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Where there's fire, there's smoke

Emissions from domestic heating with wood

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Contents

Background

Domestic heating with wood (and coal) in small private stoves and boilers emits about half of all fine particulate matter ($PM_{2.5}$) and black carbon (BC) within the European Union. Furthermore, domestic heating contributes significantly to emissions of PAH's, VOC's and dioxins, meaning that it is a serious source of health damaging air pollution and global warming. Due to stricter regulations of other emission sources, domestic heating will actually increase in its future relative share of emissions.

Air pollution from domestic heating can be reduced with better insulation, using cleaner heat sources and/or replacing old wood stoves/boilers with new appliances. However, even new wood stoves/boilers pollute disproportionally more compared to most other heat sources. Air pollution control equipment (particulate filters and catalytic converters) is still not used for wood stoves/boilers.

The purpose of this pre-study is to raise awareness about pollution from domestic heating with wood compared to pollution from other heat sources.

Emissions from heat sources

Emissions from heat sources will vary depending on the age and size of the plant/stove/boiler, fuel use, technology, geographical location etc. Hence, there can be significant differences between emissions even within the same heat source category e.g. emissions from two district heating plants.

Furthermore, firewood quality (e.g. moisture content) and user management (e.g. air supply) is crucial for wood stoves and boilers since bad fuel quality or mismanagement can increase emissions more than a factor 10. **Below is assumed best case: Best fuel quality and optimal user management.**

Table 1 shows general emission factors from heat sources per GJ house heating i.e. including typical efficiencies and losses (e.g. including heat loss in the district heating system). Emissions do not include emissions from fuel or plant/stove/boiler production/construction and transport.

Table 1: Emissions of air pollutants from heat sources (g pollutant per GJ house heating)

	Energy [1]	$PM_{2.5}$	BC	NOx	SO_2	CH_4	CO	PAHs [2]	NMVOC
Wood stove/boiler	Wood	375	22	90	14	140	3,440	0.08	465
Oil boiler	Fuel oil	6	0.25	65	8	0.9	4.5	0.0001	25
Gas boiler	Natural gas	< 0.1	< 0.1	22	0.5	1	22	< 0.0001	4
District heating (Plant < 50 MW)	Coal	6.5	0.15	125	584	1.2	13	< 0.0001	1.3
	Fuel oil	6.6	0.26	173	9	1.2	21	< 0.0001	1
	Natural gas	0.1	< 0.1	43	0.6	1.3	37	< 0.0001	2.6
	Wood	13	0.44	120	15	14.5	320	< 0.0001	9.7
Electric heating (Plant > 50 MW)	Coal	2.3	< 0.1	28	11	1	11	< 0.0001	1
	Fuel oil	5.5	0.2	126	7.4	1	16.5	< 0.0001	0.9
	Natural gas	< 0.1	< 0.1	31	0.5	1.1	16.5	< 0.0001	2.2
	Wood	5.3	0.18	90	2	3.4	100	< 0.0001	5.6
Electric heating + direct solar heat	Wind, sun, and hydro	0							
Heat pumps [3]	One third of the emissions from electric heating depending on primary energy (see above)								

1) Primary energy: For electric heating the fuel used for producing the electricity.

2) Measured as Benzo[a]pyrene.

3) Small new heat pumps covering both air to air, air to water and soil to water all having average efficiencies around 3.

The emission factors in Table 1 show that wood stoves and boilers, in general, have much higher emissions of many toxic pollutants compared to other heat sources. Furthermore, domestic heating with wood emits relatively high concentrations of dioxins (data not shown) and is therefore the most health damaging heat source.

Emissions of fine particulate matter like black carbon and NOx play an important role in health damage. New wood stoves and boilers emit lower concentrations of particulate matter (Figure 1) but higher concentrations of NOx (due to better air supply and higher combustion temperature). New wood stoves emit much higher concentrations of black carbon as well (due to higher temperatures).

