove burning wood pellets are presently unknown.

Similarly NO_2, which is a health hazard, appears to be emitted in small quantities from wood stoves. A study that compared emissions of NOx from different types of boiler found that, under steady state conditions, wood pellet boilers emitted 43-57 g/GJ (0.16-0.21 g/kWh), oil boilers emitted 43 g/GJ (0.16 g/kWh) and gas boilers emitted 26 g/GJ (0.094 g/kWh).

Conclusions

1. **Wood stoves used for heating in Winchester, which burn wood from a renewable source, are likely to have minimal detrimental impact on climate change. This contrasts with the Danish study, for example, where energy and heating arrangements are different, partly because district heating is widespread, which concluded "…. *there are no climatic gains from wood burning in private heating units and wood burning should be replaced by insulation and district heating in cities and heat pumps in rural areas*."[43] However, it is not easy to determine whether wood is actually from a renewable source.**
2. **On the other hand, particulate matter from wood burning stoves, especially that less than 2.5 microns in diameter, appears to present a serious risk to human health at all pollution levels. Nitrogen dioxide is similarly implicated in causing health problems.**
3. **Wood burning stoves emit probably small, but unknown, amounts of the greenhouse gas nitrous oxide but if they use a renewable and low-carbon supply of wood and are operated correctly their carbon dioxide emissions per kWh are less than from gas boilers. Therefore wood stoves can be less damaging than gas boilers from the climate change perspective.**
4. **Wood burning stoves emit both more nitrogen dioxide and more particulate matter than gas boilers and therefore are not a good substitute for the latter from the health perspective.**

From a climate change perspective wood burning stoves are usually better than central heating boilers burning a fossil fuel (natural gas or oil), but this depends on how renewable the source of wood is. On the other hand, wood burning stoves contribute to emissions of particulate matter and nitrogen dioxide, which are harmful to human health, and therefore should not be used in more densely populated areas.

Bob Whitmarsh, May 2017

Update on domestic burning of wood and coal in England

New legal restrictions[44] on the sale of coal, wet wood (moisture content more than 20%) and manufactured solid fuels for burning in the home came into force on 1 May 2021.

Burning at home, particularly with traditional house coal or wet wood, is a major source of the pollutant PM2.5 – tiny particles which can enter the bloodstream and lodge in lungs and other organs. PM2.5 has been identified by the World Health Organisation as the most serious air pollutant for human health.

People with log burners and open fires can still use them, **but will be required to burn cleaner alternative fuels** – if they are not already doing so – such as dry wood and manufactured solid fuels which produce less smoke. Both of these cleaner options are just as easy to source and more efficient to burn, making them more cost effective. Burning dry wood also produces more heat and less soot than wet wood and can reduce emissions by up to 50%.

The restrictions that started on 1st May 2021 mean that:

- Sales of **wet wood** in volumes under 2 m^3 are now unlawful.
- **Wet wood** in larger volumes than 2 m^3 must be sold with advice on how to dry it before burning.
- Sales of bagged traditional **house coal** are now unlawful although loose coal can be sold until 30th April 2023.
- All **manufactured solid fuels** must now have a low sulphur content and only emit a small amount of smoke.
- In addition, a **new certification scheme** will see domestic fuel products certified and labelled 'Ready to Burn' by suppliers to ensure that they can be easily identified, and retail outlets will only be able to sell fuel that is accompanied by the correct label.

The government's Clean Air Strategy committed to legislation prohibiting the sale of the most polluting fuels, with the 1st May 2021 announcement putting that ambition into action.

Brian Shorter, Bob Whitmarsh
11 June 2021

[44] The Air Quality (Domestic Solid Fuels Standards) (England) Regulations 2020. Regulations are made under section 87 of the Environment Act 1995 (c. 25).