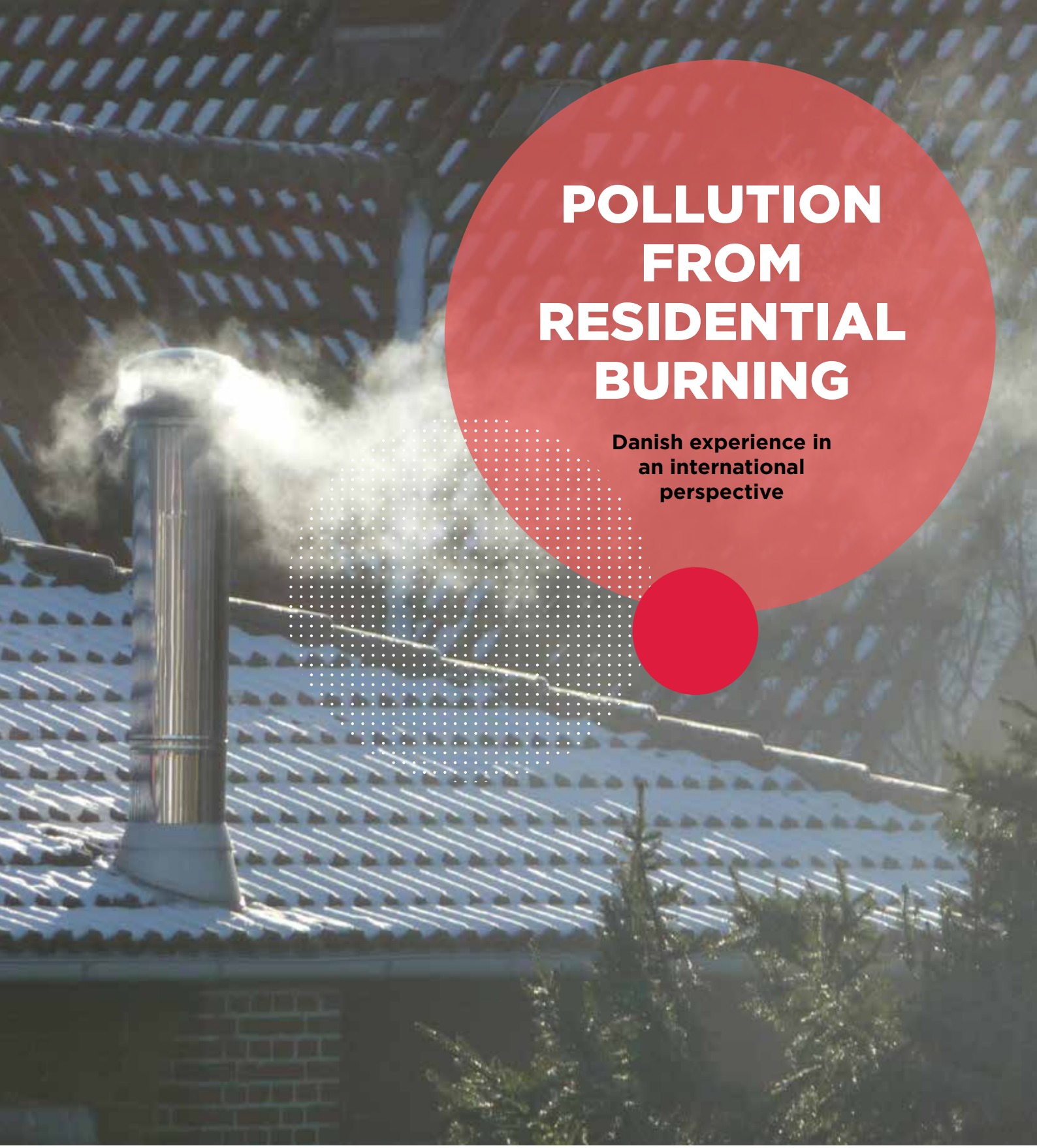

POLLUTION FROM RESIDENTIAL BURNING

Danish experience in an international perspective

THE DANISH ECOLOGICAL COUNCIL

clean heat

Deutsche Umwelthilfe

CONTENT

By joining the Danish Ecological Council you can actively support our efforts to combat air pollution – read more on www.ecocouncil.dk/en/front-page or contact us using the e-mail below.

This publication is available as a free download from: www.clean-heat.eu & www.ecocouncil.dk

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BACKGROUND

Outdoor air pollution causes approximately 400,000 premature deaths in Europe every year according to the European Commission. In addition, it causes serious diseases for millions of Europeans. A premature death due to air pollution means an average loss of ten years of living. Thereby, about 4 million life years are lost annually in the EU due to air pollution. The associated socio-economic health costs amount to approximately 500 billion euros annually.

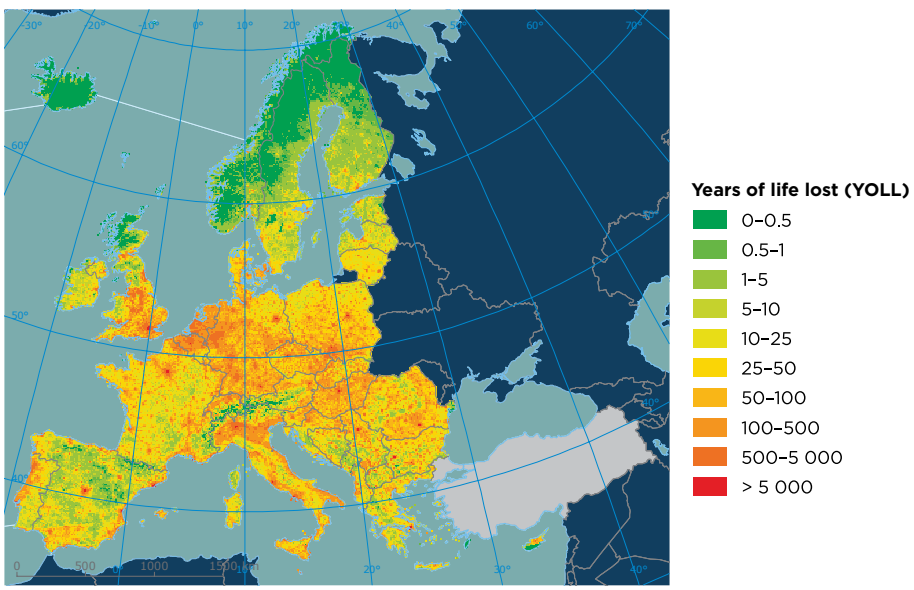
Figure 1 shows life years lost in the EU caused by air pollution with fine particles. Prior to death, people often suffer many years from severe disease. This means that the loss of healthy life years is significantly larger than the number of life years lost. In addition to the health damages comes damage to crops, the natural environment, buildings, etc. Air pollution is thereby the most expensive environmental problem in the EU. Pollution from residential burning of mainly wood causes about 60,000 premature deaths in the EU every year according to the World Health Organisation. The number of healthy life years lost is around 1 million a year. The associated socio-economic health costs are estimated to be almost 75 billion euros annually.

In Denmark air pollution with fine particles is the most health damaging problem causing about 4,000 premature deaths and 3-4 million sick days every year. The associated socio-economic health costs are around 5.5 billion euros annually. Danish pollution sources contribute to about 25% of the pollution with fine particles while 75% of the pollution comes from abroad and from international shipping.

The EU Commission's estimate for health impacts, in line with the Danish estimate, is mainly based on air pollution with fine particles (and ground level ozone, which causes much less damage). In this estimate it is assumed that all particles are equally harmful regardless of their chemical composition. Thereby, pollution from wood burning in Denmark contributes with about 50% of all health damages from Danish pollution sources corresponding to a total health cost in Denmark of around 800 million euros a year. This makes pollution from wood burning the most expensive environmental problem in Denmark harming Danes several times more than fine particles from domestic road traffic.

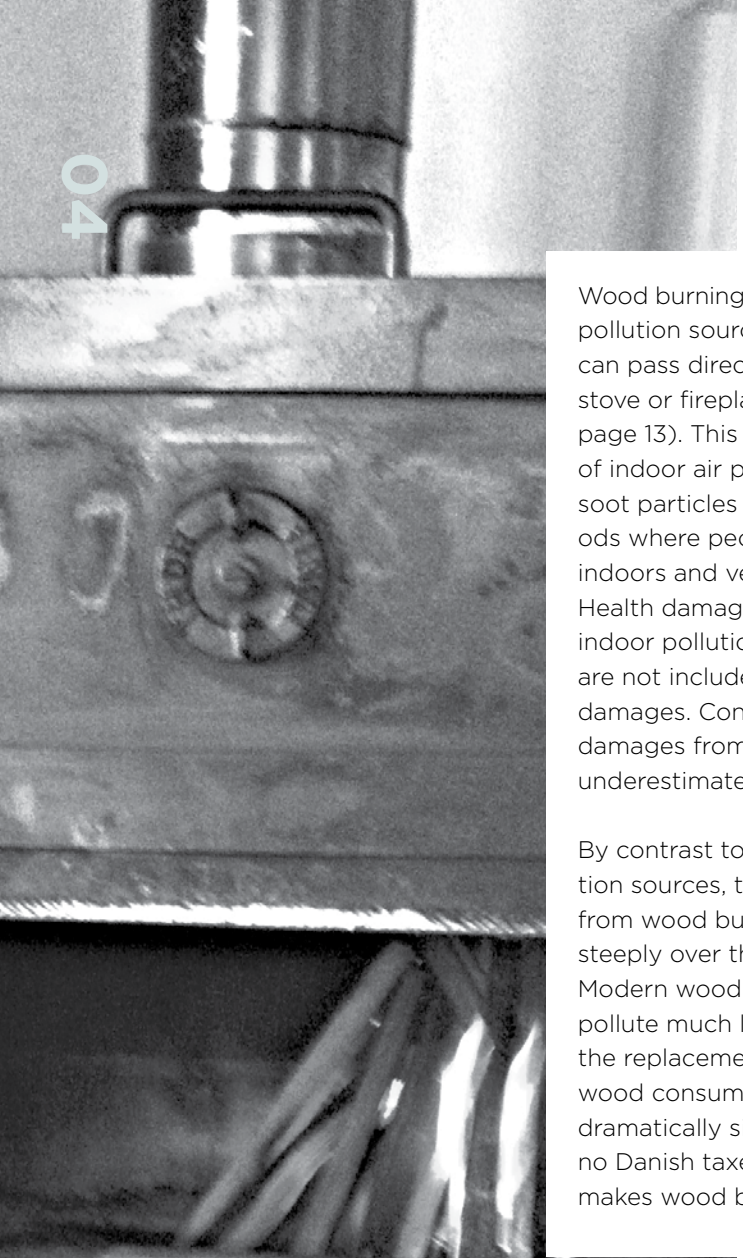
In addition, recent research indicates that soot particles from, among others, wood burning seem to be more harmful than inorganic particles formed in the atmosphere from ammonia, sulphates and nitrogen oxides. Furthermore, wood burning is a key source to many other toxic pollutants (see page 5). Thereby, air pollution from wood burning can be much more damaging than pointed out above.

Figure 1: Number of life years lost in the EU due to air pollution with fine particles



Source: European Environment Agency, 2013.

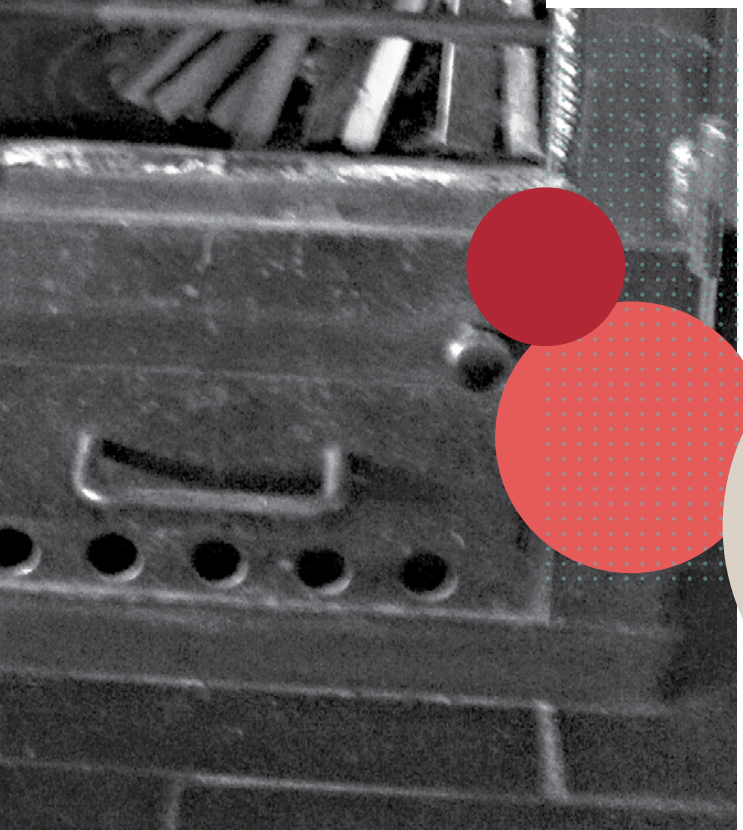
Pollution from residential burning causes about 60,000 premature deaths every year within the EU



Wood burning is different from other pollution sources, as air pollution can pass directly from the wood stove or fireplace into indoor air (see page 13). This can cause a high level of indoor air pollution with ultrafine soot particles during seasonal periods where people spend most time indoors and ventilation is limited. Health damages associated with indoor pollution from wood burning are not included in the above health damages. Consequently, health damages from wood burning are underestimated.