Figure 1: Particle emissions ($PM_{2.5}$) from heat sources (g pollutant per GJ house heating). (Eco wood stoves are wood stoves with the Nordic Swan ecolabel)

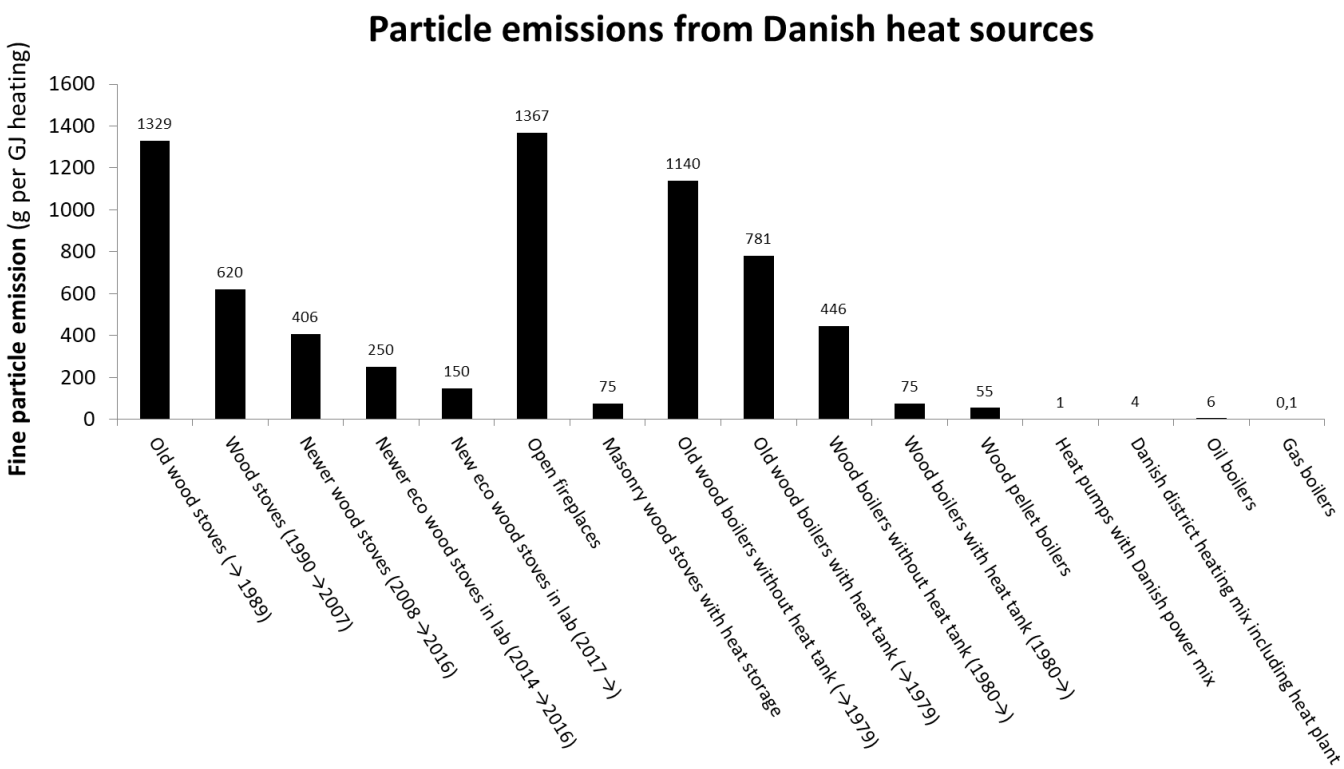


Figure 1 shows that new wood stoves/boilers—under optimal laboratory conditions—emit less particulate matter ($PM_{2.5}$) than older appliances. However, the figure also shows that emissions from other heat sources (heat pumps, district heating, oil boilers and gas boilers) are much lower than even the newest and most efficient wood stoves/boilers operating under optimal conditions (dry firewood, perfect chimney draught as well as optimal user management). Replacing old

wood stoves and boilers with new appliances will reduce the particle pollution significantly but increase NOx emissions and increase black carbon emissions for stoves. From a health perspective, the best solution is to phase out the use of small wood burning stoves and boilers for domestic heating. This can reduce air pollution by more than 90 percent (Figure 2).

Figure 2: Particle emissions (PM2.5) from heat sources (g pollutant per GJ house heating) . (Eco wood stoves are wood stoves with the Nordic Swan ecolabel)