By contrast to other Danish pollution sources, the particle emissions from wood burning have increased steeply over the last 25-30 years. Modern wood burning units may pollute much less than old units, but the replacement rate is low and the wood consumption has increased dramatically since 1990 as there are no Danish taxes on wood, which makes wood burning economically attractive compared to other heat sources. To date (September 2016) no political actions have been taken to significantly reduce pollution from wood burning in Denmark. By contrast, a political decision to phase out oil and gas boilers may increase wood burning and the resulting pollution (see page 7).

When no action has been taken it is presumably due to a lack of knowledge about pollution from wood burning among decision-makers and the public. Therefore, we have decided to write this publication about pollution from wood burning and the associated health and climate impacts, the many technical solutions as well as the political decisions needed to implement the solutions. We focus both on local actions in homeowner associations and changed behaviour on the user level that can reduce pollution from wood burning locally regardless of any political decisions.



High levels of pollution with fine and ultrafine particles have been measured inside houses using wood stoves.

POLLUTANTS

Smoke from wood burning contains health hazardous substances due to incomplete combustion. The most important pollutants are described in this section. However, wood burning can contribute significantly to emissions of volatile organic compounds, carbon monoxide and some heavy metals as well.

Measurement methods

When measuring pollutants in the smoke and thereby determining emission factors for residential burning it is very important to be aware of the fact that key pollutants such as particles may first be formed when the smoke is cooled in the surrounding air. Hence, it is necessary to dilute and thereby cool the smoke to 25-30°C to include most particles in the measurements. Measurements directly in the smoke stack under high temperature without dilution and cooling, as still done by many member states, will significantly underestimate the particle formation and cannot be used to estimate emissions. The underestimation can be up to a factor 10. Norwegian standard NS 3058-1 and NS 3058-2 show how emission measurements should be done. Furthermore, it is important to realise that real-life emissions are often many times higher than under ideal test conditions. Emission factors (see page 7) should always be stated per energy unit (joule) or per standard fuel unit (kg dry wood).

Fine particles

Fine particles ($PM_{2.5}$) are particles with a diameter less than 2.5 micrometres (µm). Fine particles are measured in units of mass; often in micrograms per cubic metre (µg/m^3). Fine particles from wood smoke make up about 65% of total Danish particle emissions. Of this, approximately 70% derives from wood stoves and 30% from wood boilers. Fine particles have a very long lifetime and are therefore transported over large distances. Therefore, the major part of pollution with fine particles in Denmark origins from other countries - just as the major part of the Danish particle emissions are exported and cause health damage abroad. In residential areas with a high level of wood burning, concentrations of fine particles can reach the same magnitude as the level found on the most polluted Danish streets during rush hour. Disease and mortality caused by air pollution are often calculated from fine particles (see page 21).

Soot particles

Soot particles are organic particles consisting of elementary carbon. Soot particles are also referred to as *black carbon*. Soot particles make up part of the fine particles emitted from combustion processes; like fine particles, they are measured in units of mass (µg/m^3). Soot particles from wood smoke make up 55% of total Danish soot particle emissions. Just like fine particles, soot particles have a long lifetime in the atmosphere and are therefore transported over large distances and deposited as far away as the inland ice in the Arctic. Recent studies show that soot particles seem to be more health hazardous than inorganic particles and they are one of the most important reasons for man-made climate change and ice melting in the Arctic (see page 23).

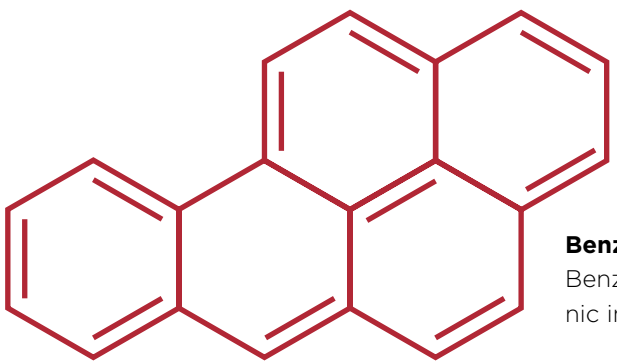
Smoke from wood burning contains a large number of health damaging pollutants.

Ultrafine particles
Ultrafine particles ($PM_{0.1}$) are particles with a diameter of less than 0.1 micrometres (µm), i.e. less than 100 nanometres (nm). Ultrafine particles are measured (counted) in numbers; often in number of particles per cm^3. No official investigations have been conducted on ultrafine particles from wood burning in residential areas. However, measurements made by the Danish Ecological Council as part of the EU LIFE project *Clean Heat* show extreme emissions from chimneys and that large residential areas are heavily polluted with ultrafine particles from wood burning (see page 17). Furthermore, indoor pollution with ultrafine particles from wood burning can be severe (see page 13).

Tar compounds
Tar compounds (PAH: polycyclic aromatic hydrocarbons) are an organic substance group consisting of polycyclic aromatic rings. Tar compounds from wood smoke make up approximately 80% of total Danish emissions. Particularly the tar compound benz(a)pyrene is of interest, since the substance is carcinogenic in very low doses. In residential areas with frequent wood burning concentrations of tar compounds are higher than what is found on the most polluted streets in Copenhagen. Tar compounds in wood smoke are found both bound to particles and as gases. In the atmosphere the tar compounds can bind to particles and thereby increase their toxicity.

Dioxins
Dioxins are an organic substance group primarily consisting of polychlorinated substances. Dioxins from wood smoke make up approximately 60% of total Danish emissions. Dioxins are one of the most harmful substance groups found and can be carcinogenic, endocrine disrupting, toxic for reproduction and harmful to the immune system. In addition, accumulation of dioxins in the food chain may cause major harm to the natural environment and increase people's intake of toxic dioxins through their food.

Smell
Most complaints about wood burning in Danish municipalities concern smell. The smell is caused by non-combusted volatile organic substances found in the smoke together with particles, tar compounds and dioxins. There is no unambiguous definition of smell since such nuisances are mostly individual. Smell is primarily a purely aesthetic problem and not harmful by itself. However, smell may be a clear indicator that wood smoke is found in harmful concentrations.



Benz(a)pyren
Benz(a)pyrene is carcinogenic in low concentrations.

PARTICLE EMISSIONS

Wood burning is responsible for about 67% of total Danish emissions of harmful fine particles; although wood burning only covers about 3% of the Danish energy consumption. By comparison, all Danish power plants account for 3% of the particle emissions while covering around half of the domestic energy consumption. The large difference is due to the fact that power plants have a substantially cleaner combustion than wood burning and that the power plants also have flue gas cleaning, i.e. power plants have much lower particle pollution per energy unit generated.

Figure 2 shows emissions of fine particles per energy unit from different heat sources. Emissions from wood stoves and boilers are shown under ideal operational conditions; in other words, in reality emissions are most likely significantly higher. In comparison, the particle emission from an old truck from 2006 without particulate filter is shown (all new trucks today have particulate filters). From the figure is seen that particle emissions from wood burning are so high that emissions from all other heat sources (and old trucks) seem negligible compared to wood burning. It is also seen that particle emissions from wood burning can be more than halved just by replacing old units with new ones, while pollution can be reduced by more than 90% by using cleaner heat sources like district heating, heat pumps, etc.

Particle emissions ($PM_{2.5}$) from heat sources
(Danish emission factors; g particles pr. GJ energy)

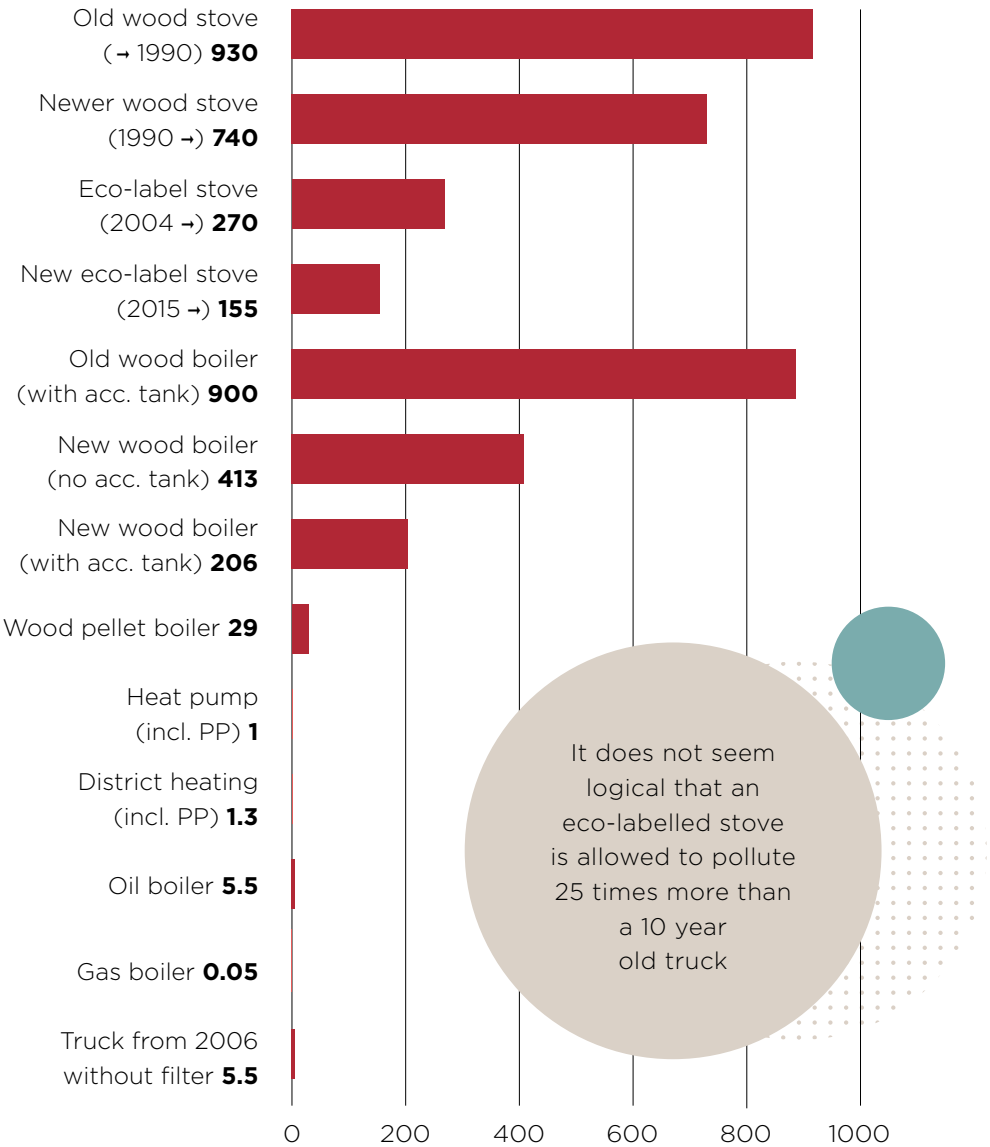


Figure 2: Particle emission from different heat sources. For comparison is shown the emission from an older truck. For boilers are shown emissions with and without accumulation tank (acc. tank). The emission from district heating and heat pumps includes the emission from power plants (PP).

Measurement of ultrafine particles from wood burning

Measurement of ultrafine particles
The Danish Ecological Council has carried out several measurements of ultrafine particles from wood burning. Some of the measurements were made in the mixing zone in the top of a chimney from a modern eco-labelled wood stove (Nordic Swan-label) from 2011 connected to a new chimney. Ultrafine particles were measured with a P-Trak (Model 8525 Ultrafine Particle Counter). To avoid direct sooting of the P-Trak and to allow cooling of the smoke a two-meter-long tube was inserted between the chimney and the P-Trak. The tube adsorbs approximately 30% of the particles.

The measurements were made under ideal operational conditions, i.e. good air intake and small pieces of completely dry wood (10-12% humidity) stacked in alternating directions in the stove. A total of 1kg of wood was used. The fire was started from the top with two small ethanol kindling blocks. The fire started quickly and had clear yellow flames.

The measurements were made under ideal operational conditions

The measurement results are shown in figure 3. It is seen that even under optimal firing conditions in a good eco-labelled wood stove, particle emissions increase instantaneously to the maximum limit of the measurement equipment of 650,000 particles per cm^3 (corrected for removal of 30% in the probing tube). Only at moments with wind (clean air) entering the mixing zone in the top of the chimney the particle level was briefly registered below the measurement limit. Therefore, in reality emissions was markedly higher than what the P-Trak was able to measure and thereby significantly higher than illustrated in the figure where the curve merely flattens at the exceedances of the measurement limit. Afterwards, sawdust briquettes were used for firing (1 kilogram), and this led to a lower, but still very high, level of emissions of ultrafine particles. For comparison, the pollution was measured in the garden of the house (windward side without smoke impact) and in a forest area near the house.

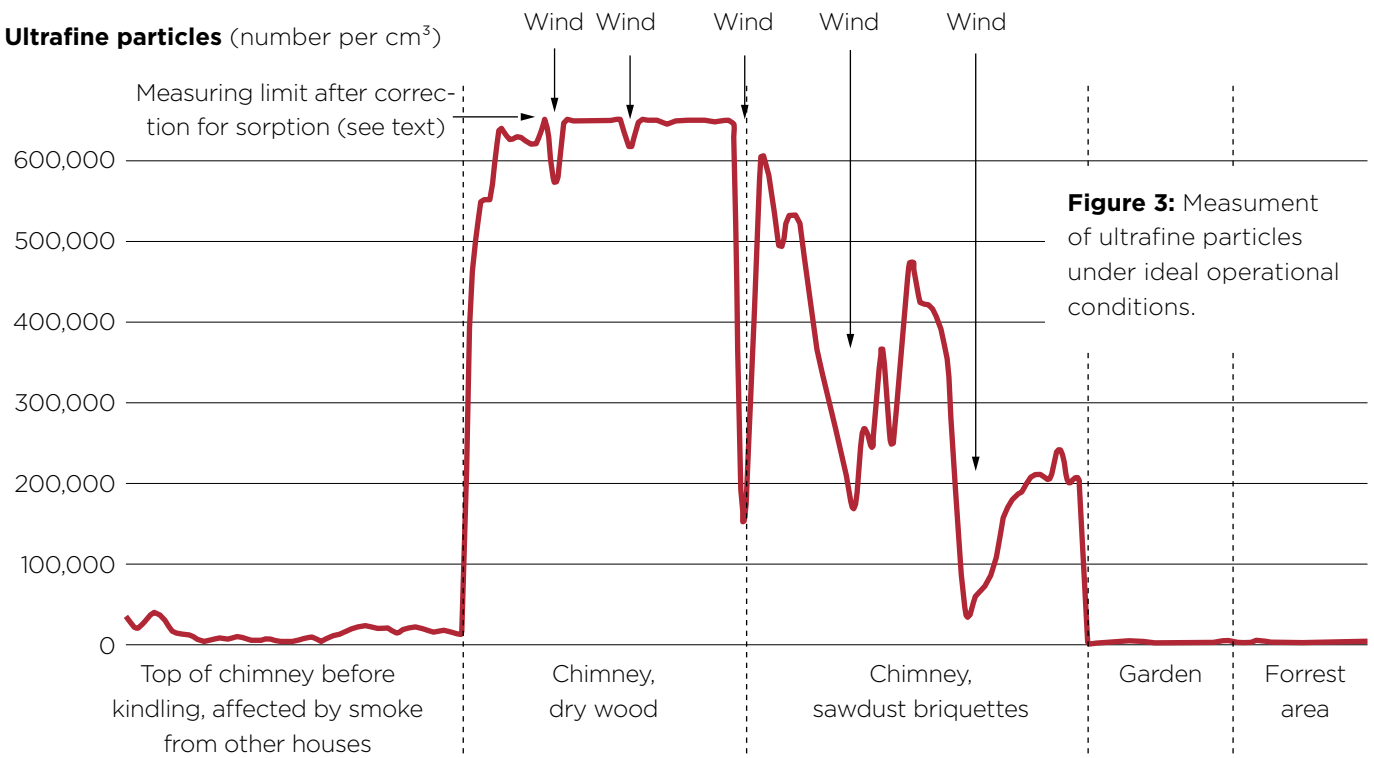


Figure 3: Measument of ultrafine particles under ideal operational conditions.

Measurements	Average pollution (particles per cm^3)
Chimney exhaust, dry wood	> 587,850
Chimney exhaust, sawdust briquettes	291,300
Garden (no smoke)	2,500
Forrest near house (no smoke)	2,500
Small diesel truck with new filter	< 1,000

Table 1:
Emission of ultrafine particles

The measurement averages of the different measurements are shown in table 1. A screening of the exhaust of a small diesel truck with a new particulate filter is shown for comparison.

From table 1 is seen that the number of ultrafine particles in the smoke is more than 230 times higher than in the garden (no smoke) even during ideal stove operation i.e. using small pieces of carefully stacked dry wood in a modern eco-labelled wood stove (Nordic Swan-label) connected to a brand new chimney. The pollution from sawdust briquettes is lower but still more than 100 times higher than in the garden. For comparison, a screening from the exhaust of a small diesel truck with a new particulate filter is shown. The filter removes almost all ultrafine particles (within the measurement interval of the P-Trak).

Wood smoke

Forrest near house

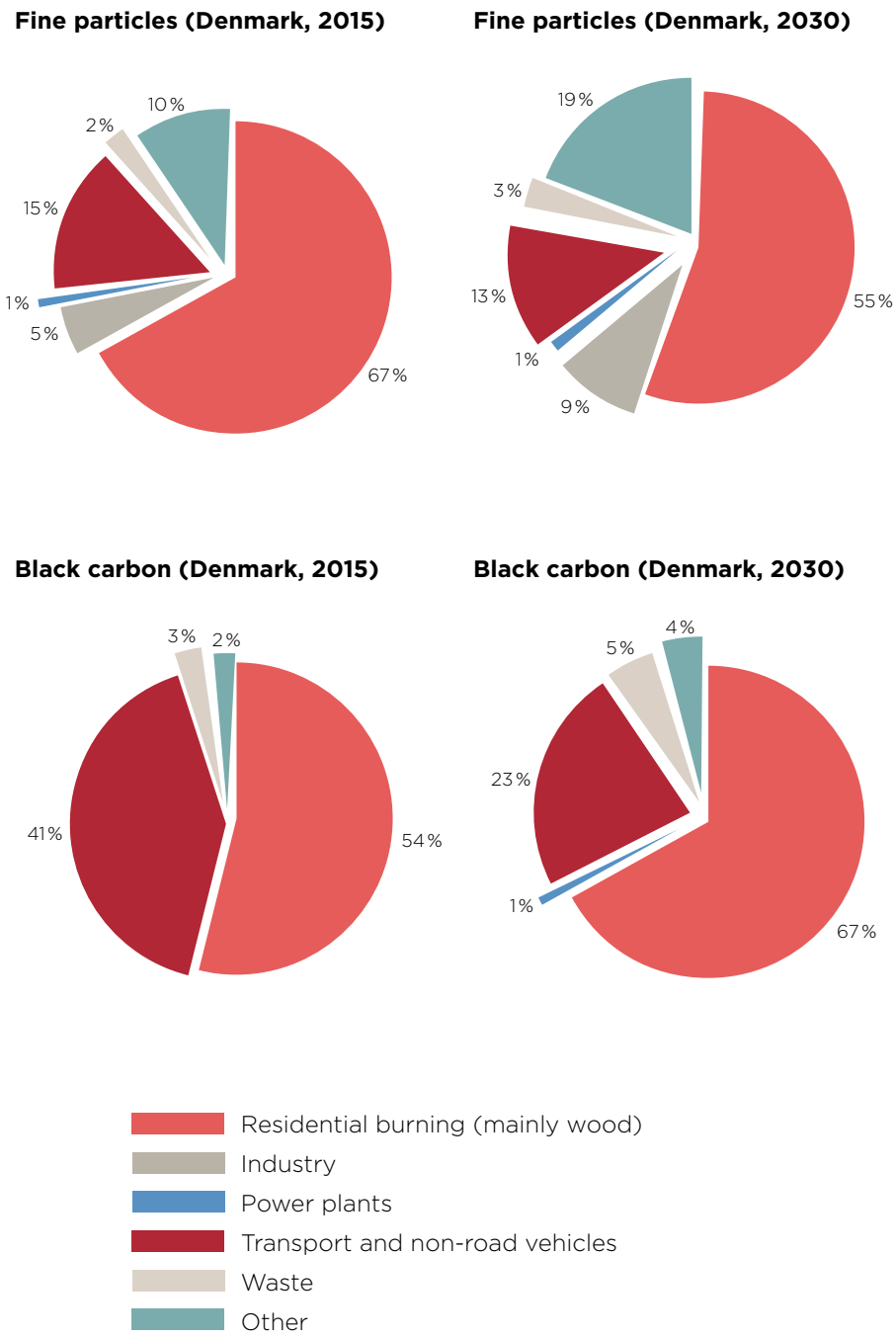
Truck exhaust (with filter)

PARTICLE INVENTORIES

The *International Institute for Applied System Analysis* (IIASA) in Austria is used as key advisor by the EU regarding emissions of air pollutants and greenhouse gasses. IIASA has developed the GAINS model: *Greenhouse Gas - Air Pollution Interactions and Synergies* model. The GAINS model explores cost-effective emission control strategies that simultaneously tackle local air quality and greenhouse gases to maximize benefits at all scales. The GAINS model contains qualified emission estimates on member state levels for fine particles and black carbon (soot) and thereby the accumulated EU emissions.

In figure 4 are shown emissions of fine particles and black carbon for Denmark in 2015 and 2030 distributed among key sectors. The 2030 emission estimates include reductions due to decided regulation and some structural as well as technological development. However, increased pollution due to a significant shift from residential use of oil and gas towards wood in 2030 has not been taken into account even though it is an official Danish target to phase out oil and gas for residential heating during the next decades. The estimates in the figure should thereby be seen as a best case. Despite this, the figure clearly shows that residential wood burning will continue to be the dominating emission source to fine particles and black carbon in Denmark in 2030. Hence, further political actions are needed now to reduce Danish emissions from wood burning.

Figure 4: Danish emissions of fine particles and black carbon



Emissions in EU-27

In table 2 are found fine particle and black carbon (soot) emission estimates for EU-27 and for some member states. Residential burning in EU mainly covers wood burning. However, in some former eastern European countries coal, lignite and coke are still burned in significant quantities as well. From the table is seen that residential burning is a dominating emission source in EU as a whole and in most member states. If no further actions are taken, wood burning will still be the dominating emission source in 2030. Hence, there is an urgent need for further political actions to minimize pollution from residential burning in the EU.

Table 2: Fine particle and black carbon emission estimates

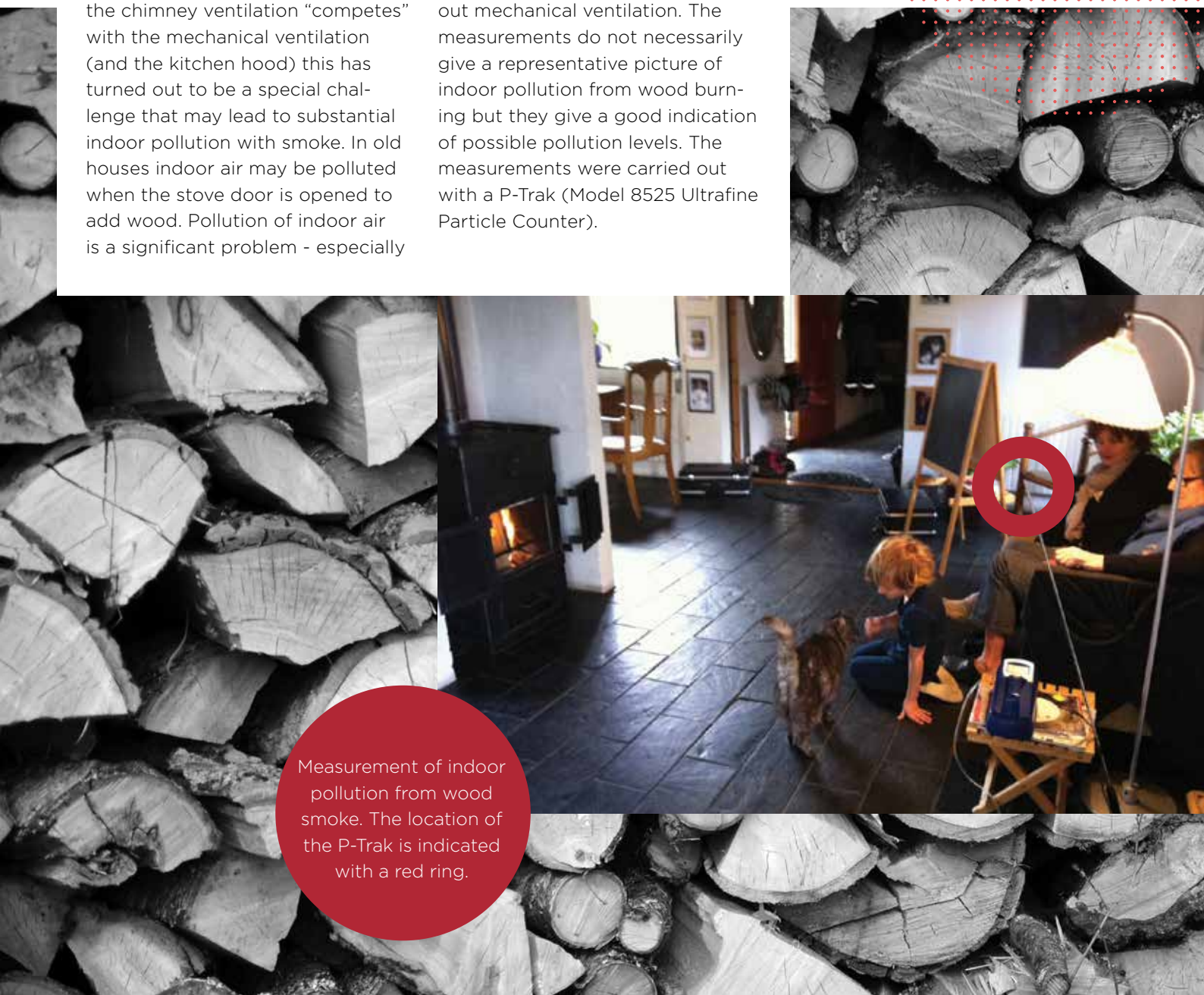
		2015				2030			
		Fine particles		Black carbon		Fine particles		Black carbon	
		Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%
EU 27	Residential burning	654000	46%	152290	56%	454880	41%	111380	69%
	Road transport	149500	11%	63710	23%	95040	8%	10210	6%
	Other sources	608280	43%	57100	21%	566200	51%	39990	25%
Austria	Residential burning	6670	39%	2430	55%	4530	34%	1690	76%
	Road transport	3130	18%	1290	30%	2160	16%	160	7%
	Other sources	7290	43%	660	15%	6770	50%	380	17%
Belgium	Residential burning	17580	49%	2690	47%	15810	50%	2590	76%
	Road transport	3780	11%	1960	35%	1700	5%	190	6%
	Other sources	14430	40%	1030	18%	14100	45%	600	18%
Denmark	Residential burning	15610	67%	2000	54%	7060	55%	1070	67%
	Road transport	1620	7%	750	21%	930	7%	110	7%
	Other sources	6120	26%	920	25%	4890	38%	410	26%
France	Residential burning	89250	48%	26740	57%	44250	35%	15430	74%
	Road transport	27350	15%	12990	27%	15990	13%	970	5%
	Other sources	70070	37%	7390	16%	66270	52%	4290	21%
Germany	Residential burning	26860	26%	8240	44%	20870	26%	6620	67%
	Road transport	16700	16%	5790	31%	11820	14%	1070	11%
	Other sources	59450	58%	4690	25%	49290	60%	2240	22%
Hungary	Residential burning	16350	59%	2700	62%	10730	53%	1900	79%
	Road transport	2370	8%	1020	24%	1210	6%	150	6%
	Other sources	9130	33%	610	14%	8270	41%	370	15%
Poland	Residential burning	194770	79%	46040	86%	146830	76%	35080	93%
	Road transport	9570	4%	4460	8%	6090	3%	1020	3%
	Other sources	42900	17%	3060	6%	41660	21%	1550	4%
Slovakia	Residential burning	17980	69%	2520	76%	14150	64%	2250	86%
	Road transport	1220	5%	540	16%	750	4%	120	5%
	Other sources	6640	26%	270	8%	7100	32%	240	9%
Czech Republic	Residential burning	12630	41%	3630	57%	9580	39%	3020	72%
	Road transport	3850	13%	1580	25%	1930	8%	350	9%
	Other sources	14220	46%	1170	18%	12820	53%	800	19%
United Kingdom	Residential burning	12800	18%	3030	25%	11260	17%	2220	33%
	Road transport	11430	16%	3920	32%	9290	14%	600	9%
	Other sources	48300	66%	5140	43%	46690	69%	3900	58%