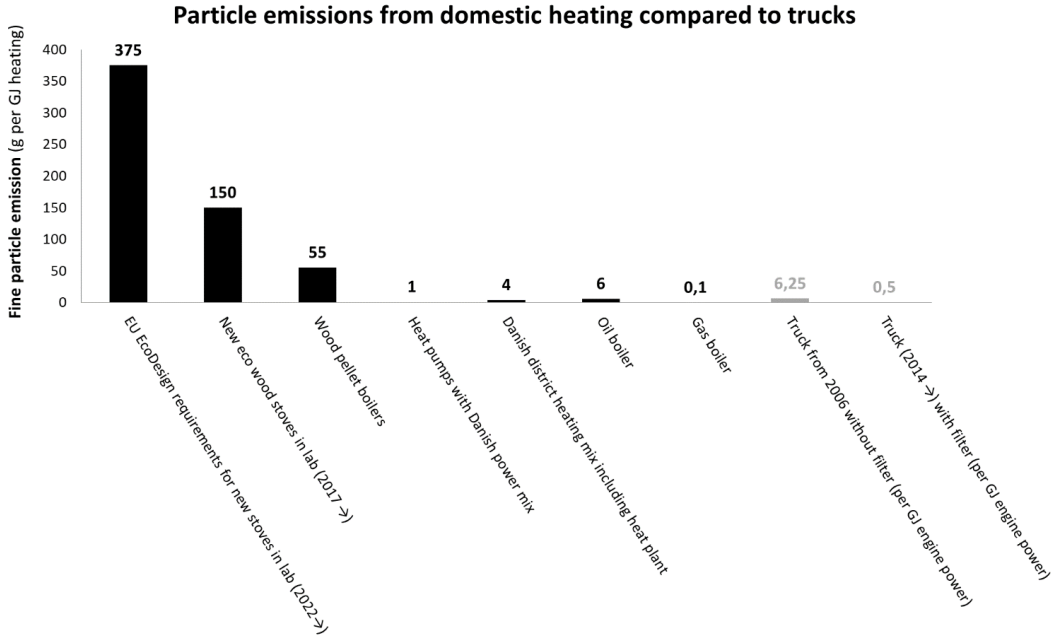


Figure 2 shows that both the EU EcoDesign requirements and the more ambitious Nordic eco-label fail —under optimal laboratory conditions— to reduce new stoves' particle emissions to acceptable low levels. Furthermore, it is clear that particle pollution from wood stoves and boilers is heavily under regulated in comparison to the regulation of trucks. A new EcoDesign stove in 2022 is allowed to emit 60 times as much particulate matter as an old truck from 2006 and 750 times as much as a newer truck from 2014 per GJ. A new EcoDesign stove in 2022 is allowed to emit 5 g fine particles per kg wood. Burning just one kg of wood will pollute 500,000 m^3 of completely clean air to up the level of the current WHO air quality guideline for fine particulate matter (10 µg/m^3).

Climate

Table 2 shows general emissions of climate pollutants from heat sources per GJ house heating i.e. including typical efficiencies and losses (e.g. including heat loss in the district heating system). Emissions do not include emissions from the fuel or plant/stove/boiler production/construction and transport. Furthermore, emissions do not include loss of potent greenhouse gasses from heat pumps. The table summarises the net global warming potential (GWP) as kg CO_2-equivalents (kg CO_2-e) both as global warming potential over 20 years and 100 years using the IPCC factors for GWP of each climate pollutant in the two-time perspectives.

Table 2: Emissions of climate pollutants from heat sources (per GJ house heating)

	Energy [1]	CO_2	BC	N_2O	CH_4	GWP100 ($kg CO_2$-e)		GWP20 ($kg CO_2$-e)	
		kg	g pollutant			Incl. CO_2 from wood	Excl. CO_2 from wood	Incl. CO_2 from wood	Excl. CO_2 from wood
Wood stove/boiler	Wood	140	22	5	140	165	25	223	83
Oil boiler	Fuel oil	87	0.3	1	0.9	87	87	88	88
Gas boiler	Natural gas	63	< 0.1	1.1	1	63	63	63	63
District heating (Plant < 50 MW)	Coal	125	0.2	1.1	1.2	125	125	126	126
	Fuel oil	98	0.3	0.5	1.2	99	99	99	99
	Natural gas	75	< 0.1	1.3	1.3	76	76	76	76
	Wood	149	0.4	5.3	14.5	151	2,2	153	4
Electric heating (Plant > 50 MW)	Coal	104	< 0.1	1.6	1.0	104	104	104	104
	Fuel oil	82	0.2	0.4	1.0	82	82	83	83
	Natural gas	63	< 0.1	1.1	1.1	63	63	63	63
	Wood	124	0.2	0.9	3.4	124	0.5	125	1,1
Electric heating + direct solar heat	Wind, sun, and hydro	0							
Heat pumps [2] [3]	One third of the emissions from electric heating depending on primary energy (see above)								

1) Primary energy: For electric heating the fuel used for producing the electricity.