Source: IIASA, GAINS model scenario WPE_2014_CLE, 2014

INDOOR POLLUTION

According to several studies conducted by the Danish Building Research Institute, smoke from wood burning can pass directly from the stove to the ambient air. Hence, if a wood stove is located in a living room, it can pollute the air in the room. In new tight houses in which the chimney ventilation "competes" with the mechanical ventilation (and the kitchen hood) this has turned out to be a special challenge that may lead to substantial indoor pollution with smoke. In old houses indoor air may be polluted when the stove door is opened to add wood. Pollution of indoor air is a significant problem - especially in the winter months when people spend most time indoors and ventilation is limited.

The Danish Ecological Council has carried out several measurements of ultrafine particles from wood burning in Danish houses without mechanical ventilation. The measurements do not necessarily give a representative picture of indoor pollution from wood burning but they give a good indication of possible pollution levels. The measurements were carried out with a P-Trak (Model 8525 Ultrafine Particle Counter).



Measurement of indoor pollution from wood smoke. The location of the P-Trak is indicated with a red ring.

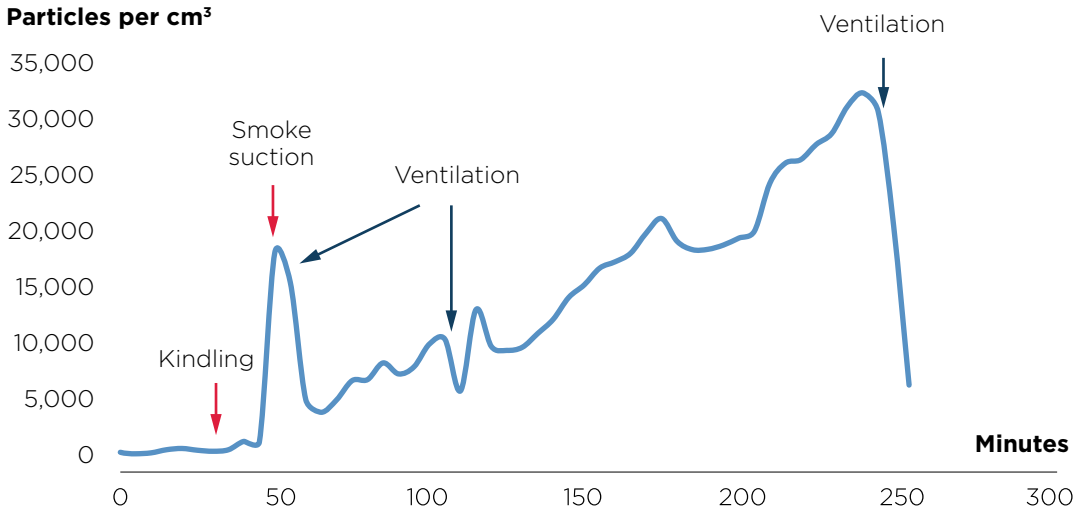
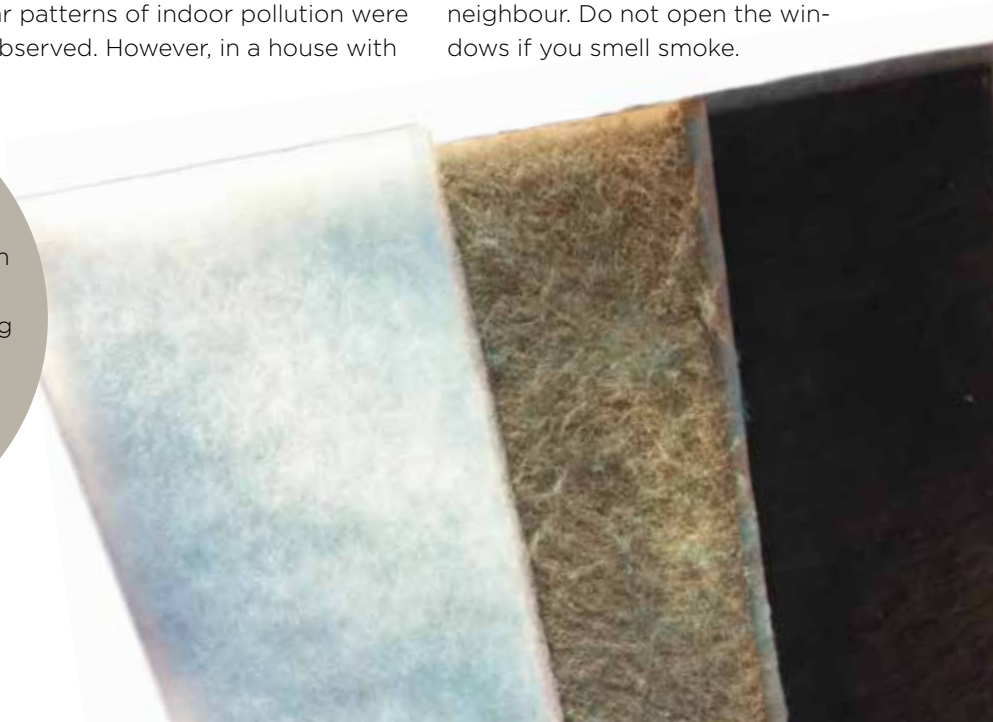


Figure 5: Indoor air pollution from wood stoves

In all investigated Danish houses significant indoor pollution associated with wood smoke was observed. The worst example was found in a living room with an old wood stove where the pollution increased throughout the day. The measurements are shown in figure 5. Before kindling the background pollution in the house were 1,700 particles per cm³ corresponding to relatively clean air. Around 10 minutes after start-up the garden door was opened with the stove door open as well creating a draught directly down the chimney out into the living room (smoke suction). The room were thoroughly ventilated and burning continued as usual in the stove. After three-four hours of burning the concentrations of ultrafine particles from wood smoke in the living room reached about 30,000 particles per cm³ corresponding to levels found at roads with heavy traffic; a level about 20 times higher than before kindling the stove. The pollution had spread to all rooms in the house including the bedroom.

In other houses with old stoves similar patterns of indoor pollution were observed. However, in a house with a modern wood stove it was possible (after some practice) to carefully open the stove door and add wood not causing a measurable indoor pollution.

In houses with modern mechanical ventilation it is important to have good filters in the ventilation system to remove harmful soot particles and thereby prevent indoor pollution from wood burning in the neighbourhood. Ventilation through windows can cause pollution from your own stove or that of your neighbour. Do not open the windows if you smell smoke.



Mechanical ventilation
New filter (left). In the ventilation filter to the house (right) black soot particles from wood burning are removed while grey dust is removed in the ventilation filter from the house (middle).

Hotel measurements
In the unpolluted areas of the Slovakian mountains were rented two identical hotel rooms next to each other. Both had modern wood stoves. At the reception was paid to get a fixed amount of dry wood with integrated small ignition blocks placed in one of the stoves. Both rooms had same low pollution levels in the morning. Before breakfast (8:35) the stove with wood was kindled and both rooms were left alone. After breakfast (9:45) the pollution with ultrafine particles was almost unchanged in the room without an active stove, whereas the pollution was about 60 times higher in the room with an active stove. The measurements are shown in figure 6. The measurements underline that even dry wood burned in modern wood stoves can cause significant indoor particle pollution even if the stove doors are left closed. It is interesting to notice that the pollution increases with a much higher rate after one hour (about 9:30).

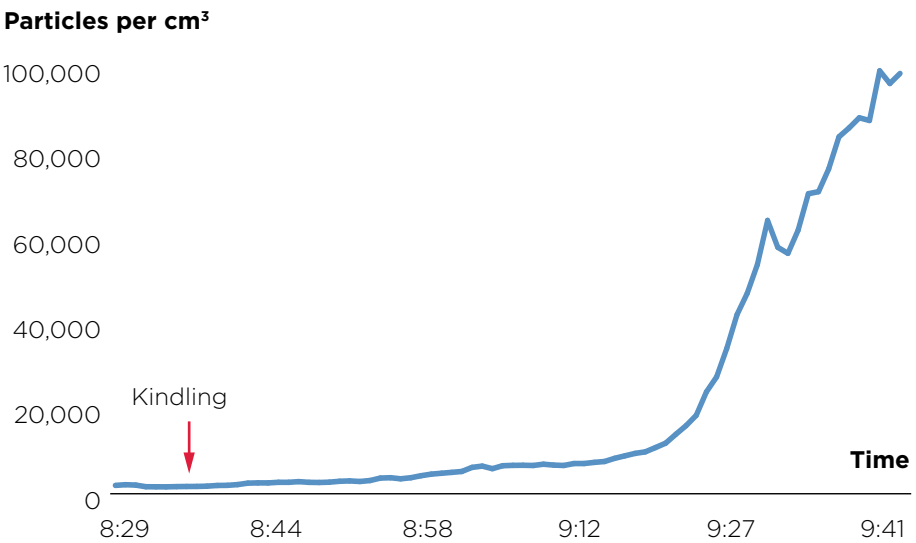


Figure 6: Indoor air pollution from wood burning in a hotel room.

Traditional stove
Traditional old stoves might cause significant indoor air pollution. In a small Slovakian summer house, air pollution with ultrafine particles from a traditional wood stove, still used by many poor families in the former Eastern Europe, was measured. The measurements are shown in figure 7. It is seen that the air in the summerhouse is clean before kindling but already 3 minutes after kindling the pollution has increased 125 times to 275,000 particles per cm^3. These measurements indicate that air pollution from wood burning could have an important adverse social side as well: Poor people without the ability to buy new stoves, insulate their houses, use modern heat sources or buy medicine may be constrained with extremely polluting stoves leading to harmful indoor air pollution.

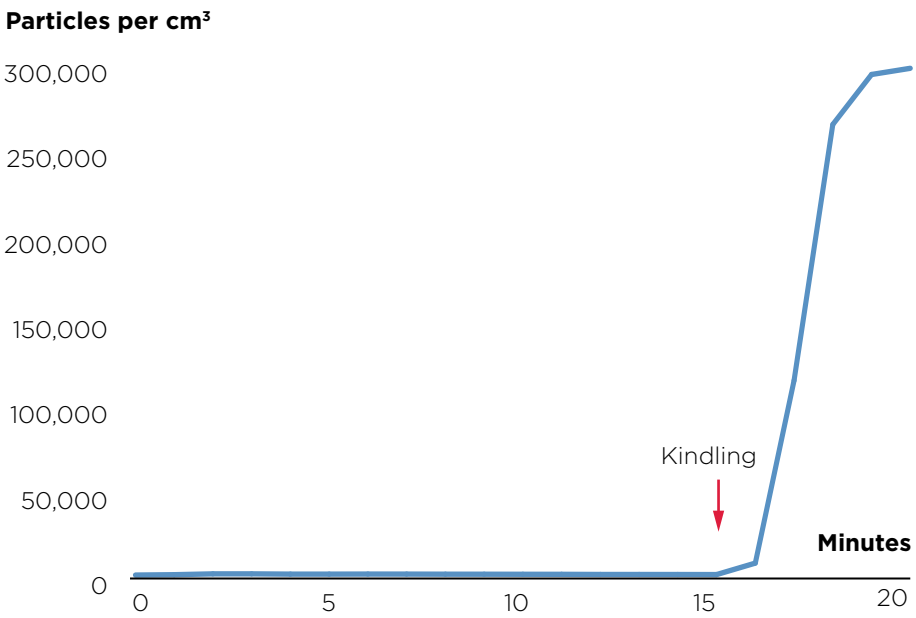


Figure 7: Indoor air pollution from a traditional old stove.

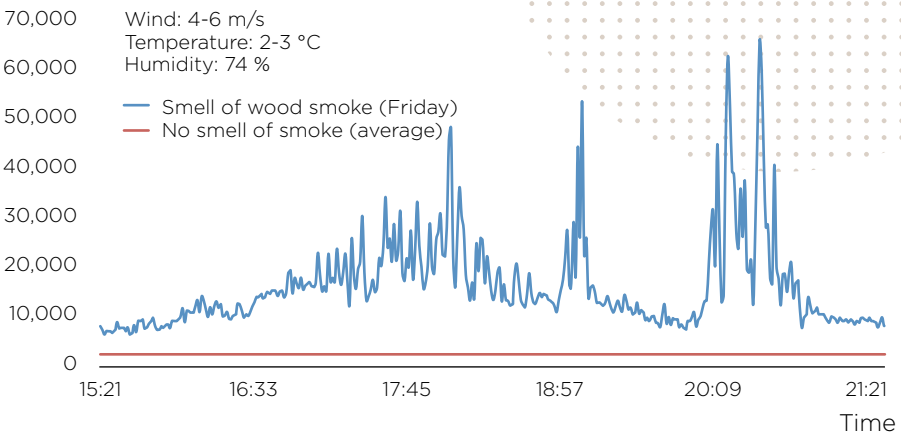
OUTDOOR POLLUTION

The Danish Ecological Council has carried out many measurements of air pollution in residential areas as a part of the EU LIFE project Clean Heat. Ultrafine particles emitted by wood burning were measured with a P-Trak (Model 8525 Ultrafine Particle Counter). Furthermore, temperature, wind speed and humidity was measured with a WindMate-300 to ensure optimal measuring conditions.

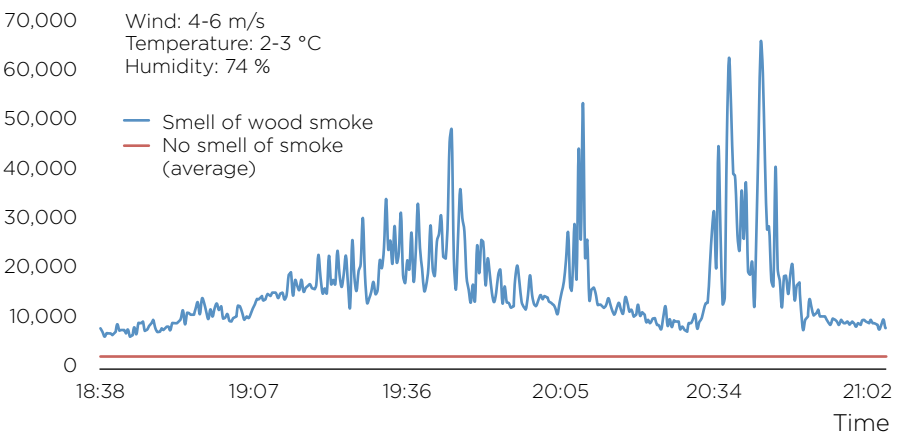
Measurements were carried out in residential areas with smell of wood smoke (air pollution) and in the same areas at locations (or at times of the day) with no smell (background). Thereby, it can be estimated how much pollution from wood burning increases local air pollution. The measurements were carried out in private gardens and on small roads in residential areas. There were no other significant sources of pollution in any of the residential areas.

In figure 8 are results from measurements in residential gardens where a clear smell of smoke from wood burning was perceived (from neighbours). For comparison the average background concentration is shown. It is assumed that the background concentration is almost unaffected by local wood burning as the variation in the pollution levels were limited. It is seen that the pollution levels in the gardens with smell (wood smoke) were 25-30 times above the background concentration. Furthermore, during ventilation through open windows pollution of the indoor air by wood smoke from the gardens was observed. Hence, ventilation should be avoided if there is a smell of wood smoke.

Figure 8:
Pollution from wood burning in Copenhagen
Particles per cm^3



Pollution from wood burning in Frederikssund.
Particles pr. cm^3



Complain to the authorities if you smell wood smoke. Do not tolerate pollution of the air in your garden.

Figure 9:
Air pollution from wood burning in an allotment society in Copenhagen

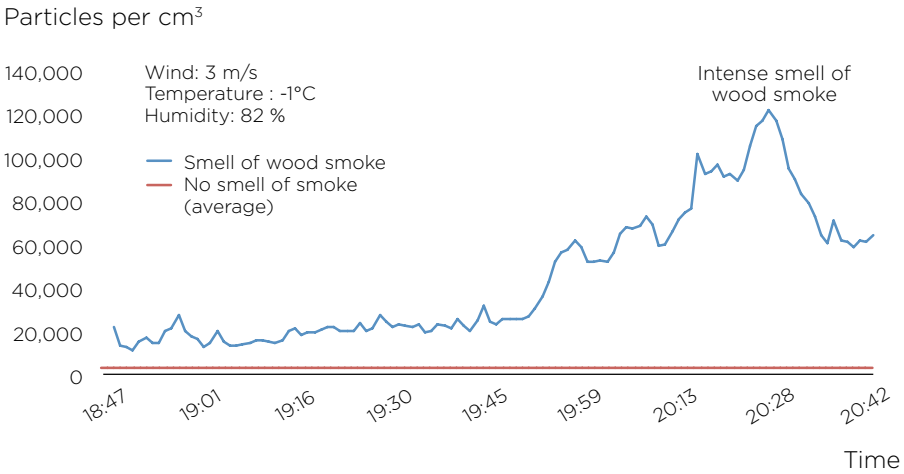


Figure 9 shows a measurement from an allotment society in Copenhagen where wood burning is used as supporting heat source in the winter. For comparison are shown background concentrations in a residential area a few hundred meters away. Background concentrations could not be measured in the allotment society since all air was heavily polluted by local wood burning. When an intense smell of smoke was observed the concentration was 30-40 times above the background concentration in the nearby residential area. The pollution thereby reaches much higher levels than the most polluted streets in Copenhagen where the average value lies around 40,000 particles per cm^3 during rush hour.

Use your nose

There was a clear coherence between smell of smoke and air pollution from wood burning. Even a weak smell of wood smoke results in air pollution levels of 5-10 times higher than at locations in the same residential area without smell. Pollution levels can increase to more than 50 times above background concentrations when heavy smell of wood smoke occurs. Air pollution in residential areas with wood burning thereby reaches the same high levels as on the most polluted streets during rush hour. In conclusion, use your nose and talk to your neighbours if you smell smoke in your garden. If that does not help, complain to the local authorities. The authorities can only allocate resources to limit pollution from wood burning if citizens call attention to the problem.

WASTE BURNING

Burning of waste from gardens, agriculture, households and industry is still a challenge and can cause severe air pollution. The waste is burned because it is easier than to dispose it in a correct manner (public waste collection) or because no waste collection exists e.g. for agricultural or garden waste.

The waste is typically burned as a bonfire or used directly in heating appliances e.g. burning of painted wood in stoves or straw in straw-fired boilers. Burning garden waste is forbidden in many larger Danish cities just as burning fields have been forbidden for decades in Denmark. However, the ban does not include agricultural waste burned as bonfires or straw burned in straw-fired boilers.

Burning of waste is not included in the official Danish pollution statistics. Health damages and costs connected to this pollution therefore have to be added to the damages and costs from wood burning in this publication. Likewise, burning of waste (including garden and agricultural waste) can cause significant soil pollution containing tar substances and heavy metals.

▼ Straw-fired boilers are in reality agricultural waste burning.
▼▼ Burning of agricultural waste can be seen over long distances.
▼ Burning of wet garden waste as a primitive bonfire.
▼▼ Burning of household waste in Norway.

NEW CHALLENGES

Primitive or modern fire rings in private gardens or institutions along with wood burning in outdoor stoves and pizza ovens for private citizens are new growing trends. None of these wood burning appliances are included in the Danish environmental regulation. Hence, these appliances can pollute without any limits.


Brønshøj-HusumAvis 2. SEKTION

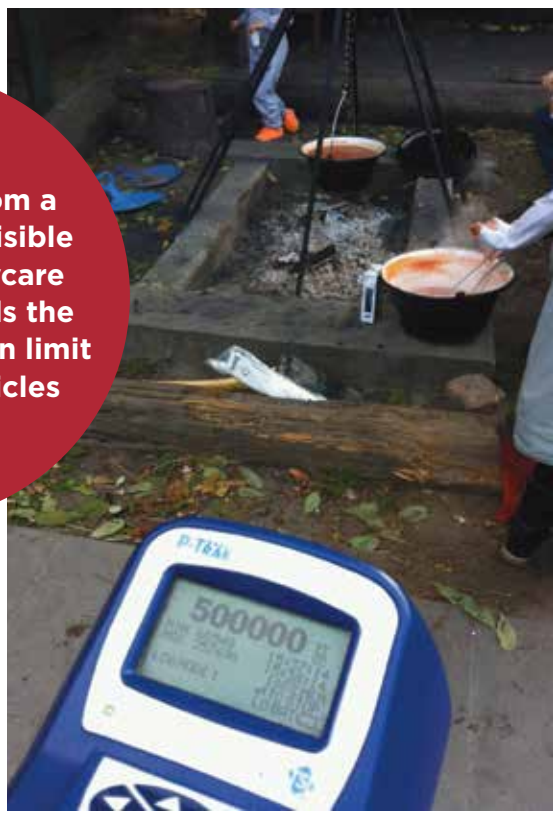
Grill, bål og hygge i haven

Modern fire rings are presented as cosy elements in the garden without mentioning the associated air pollution. (Article text: A cosy time in the garden with fire).

In Danish cities millions of euros are used every year to replace slightly polluted soil with clean soil before establishing daycare institutions. Afterwards, the "creative" staff often decides to make a fire ring for fun and cooking, which then causes massive soil pollution with tar substances and fills up the institution with potentially carcinogenic smoke.

Modern fire rings, outdoor stoves and private pizza ovens are marketed under the pretext of a cosy garden atmosphere. The associated air pollution is not mentioned anywhere in the advertisements. That is despite the fact that the smoke is emitted at inhalation altitude at times where families often stay nearby breathing in extensive amounts of harmful smoke. Preparation of food on a gas barbecue is more environmentally friendly; just as it is easier to stabilize the preferred temperature and thereby achieve successful cooking. Additionally, a warm sweater or a blanket can keep you warm on a cold night without causing air pollution or having wood expenses.

The pollution from a bonfire without visible smoke at the daycare institution exceeds the maximum detection limit of 500,000 particles per cm^3.



HEALTH DAMAGES

Morbidity and mortality caused by air pollution are mainly calculated from the concentration of fine particles and ground level ozone where fine particles by far cause the majority of health damages. However, this does not mean that other types of pollution are not harmful. By contrast, recent research indicates that soot particles are substantially better indicators of health damages than fine particles, since soot particles seem to be markedly more harmful than fine particles in general. As there are no detailed measurements of ultrafine soot particles from wood burning, and the number of soot particles varies significantly from one location to another, it is not possible to estimate how many soot particles various population groups are exposed to and thereby it is not possible to identify the associated health damages. The contribution to health damages from tar compounds, dioxin and heavy metals, however, is included indirectly when health damages are calculated based on pollution with fine particles, since the substances adsorb to the surface of the particles, thereby increasing the general toxicity of these particles.

Most deaths related to air pollution with fine particles happen due to higher occurrence of cardiovascular diseases caused by long-term exposure. Most diseases, by contrast, are related to the respiratory system - asthma, bronchitis and COPD ("smoker lungs"), etc. that are also associated with short-term exposure to air pollution.

Table 3 shows health damages in Denmark and Europe related to pollution with fine particles from wood burning in Denmark. Since the fine particles have a long lifetime much of the particle pollution is carried by the wind to other more densely populated areas of Europe exposing foreigners to Danish pollution (although diluted) - just as Danes are exposed to pollution from abroad. However, the table does not take into consideration that soot particles from wood burning are probably more harmful than inorganic particles; if this is taken into account health damages become worse than shown in table 3.

Half of all premature deaths connected to Danish pollution sources are caused by wood burning.

Table 3: Health damages due to fine particles from Danish wood burning

	Denmark	Europe
Premature deaths	550	1,000
Lost life years	5,500	10,000
Respiratory diseases	330,000	600,000
Sick days	530,000	950,000

Source: Estimated by DCE, University of Aarhus, 2016.
All fine particles are assumed equally harmful.
Cases in Europe include cases in Denmark.