2) Small new heat pumps covering both air to air, air to water and soil to water all having average efficiencies around 3.
3) Do not include loss of potent greenhouse gasses which can increase global warming significantly for some heat pumps.

Health costs

The main (90-95 percent) health effects (mortality and morbidity) due to air pollution are related to air pollution with fine particulate matter and NO_2, the rest is mainly caused by ozone. The following section focuses only on costs related to fine particulate matter and NO_2.

Air pollution with fine particulate matter originates from directly emitted fine particles and from so-called secondary fine particles that are formed in physical-chemical processes in the atmosphere from pre-cursor pollutants, such as NOx, SO_2 and NH_3. Such secondary particle formation takes time. Thereby air pollution causes health effects hundreds and even thousands of km from the source - often in other countries. Air pollution with NO_2 is caused by NOx-emissions.

Health effects (and thereby costs) will differ depending on where the emission takes place on a local scale (inside or outside cities, low or high chimneys) and on a regional scale (e.g. in the central or the northern parts of Europe). Health effects increase when more people are exposed to elevated levels of air pollution. Health costs depend as well on the population exposed to pollution (costs for morbidity and mortality grows with increasing GNP).

Table 3 shows average Danish health costs related to pollution from domestic heating, it focuses on emissions of four key pollutants: $PM_{2.5}$, NOx, SO_2 and NH_3. The costs reflect toxic effects of pure gas (e.g. NO_2) and toxic effects of the share of gasses transformed into secondary fine particulate matter. Costs do not include emissions from fuel or plant/stove/boiler production/construction and transport.

Table 3: Average Danish health costs due to emissions from domestic heat sources

	Energy [1)]	$PM_{2.5}$	NOx	SO_2	NH_3	Costs (euro per GJ house heating)	
		g pollutant per GJ house heating				Inside Denmark	Outside Denmark
Wood stove/boiler	Wood	375	90	14	61	**15.6**	**18.9**
Oil boiler	Fuel oil	6	65	8	< 0.1	**0.7**	**2.4**
Gas boiler	Natural gas	< 0.1	22	0.5	< 0.1	**0.1**	**0.7**
District heating	Coal	6.5	125	584	< 0.1	**1.3**	**3.5**

(Plant < 50 MW)	Fuel oil	6.6	173	9	< 0.1	**0.3**	**3.5**
	Natural gas	0.1	43	0.6	< 0.1	**0.1**	**0.8**
	Wood	13	120	15	< 0.1	**0.3**	**2.9**
Electric heating (Plant > 50 MW)	Coal	2.3	28	11	< 0.1	**0.1**	**0.8**
	Fuel oil	5.5	126	7.4	< 0.1	**0.3**	**2.6**
	Natural gas	0.1	31	0.5	< 0.1	**0.1**	**0.6**
	Wood	5.3	90	2	< 0.1	**0.2**	**1.8**
Electric heating + direct solar heat	Wind, sun, and hydro	**0**					
Heat pumps [2)]	One third of the emissions from electric heating depending on primary energy (see above)						

1) Primary energy: For electric heating the fuel used for producing the electricity.

2) Small new heat pumps covering both air to air, air to water and soil to water all having average efficiencies around 3.

Table 3 shows that domestic wood burning in small stoves and boilers is the most expensive heat source—both in a national and international contexts—due to the high health effects of the connected air pollution (especially the emission of fine particulate matter). Society will achieve high health benefits by replacing domestic wood burning with better insulation and cleaner heat sources.

Ultrafine particles

Domestic wood burning contributes significantly to pollution with ultrafine particulate matter ($PM_{0.1}$) in domestic areas. This has not been discussed above. The pictures below show measurements of ultrafine particles from a newer wood stove with the Nordic Swan ecolabel under optimal conditions and similar measurements from an idle running truck with a particulate filter.