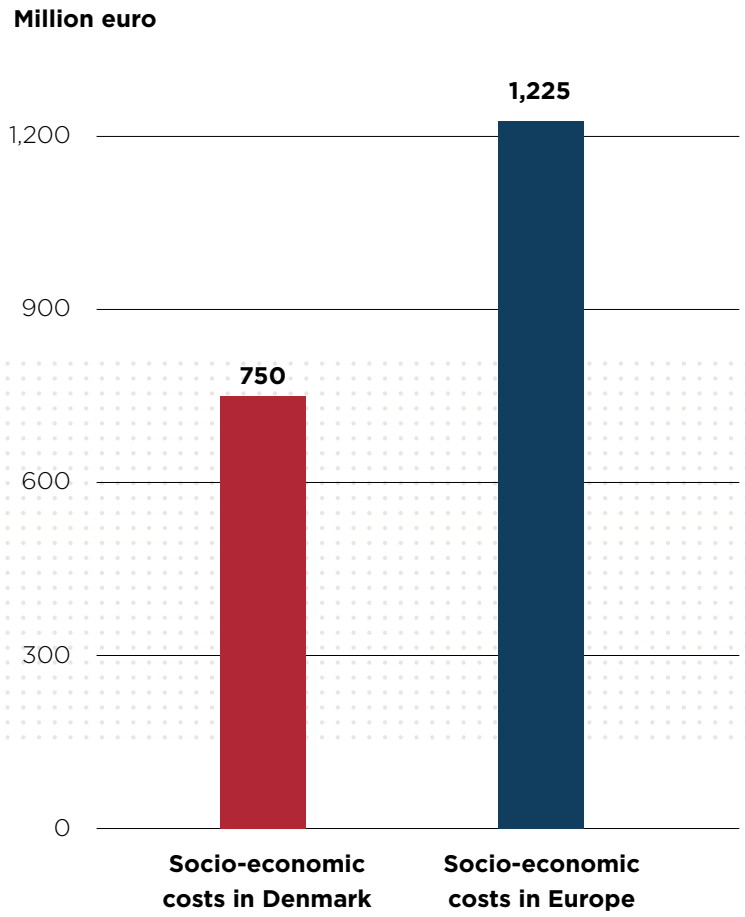


Figure 10: Costs related to particle pollution from Danish wood burning

Source: Estimated from DCE, University of Aarhus, 2016.
Costs in Europe include costs in Denmark. It is assumed that all particles are equally harmful.

Figure 10 shows socio-economic costs related to air pollution from Danish wood burning under the assumption that all particles are equally health hazardous. Thereby, pollution from wood burning causes around 50% of the total costs associated with air pollution from pollution sources in Denmark; wood burning is thus the most expensive environmental problem.

The calculation of health damages does not include damages from secondary organic particles and ultrafine particles from wood burning - neither does it include the soot content that probably makes particles from wood burning particularly harmful. Furthermore, health damages from indoor pollution are not included in the calculation, and high local concentrations in residential areas are not considered (it is assumed that pollution from each chimney is immediately diluted in a large air volume). Finally, some very serious diseases have not been included in the calculation of health damages, for instance low birth weight and low IQ among children, reduced lung function among children, strokes, diabetes, etc. The calculated health damages and associated socio-economic costs in figure 10 related to air pollution from Danish wood burning are thereby underestimated.

Recent studies from the US, Canada and Australia document health damages of long-term exposure to smoke from wood burning in low concentrations. Danish short-term studies (a few hours of exposure to wood smoke) have not documented serious acute effects on healthy trial subjects. However, all health damages in this section are based on long-term exposure to low concentrations. Some recent studies indicate that particles from wood burning are less harmful than diesel particles. But since all modern diesel vehicles today are equipped with effective particle filters removing more than 99% of particles, pollution with diesel particles will be almost eliminated in five to seven years.

In Copenhagen one hour of burning in an older stove costs 5.5 EUR in air pollution health damages according to the Danish national Economic Council

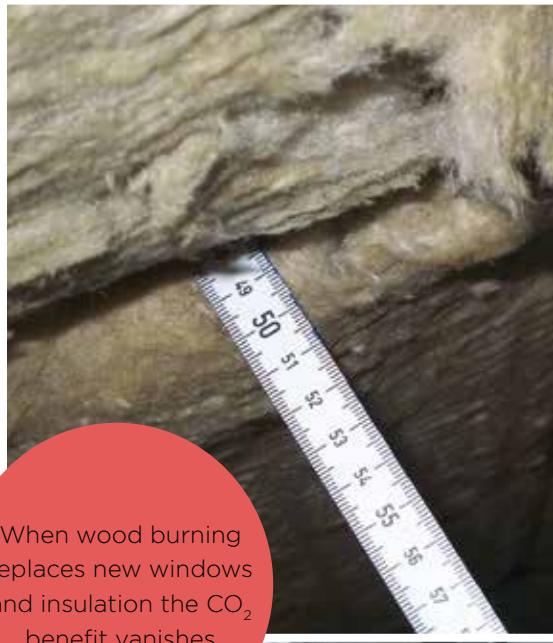
CLIMATE IMPACT

Wood burning is defined as carbon neutral because trees accumulate the same amount of CO_2 throughout their lifetime as the amount released when wood is burned. In other words, assuming that the level of reforestation is adequate and that wood burning is slower than growth of new trees, wood burning does not lead to net increasing CO_2 levels in the atmosphere. In countries like Denmark the forest ratio is increasing and political targets have been adopted to increase this ratio continuously. Thereby, from a purely national viewpoint it can be claimed that wood burning in Denmark is carbon neutral. However, the equation is not that simple. We also import wood, some wood is oven-dried, and most firewood is transported consuming fossil fuel (diesel). Also, we may consider forests, forest floors and trees as a solid permanent carbon sink that should not be used, thus releasing CO_2. Nevertheless, in this publication wood burning is considered as carbon neutral although this can be questioned and is not necessarily correct.

In Denmark approximately 25,000,000 GJ of firewood is burned every year. If we assume that all wood substitutes oil, we attain a total CO_2 reduction of around 1.8 million tonnes of CO_2. However, much wood burning is merely done to create a cosy atmosphere; thereby it does not necessarily substitute other energy sources. Furthermore, much wood burning takes place in areas supplied with gas and district heating, making CO_2 reductions significantly lower than if substituting oil.

More than half of all Danish homes have district heating. Most district heating is already CO_2 neutral or will become so soon, which implies that there will be no CO_2 gain from wood burning in district heating areas. Further, to limit wood burning in areas with district heating the tax structure on district heating is constructed in a way that it does not motivate to install insulation. Finally, wood burning replaces insulation and other energy renovation alternatives, as cheap wood burning makes many basic energy optimisation measures of houses unprofitable. It is therefore doubtful whether wood burning causes any CO_2 reductions at all or whether it may even increase Denmark's CO_2 emissions.

All Danish power plants will be CO_2-neutral within the next 15-20 years eliminating any CO_2 benefits from wood burning. At the same time there will be a need for wood as a fuel in the power plants, so the import of biomass is limited, as imported biomass (in particular wood pellets) is not always produced in a sustainable manner. Burning of firewood at power plants in the future energy system combined with heat pumps more than double the energy benefit compared with burning the same quantity of wood in private wood stoves.



When wood burning replaces new windows and insulation the CO_2 benefit vanishes

Even if all firewood is assumed to substitute fuel oil the global warming from soot particles from wood burning would eliminate the CO_2 benefit.

Climate accounting

Nevertheless, if we assume that all wood burning substitutes oil and gives a CO_2 benefit of 1.8 million tonnes of CO_2, we still need to deduct the contribution to global warming from soot particles from wood burning (cf. page 5). According to recent surveys, soot particles *(black carbon)* have a GWP (Global Warming Potential) of 3,200 CO_2 equivalents (over 20 years) and 900 CO_2 equivalents (over 100 years). The relevant time horizon depends on the time we have to mitigate man-made climate change. If we are to meet the current objectives of a temperature increase of no more than 2 degrees and avoid serious and irreversible damages, so-called tipping points, a 20-year time horizon is most relevant. Projections made by the UN show that only by both reducing emissions of soot particles and greenhouse gases we can attain that objective. However, making a calculation for a 20-year time horizon including emission of soot particles from wood burning, it is clear that firewood burning cannot even compete with an oil-fired boiler when seen in a climate perspective, although it is taken into consideration that organic particles from wood burning has a cooling effect and that oil-fired boilers emit both CO_2 and small amounts of soot. Compared to district heating, heat pumps and gas the climate accounts for wood burning are worse. Therefore, 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. For creating a cosy atmosphere electrical fireplaces and gas stoves can be used, which hardly pollute compared to traditional stoves. Power plants can benefit by burning wood as they emit a minimum of pollution.

Ignoring this fact, the entire industry (firewood sellers, stove manufacturers, chimney sweepers) keep on praising wood burning as carbon neutral heating in their marketing, on websites, etc. They do not mention that soot particles from wood burning (in addition to the health hazard) significantly contribute to global warming and thus more than eliminate the CO_2 benefit from firewood. Wood burning may be partly carbon neutral, but not *climate* neutral - and definitely not environmentally friendly.

Expensive CO_2 reduction

A simple CO_2 calculation where only issues that benefit wood burning are included (assume that all wood burning replaces oil and ignoring soot particles from wood burning), wood burning would then give a maximum CO_2 benefit of 1.8 million tonnes of CO_2. But health damages from the pollution with fine particles from wood burning alone amount to 1,225 million euro annually (figure 10). Thereby, reduction costs are almost 700 euro per tonne of avoided CO_2 (to this should be added costs of wood). This would make wood burning an extremely expensive way of reducing CO_2 emissions. In comparison, it should be mentioned that many reduction measures in other sectors cost society less than 70 euro per tonne CO_2.

TECHNICAL SOLUTIONS

Air pollution from wood burning may be reduced substantially through a large number of technical measures. Below, the most effective measures are described in prioritised order with the most important first. The conclusion is that air pollution from wood burning can be reduced by more than 98% through energy renovation and environmentally friendly heat sources as well as particle filters, while the pollution can probably be halved by replacing old stoves and boilers combined with information campaigns.

A gas stove or an electric fire place gives exactly the same cosy atmosphere, but without health hazardous air pollution

1) Energy renovation
The soundest measure in terms of environment and energy is to minimise the heat consumption of houses by installing new windows, insulation, etc. Once the house has been insulated the use of wood burning as supplementary heat source is unnecessary. At the same time, heat from the primary heat source is saved, the indoor climate is improved and the value of the house increases. No matter if wood burning is a supplementary heat source (wood stoves) or the primary heat source (wood boilers) energy renovation will effectively reduce the amount of wood burned and the connected air pollution.

2) Environmentally friendly heat
Health hazardous particle pollution from new eco-labelled wood stoves under optimal firing is typically 100 times higher than the pollution from district heating and gas (figure 2). Older wood stoves or incorrect stove operation may pollute 500 times more than district heating and gas. The pollution from modern wood boilers under optimal firing is typically 200 times higher than pollution from heat pumps and 7 times higher than that of wood pellet boilers. Old wood boilers typically pollute 500-1,000 times more than heat pumps. So it is possible to attain high environmental benefits if wood burning is replaced by environmentally friendly heat sources. The most eco-friendly solution is renewable energy: geothermal energy, solar heat, biogas, etc. This is followed by biomass based district heating from combined heat and power plants as well as surplus heat from industry, etc. in cities and heat pumps in combination with solar energy in rural areas.

A cosy atmosphere can be obtained by electrical fireplaces or wood stoves burning gas instead of wood. These are widespread in the US and are also gaining ground in European restaurants, hotels, etc. The cosy atmosphere is exactly the same but without the health hazardous air pollution of indoor and outdoor air (cf. p. 13 and 17).

3) Flue gas cleaning
Only a few studies on filters for small residential heating appliances exist and many filters are still only at an experimental level. The newest (summer 2016) investigation by Ellen Marie Drastrup from DTU Environment as part of her master thesis at the Technical University of Denmark shows, that some filters (developed by Tonny Sander Holm and PHX Innovation) have high (85-99%) removal rates for soot particles, fine particles and ultrafine particles. The challenge is to lower the filter price and develop an automatic regeneration of the filters. Through taxation people can be motivated to retrofit filters on chimneys (see page 29).

4) Good stoves and boilers
The health hazardous particle pollution from eco-labelled modern wood stoves and boilers connected to a good new chimney will under optimal conditions be less than half that of older units - and up to 80% lower than the pollution from very old units. Thereby, a significant environmental benefit can be gained from the replacement of old units with modern ones. But the replacement of old units takes place at a very slow rate; stoves often have a lifetime above 30 years. Furthermore, the pollution from new stoves is, however, still much higher than the pollution from cleaner heat sources and some studies suggests that new stoves may emit fewer organic particles (cooling effect) but the same amount of soot particles (warming effect), thereby, contributing more to global warming than older stoves (cf. page 24).

5) Optimal stove operation
Optimal stove operation is kindling from the top of a tower of carefully stacked, dry wood in small pieces under high air supply followed by using small pieces of dry wood under high air supply. This can reduce particle pollution by more than a factor 10 compared with incorrect operation i.e. using wet wood in large pieces and low air supply. However, new German studies show that there is no particle reduction just by kindling from the top and that the amount of harmful soot particles can increase up to 400% when using really dry wood (humidity of 5%). That makes it difficult to give recommendations for optimal operation. Since there is no control of wood burning inside people's living rooms it must be assumed that most people use their wood stove in the easiest way, and that is hardly the optimal stove management.
For instance, it is easier to place a large log of wood in the stove at bedtime, turn down the air supply and have the fire smoulder releasing heat throughout the night than it is to add small pieces of wood every half hour all night. Campaigns for optimal stove management without a subsequent control will probably only give a limited effect on pollution from wood burning. Finally, even optimal operation in a new eco-labelled wood stove will cause serious pollution with ultrafine particles (cf. pp. 8-10).

A typical modern eco-labelled wood stove pollutes less than half as much as an old wood stove but still more than 100 times as much as district heating and gas.

EXISTING REGULATION

Transboundary air pollution must be regulated internationally and reduced locally

Air pollution from wood burning is indirectly regulated through UN protocols and EU directives and directly in Denmark by the Danish Statutory Order on wood stoves. The new EU NEC directive is expected to lead to a significant reduction of air pollution from wood burning in some member states (but not in Denmark). On the other hand, EU's Ecodesign directive may limit national opportunities for reducing air pollution from wood burning in Denmark and Germany.

Stockholm Convention

Denmark has signed the Stockholm Convention and is thereby under the obligation to reduce emissions of persistent organic pollutants. The Convention entered into force in 2004. Denmark is thereby committed to reduce dioxin emissions. Since 2004, however, we have seen no significant reductions of Danish emissions of dioxins, as dioxin pollution from wood burning has increased and has outweighed reductions in other sectors. Wood burning dominates Danish dioxin emissions (cf. p. 6). Hence, Denmark does not meet its obligations under the Stockholm Convention as dioxin pollution could have been brought down significantly by replacing wood burning with insulation and environmentally friendly heat sources (cf. p. 25-26). However, politicians have not taken the decisions needed to implement these solutions to a sufficient degree (see p. 29-30).

Gothenburg Protocol

According to the Gothenburg Protocol from 2012, Denmark must reduce emissions of fine particles with 33% by 2020 compared with the emission level in 2005. Special focus should be given to the reduction of soot particle emissions. Danish particle emissions have already decreased more than 33% since 2005, which clearly shows how unambitious the targets in the Gothenburg Protocol are. Denmark already fulfils the protocol which will therefore not lead to further reductions.

National Emission Ceilings directive

EU has implemented the 2020 target of the Gothenburg Protocol through the new National Emission Ceilings directive (NEC directive) i.e. according to the NEC directive Denmark must reduce emissions of fine particles with 33% by 2020. In addition, the EU NEC directive further requires a 53% reduction by 2030 compared to the 2005 emission level. All other things being equal, these reductions will happen without taking further initiatives in Denmark and, again, illustrate how unambitious the Danish NEC directive targets are. However, the NEC directive will lead to reductions in some member states.

Ecodesign directive

EU's Ecodesign directive sets requirements for energy consumption and adverse emissions from products on the EU market. The Ecodesign directive introduces emission requirements for i.a. wood stoves and boilers. The directive requirements are however so moderate that they are already fulfilled by almost all existing units available on the Danish market. As the Ecodesign directive is also a total harmonisation directive the directive requirements imply that member states (including Denmark) cannot adopt more stringent requirements for firing units in national legislation. The directive can thereby be a direct barrier to national requirements for cleaner wood burning units.

Air quality directive
Air quality limit values for fine particles and tar compounds in EU's Air Quality Directive are of relevance to wood burning. However, these limit values are based on annual averages and are probably not exceeded in residential areas since wood burning mainly takes place in the winter; the high winter concentrations are outweighed by the low summer concentrations in the calculation of annual averages. If EU introduces the limit value for particle pollution as proposed by the World Health Organization (10 micrograms of fine particles per m^3) this limit value would be exceeded on an annual basis in most residential areas with wood burning.

Statutory Order on wood stoves
The Danish Statutory Order on wood stoves sets up a framework for the sale, transfer and connection of wood stoves and boilers and imposes the overall framework of local authorities to regulate air pollution from wood burning.

The appendix to the Statutory Order gives emission limits that stoves and boilers must comply with when sold, transferred and connected. However, the limit values are so weak that also old units comply with the requirements and can thereby be re-sold; this means that the requirements have limited effect. At the same time there are many exemptions to the provisions, such as existing installations and straw boilers, outdoor stoves, fireplaces, etc.

The Danish Environmental Protection Agency has submitted a new order with more strict requirements to restrain the re-sale of old stoves and boilers. This, however, does not solve the problem since the life time of these units is very long (often more than 30 years). Hence, the Danish Environmental Protection Agency expects that the order will only reduce pollution by approximately 2%.

Furthermore, the order states that local authorities can set requirements for higher chimneys, reduced use of units under specific weather conditions, fuel quality, operational requirements, etc. in pursuance of section 42 of the Danish Environmental Protection Act, i.e. only if units cause "unhygienic conditions or significant pollution". In real-life, however, the regulation entails a number of challenges. First of all, many local authorities request that the person annoyed by wood smoke first approaches the polluter. For that reason many cases fall flat since many Danes do not wish to face their neighbour in this way. In addition, it is not always possible to determine the source of the smoke at night or in windy conditions. Furthermore, the local authority must make a concrete assessment legally documenting a "significant pollution", which is naturally difficult. Especially because wood burning very often takes place outside the opening hours of the administration. For example, a complaint is made on Saturday night at 9.30 p.m. and the authority makes a supervisory visit the following Tuesday at 1 p.m. at which time the stove is not in use. However, a court ruling based on a case from the Municipality of Guldborgsund in Denmark states that visible smoke (documented by pictures) and smell of smoke document "a significant pollution" as the smoke contains health hazardous substances.

A court ruling from 2012 states that visible smoke and smell of smoke by itself documents "significant pollution" from wood burning and makes it possible to issue an enforcement notice due to the content of health hazardous substances in the smoke.

NATIONAL SOLUTIONS

Table 4: Danish taxes on heat sources

	Wood	Electricity	Heat pump	Oil	Gas	District heating
Taxes per year for heating (euro)	0	1,400	400	550	550	775 (max)
Taxes incl. VAT (euro per GJ)	0	22	22	8.5	8.5	12 (max)
Pollution (g particles per GJ)	155-930	1.5	0.5-1	5	0.1	1.5

Taxes incl. VAT on different heat sources (2016). For district heating the maximum taxation is shown.
Source: PricewaterhouseCoopers, 2013 and the Danish Ministry of Taxation, 2016

Air pollution from wood burning can only be reduced if national politicians take decisions to promote implementation of technical solutions (cf. p. 25) and discourage the use of wood stoves in areas supplied with gas and district heating. Below, some of the most efficient national policy instruments are described. It is estimated that taxes will reduce pollution from wood burning by 80 - 100% depending on the magnitude and design of taxation. Bans against wood burning without effective filters in cities supplied with district heating and gas can reduce pollution from local sources in residential areas with more than 90%, but will reduce nationwide pollution from wood burning with less than 40%. A mandatory replacement can halve pollution from wood burning, while a scrapping payment is inefficient from an economic point of view and will typically have no effect.

Taxes

Wood burning is the most health hazardous heat source and thereby the most expensive environmental problem in Denmark. And yet, wood burning is exempted from environment and energy taxes by contrast to more environmentally friendly heat sources (table 4). The firewood consumption in Denmark has tripled over the last 30 years, because increasing taxes on other heat sources have made wood burning more and more economically attractive.

In table 4 Danish taxes on different heat sources are shown. It is clearly seen that wood burning is economically favourable and appears as an economically attractive heat source. This is a barrier to energy savings (insulation, etc.) and environmentally friendly heat sources that, from a technical point, can replace wood burning and thereby eliminate the associated air pollution. Also, there are no direct economic incentives for replacing old stoves and boilers and thereby reducing the pollution. By aligning taxes on wood burning to other heat sources and by directly imposing taxes on particle pollution from wood burning corresponding to the associated health costs, the following incentives would be created:

1) Energy savings (insulation, etc.) of houses with wood burning.
2) Use of environmentally friendly heat sources instead of wood burning.
3) Change to new and less polluting wood burning units or installing filters.

Taxes may be designed in a relatively simple manner since the energy consumption and pollution of the stoves and boilers depend exclusively on the power of the units (kW), the hours of operation as well as the pollution per hour of operation. The power and pollution of the units can be registered from the manufacturing data (type of unit).

It is simple to register the number of operating hours with a small temperature meter with a temperature sensor sealed in the chimney. The meter registers and saves only the number of hours during which the temperature in the chimney exceeds a limit of, for instance, 60°C which only occurs when the unit is in use. It would be an advantage to use a remote meter reader to reduce costs for reading and control and to minimise cheating opportunities. Alternatively, the meter may be read and reported once a year by the resident (as many people know it from water and heat meters), and the meter may then be controlled and reported by the chimney sweeper during the existing yearly mandatory chimney inspection. According to the Danish technology company C.B. Svendsen such a meter can be manufactured for more or less the same price as an electricity meter. The principle would be similar to the principle many people know from payment after use of electricity, heating, gas and water. The Danish Economic Council has in 2016 made a detailed report showing that taxation of wood burning using this method is the socio-economically most optimal and can save several hundred Danish lives as well as around 500 million euro a year.

Bans

In cities supplied with district heating and gas a national ban on wood burning could be introduced, i.e. a type of low-emission zone ensuring clean air in the residential areas. Alternatively, local authorities could be given the opportunity to introduce a ban on wood burning if desired by a majority of the local council. The first solution would have the fastest and largest impact, as wood burning would be banned in more than 75% of Danish homes. This solution would, as well, be the easiest to administer. But the pollution from wood burning would be reduced by less than 40% as the ban would cover the part of homes that burn the smallest amount of wood. However, the ban would lead to a significant reduction of air pollution with particles, tar compounds and dioxin in the vulnerable residential areas with a high population density and thereby a significant reduction of the large health damages. According to DCE at the University of Aarhus, and as an example, the diminutive amount of only 16-17,000 existing wood stoves in Copenhagen emit as many fine particles in a winter season as all road traffic in Copenhagen emits in a whole year; despite the fact that the wood consumption per stove in Copenhagen is much lower than the average use in Danish stoves.

Mandatory replacement

It could be made a requirement that all wood stoves and boilers produced before a certain year should be replaced by modern units (or units documenting emissions below a certain level e.g. by installing filters) - or that the replacement only applies to units in cities. A regulation similar to this has been adopted in Germany. National requirements secure the greatest impact and would, all other things being equal, halve the pollution.

Scrap payment

Experience from a previous scrapping system for wood boilers shows that mainly homes that are anyhow envisaging a replacement are the ones scrapping their unit. Thereby, a scrapping system is very expensive per kilogram of avoided pollution, since people that would replace their unit anyhow receive scrapping payment. Also, citizens not using their units can scrap it just to get the payment. Finally, a scrapping system will often only accelerate the replacement by one-two years, since the scrapped units would have been replaced anyway one-two years later. A scrapping system therefore has a very limited impact. If a scrapping premium is introduced it should not be paid by tax payers but through a tax on wood burning. If it were to be paid by the tax payers this would be a “pay the polluter” principle. The taxes suggested (see above) by contrast, would introduce a sound “polluter pays principle”. Nonetheless, in the fall 2015 the Danish government chose to implement a scrap payment for old wood stoves financed by tax payers. Now, a year later it is obvious that the scrap payment has been almost without any impact and has only left the tax payers 5.5 million euro poorer.

LOCAL SOLUTIONS

So far no national decisions have been made to reduce air pollution from wood burning in Denmark. But much can be done at a local level in the cities and in the homeowner associations e.g. making local campaigns and implementation of all actions of the Statutory Order on wood stoves by municipalities (cf. p. 28). Local solutions are important since reductions must take place in local residential areas.

Campaigns: Smoke-free residential areas

Many Danes do not know that wood burning is the most health hazardous heat source since wood burning is often branded as an environmentally friendly solution by industry, dealers and chimney sweepers (see p. 33). Therefore, local authorities should carry out information campaigns in areas supplied with district heating and gas. Such campaigns should focus on local air pollution from wood burning and associated health damages. Campaigns should point out that local wood burning have an adverse impact on local air quality – both outdoor and indoor – and thereby the health of the local population. Such a campaign may be called: *Smoke-free residential areas.*

The campaign should include heat savings and district heating/gas/heat pump as environmentally friendly alternatives to the pollution from wood burning. Also, electrical fireplaces or *wood stoves* burning gas to create a cosy atmosphere (cf. p. 25) should be presented. By combining information about harmful wood burning with information about environmentally friendly alternatives the platform of the campaign is created.

The homeowner associations of the municipality and health associations (such as Asthma Association and/or Cancer Society) should be informed about the campaign as early as possible with an invitation to participate in the campaign. The campaign could be launched by an extensive information meeting for all board members in the homeowner associations of the municipality. In addition to presenting the details of the campaign, local energy-saving companies could be invited to inform about profitable heat savings and heat pumps while the district heating and gas companies could inform about environmentally friendly heat sources. A dealer of electrical fireplaces and gas stoves could inform about cosy atmosphere without causing health hazardous air pollution, and local banks could inform about their financing options for investment in heat savings. Thereby, a solid foundation would be created for the campaign and the homeowner associations may in this way become active players to create clean air in their residential areas (and thereby the municipality). This would push more homeowner associations to follow suit. As a follow-up, the local authority could organise similar citizens' meetings for house owners.