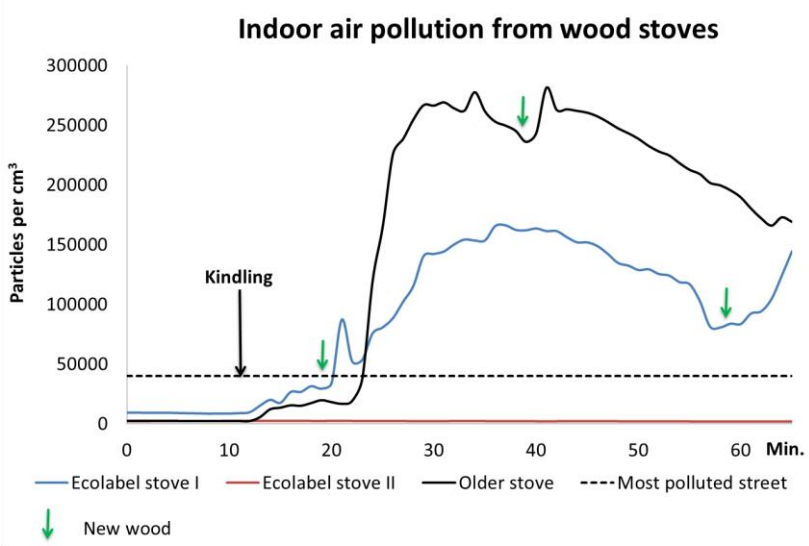


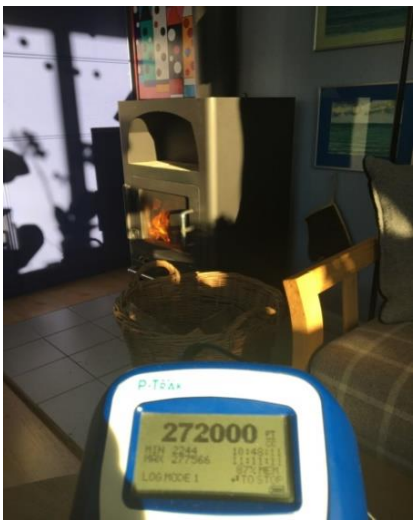

The pictures show that the concentration of ultrafine particles in the wood smoke is above the detection limit of the device (500,000 particles per cm^3), even during optimal conditions in an ecolabel stove with no visible smoke from the chimney. For comparison, the concentration in the exhaust of a truck with particulate filter is about 250 i.e., at least 2,000 times less.

Indoor air pollution

Domestic wood burning stoves can contribute significantly to indoor air pollution. The impact is vital as European citizens on average, spend approximately 90 percent of their time indoors. Since stoves are placed inside houses, they can leak pollution directly to indoor air, this is especially harmful in colder seasons with limited ventilation. Both old stoves and stoves carrying the Nordic Swan ecolabel can—but do not always—cause indoor pollution. This is illustrated in the diagram below and compared to the most polluted Danish street.

Figure 3: Indoor air pollution from different wood stoves (particles per cm^3)





Conclusion

Out of all heat production sources, small-scale domestic wood (coal and straw) burning is the most severe polluter, in turn causing the highest health costs. While newer wood stoves and boilers do in fact emit fewer particles than previous stove/ boiler models, these newer models of stoves/ boilers still pollute much more than other available heat production methods, and therefore should not be considered a viable solution for air pollution reduction. Instead, we will achieve higher health benefits if we discontinue the use of small-scale wood burning and instead utilize better insulation and clean heat solutions, such as district heating in cities and heatpumps outside of cities.

Recommendations

Based upon the conclusions of this pre-study it is recommended to:

1) Carry-out a more detailed study concerning air and climate pollution from domestic heating.
2) Set much stricter emission limit values in the EcoDesign directive for wood stoves/boilers.
3) Start a Europe-wide campaign focusing on better insulation and cleaner domestic heating i.e local/national actions to ban/limit domestic solid-fuel combustion.

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Emission factors: https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/emission-factors/

Annex: Basic methodologies and assumptions

Limitations

Emissions and the related health costs do not include emissions from the fuel or plant/stove/boiler production/construction and transport. Only direct emissions from the user phase are included.

Emissions do not include loss of potent greenhouse gasses from heat pumps which can increase global warming significantly during the use of some specific heat pumps containing HFC-gasses.

Condensate particles

Emissions include condensate particles from wood burning and are thereby higher than emissions factors from methods (EN 13240 DIN+) ignoring condensate particles. Condensate particles are very important concerning public health and constitute by far the majority of the particle emissions and health effects caused by domestic wood heating. Typically, emissions including condensate particles (e.g. NS3058-59) measure 5-8 times more particles than methods ignoring condensates (EN 13240 DIN+).

Energy efficiencies

Oil boiler (85 %), gas boiler (90 %), district heating (75 %), electric heating (90 %) and domestic wood burning (80 %).

Global Warming Potentials

Methane (CH_4): 85 (GWP-20) and 30 (GWP-100).

Dinitrogen oxide (N_2O): 280 (GWP-20) and 266 (GWP-100).

Black Carbon (BC): 3,200 (GWP-20) and 900 (GWP-100).

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