Information meetings with homeowners are an important local instrument.

Such a campaign can be carried out almost without a budget and be communicated in the local papers just before and during the heating season. The campaign can start with articles about local pollution from wood burning and environmentally friendly alternatives followed by information about indoor climate pollution from wood burning and measurements of air pollution from wood burning in the municipality - both in residential areas, from chimneys and indoors. Another possibility is to make a local competition about taking a picture of the most polluting chimney in the municipality. Finally, homeowner associations could be encouraged to make a principle decision about not using wood burning in their district after which they could be labelled as a "smoke-free residential area" and be presented in the local papers. The local papers could also follow families carrying out insulation or buying an electric fireplace or wood stove burning gas as an alternative to wood burning. This will give the campaign a local focus, which by itself works in an inspiring and committing way. The entire campaign should focus on the benefits of smoke-free, healthy residential areas, not on pointing fingers at people using wood burning.

Efficient regulation

Many Danish municipalities have a number of opportunities of using the Statutory Order on wood stoves (cf. p. 28) much more than they do today. This can be cunningly done in connection with the campaign *Smoke-free residential* areas as described above since the campaign will legitimate a much more strict regulation.

As a first thing, Danish municipalities should exploit the options of the Statutory Order on wood stoves, for instance by introducing bans on overnight burning, burning waste and wet wood, etc. In addition, local authorities should post a standardised complaint letter on their webpage that may be filled in and sent so citizens do not need to contact the household causing the pollution. The local authority should encourage annoyed citizens to take dated pictures of the smoke, since visible, dark smoke will be sufficient, all other things being equal, for submitting an enforcement notice under the Statutory Order on wood burning stoves (cf. p. 28). Finally, local authorities should pay supervisory visits at relevant times in relation to wood burning and submit enforcement notices in case of smell of smoke (cf. the Guldborgsund case described on p. 28) - or acquire a particle counter that can measure (count) ultrafine smoke particles and make measurements to document a "significant pollution" from wood burning.

It is important to document "significant pollution" as the basis for an enforcement notice.

MYTHS AND YARNS

There are many myths about wood burning in the public debate. Here, the most frequent myths are discussed in detail.

”WOOD BURNING IS ENVIRONMENTALLY FRIENDLY”

The stove industry and dealers as well as chimney sweepers often claim in their marketing that wood burning is environmentally friendly. In an advertisement brought in the Danish magazine Mediaplanet in November 2013 the stove industry claims that the use of wood stoves is “a cheap and environmentally friendly heating method”. As mentioned, pollution from wood burning is the largest and most expensive environmental problem in Denmark (cf. p. 3). Air pollution from wood burning accounts for more than half of the Danish emissions of particles, soot, tar compounds and dioxins (cf. p. 5-6) - despite the fact that wood burning only covers around 3% of Denmark’s energy consumption - and pollution from wood burning (by contrast to power plants) takes place in low altitude in densely populated residential areas and inside houses. Thereby, it is a myth that wood burning is environmentally friendly.

”MODERN WOOD STOVES DO NOT POLLUTE”

It is often said in the public debate that modern eco-labelled wood stoves hardly cause any pollution if fired optimally since they have low particle emissions (e.g. at the homepage of the Danish stove industry). New eco-labelled wood stoves emit approximately 155 grams of particles per GJ under optimal test conditions in laboratories. By comparison, district heating and heat pumps emit less than 1.3 grams of particles per GJ (incl. particles from power plants), gas emits less than 0.1 grams of particles per GJ, while oil burners emit approximately 5 grams of particles per GJ (cf. p. 7). In measurements of ultrafine particles in the chimney exhaust of a modern eco-labelled wood stove under ideal operational conditions a higher pollution level than the measurement limit of the equipment was measured (cf. p. 8-10). It is therefore a myth that eco-labelled wood stoves under optimal firing conditions do not pollute.

”WOOD BURNING IS CARBON NEUTRAL”

Wood burning is often branded as carbon neutral and thereby a good heat source when it comes to limiting global warming (e.g. on the website of the Danish stove industry). However, cheap wood burning often replaces insulation, and to avoid increasing wood burning the tax structure on district heating limits the incentive for heat savings. Thereby, cheap wood burning indirectly contributes to higher emissions of CO_2 (cf. p. 23). In addition, the substantial contribution to global warming from soot particles from wood burning is often neglected. This will eliminate any CO_2 benefits from wood burning (cf. p. 24). Even if wood burning is defined as carbon neutral (under certain conditions) it is certainly not a good heat source when it comes to limiting global warming. At the same time, the fast phasing-in of renewable energy at power plants means that alternatives to wood burning in many situations will soon be carbon neutral.

”LESS HARMFUL THAN DIESEL FUMES”

It is often claimed in the public debate that particles from wood burning are less harmful than diesel particles. Several studies confirm that this is true for acute health damages. But most deaths and diseases related to particle pollution from wood burning are caused by long-term exposure (chronic exposure) to particle pollution and there is no evidence that particles from wood burning are less harmful than particles from diesel fumes. This fact is completely ignored in the public debate. Finally, it is also ignored that the alternative to wood burning is not diesel, but district heating, gas or heat pumps.

RECOMMENDATIONS

The air quality in the EU can only be improved significantly if serious efforts are made to limit air pollution from residential burning in small stoves and boilers.

FOR THE EUROPEAN COMMISSION

The Danish Ecological Council recommends that the Commission:

1) Introduces much stricter particle emission limit values including particle number limits for stoves and boilers and a much better measurement procedure for stoves and boilers in the next revision of the Ecodesign directive and allows countries to have stricter national limits.

2) Harmonises particle measurements from stoves and boilers by methods that include condensates (smoke temperature 25-30 °C) per energy unit (joule) or per standard fuel unit (kg dry wood).

3) Implements the WHO limit value of 10 µg $PM_{2.5}$ per m^3 (annual average) and 25 µg $PM_{2.5}$ per m^3 (daily mean) in the next revision of the Air Quality Directive and a three months limit value for both PAH's and $PM_{2.5}$.

FOR THE NATIONAL GOVERNMENT

The Danish Ecological Council recommends that governments:

1) Support strict emission limits in the Ecodesign directive and much stricter air quality limits in the Air Quality Directive under next revisions.

2) Adopt ambitious measures to address PM and BC emissions from wood burning when developing the NEC directive's National Air Pollution Control Programmes" .

3) Introduce taxes on wood burning according to particle pollution as described above.

4) Introduce ban on wood burning in cities with collective supply of district heating or gas.

5) Allocate funds for actions in municipalities wishing to test various initiatives for reducing air pollution from wood burning.

6) Ask the relevant agencies to include climate impacts from soot particles in their statistics and other public documents on global warming.

7) Launch measurements of ultrafine particles and soot particles in residential areas.

FOR LOCAL AUTHORITIES

The Danish Ecological Council recommends that municipalities:

1) Carry out the described campaign: "Smoke-free residential areas" in cooperation with homeowner associations and the national Asthma Association or Cancer Society.

FOR HOMEOWNER ASSOCIATIONS

The Danish Ecological Council recommends that homeowner associations:

1) Inform locally about air pollution from wood burning and about how wood burning deteriorates the local air quality in their residential areas.

2) Make a principle decision (even if it may not be enforceable) that wood burning is not used in their area.

FURTHER INFORMATION

Links
Clean Heat project page: www.clean-heat.eu

Project partners
Deutsche Umwelthilfe: www.duh.de
Ecological Council: www.ecocouncil.dk
European Environmental Bureau: www.eeb.org

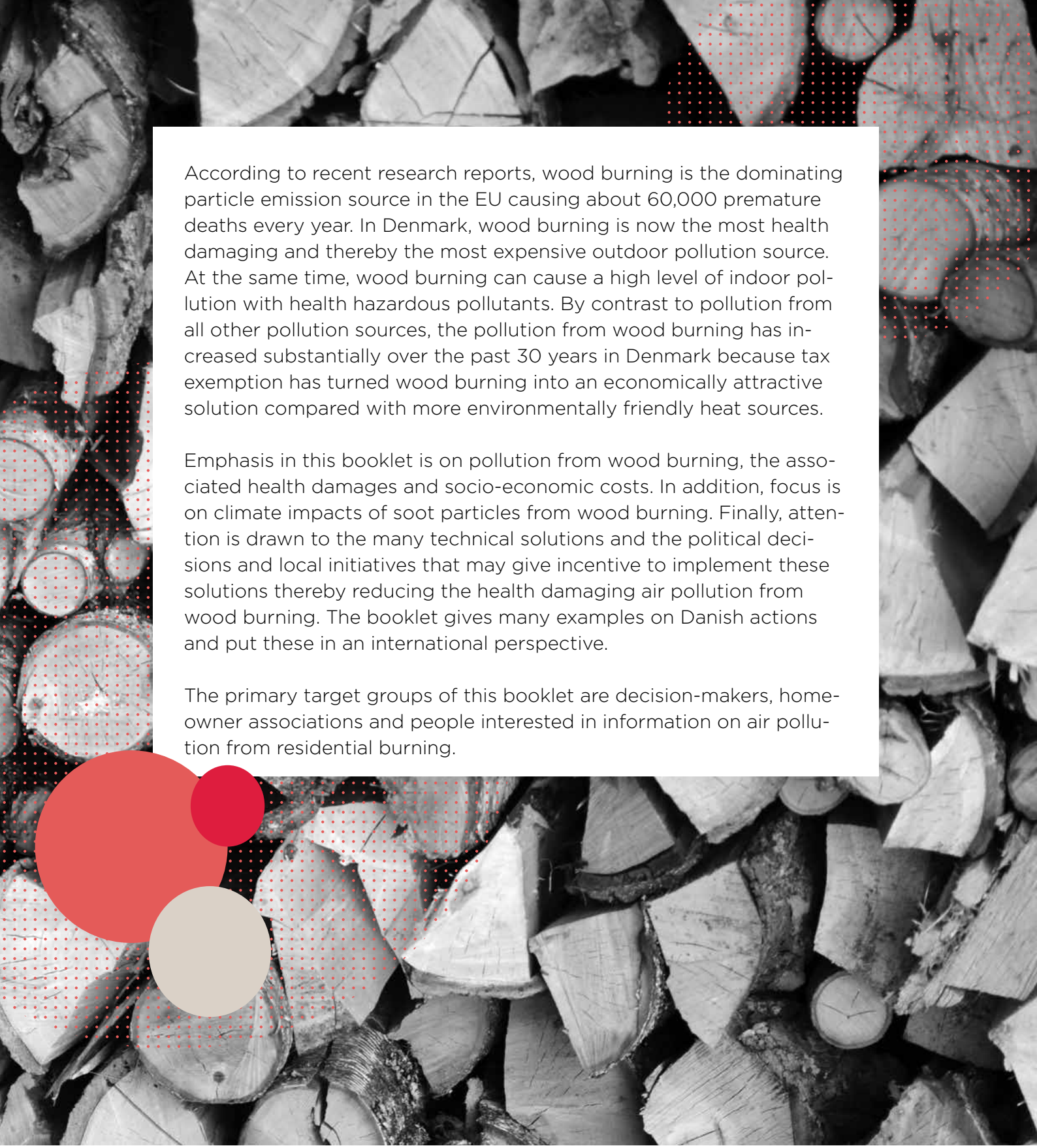
Models
International Institute for Applied Systems Analysis, Greenhouse Gas - Air Pollution Interactions and Synergies (GAINS model): http://gains.iiasa.ac.at/models/

Literature
World Health Organisation, 2015:
Residential heating with wood and coal
http://www.euro.who.int/__data/assets/pdf_file/0009/271836/ResidentialHeatingWoodCoalHealthImpacts.pdf

University of Aarhus, 2014:
Annual Danish informative inventory report to UNECE
http://dce2.au.dk/pub/SR183.pdf

Danish Statutory Order on wood burning stoves:
http://eng.mst.dk/media/131065/statutory-order-on-wood-stoves-2015.pdf

Many people do not know that they create health damaging pollution by residential burning – even if they have a new eco-labelled stove operating under optimal conditions. Information about air pollution from residential burning is the way to cleaner air.



According to recent research reports, wood burning is the dominating particle emission source in the EU causing about 60,000 premature deaths every year. In Denmark, wood burning is now the most health damaging and thereby the most expensive outdoor pollution source. At the same time, wood burning can cause a high level of indoor pollution with health hazardous pollutants. By contrast to pollution from all other pollution sources, the pollution from wood burning has increased substantially over the past 30 years in Denmark because tax exemption has turned wood burning into an economically attractive solution compared with more environmentally friendly heat sources.

Emphasis in this booklet is on pollution from wood burning, the associated health damages and socio-economic costs. In addition, focus is on climate impacts of soot particles from wood burning. Finally, attention is drawn to the many technical solutions and the political decisions and local initiatives that may give incentive to implement these solutions thereby reducing the health damaging air pollution from wood burning. The booklet gives many examples on Danish actions and put these in an international perspective.

The primary target groups of this booklet are decision-makers, homeowner associations and people interested in information on air pollution from residential burning.

THE DANISH ECOLOGICAL COUNCIL

clean heat

Deutsche Umwelthilfe