# POLLUTION FROM RESIDENTIAL BURNING

## Danish experience in an international perspective

GREEN TRANSITION
DENMARK

clean heat

Deutsche Umwelthilfe

# CONTENT



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# PARTICLE POLLUTION

According to the European Environment Agency (EEA), almost 400,000 Europeans die prematurely every year due to air pollution with fine particles. A premature death caused by air pollution results, on average, in about 10.5 years of lost living. In Europe, that adds up to more than 4 million lost years of living every year due to air pollution with fine particles. On top, millions of Europeans fall seriously ill from this pollution.

Figure 1 shows the number of lost years of living caused by air pollution with fine particles in the EU. Prior to a premature death, a person has often experienced several years of illness and/or serious disease. The number of lost healthy years of living is therefore significantly higher than shown in the figure.

According to the World Health Organization (WHO), health costs from particle pollution add up to around 800 billion euros a year in Europe. For comparison, Denmark's GDP was about 320 billion euros in 2021. That puts air pollution with fine particles to the top as the most expensive environmental challenge in the EU. According to WHO, residential burning of mainly wood is a significant source of fine particles and causes around 60,000 premature deaths in Europe every year.

In Denmark, air pollution with fine particles causes around 4,000 premature deaths every year as well as a long list of serious diseases, according to DCE at Aarhus University. About 7.5% of all Danish deaths relates to particle pollution, which makes particle pollution the third highest risk factor only surpassed by smoking and physical inactivity. According to DCE, health costs from particle pollution add up to around 11 billion euros/year. Danish sources contribute with around 20% of the fine particle pollution in Denmark while 80% is transboundary and/or from international shipping.

Despite that 80% of residential areas are connected to district heating or natural gas, Denmark is one of the countries that have most installations of wood stoves and fireplaces per inhabitant; it is estimated that Denmark has around 700,000 wood stoves and fireplaces. Although there has been a significant drop in wood consumption in recent years, outdoor pollution from wood smoke still causes about 300 premature deaths in Denmark every year and adverse health costs of around 0.7-0.8 billion euros every year. That makes wood smoke the most health damaging and expensive environmental problem in Denmark.

The most recent research shows that soot particles from, among others, wood burning seem to be more health hazardous than inorganic particles, which dominates the transboundary air pollution. Further, wood burning is a dominant source of other health hazardous compounds. Considered this, the pollution from Danish wood burning is an even greater health issue than pointed out above.

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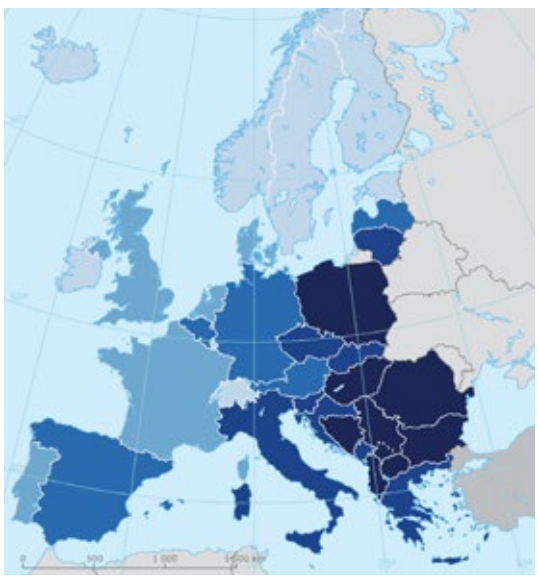
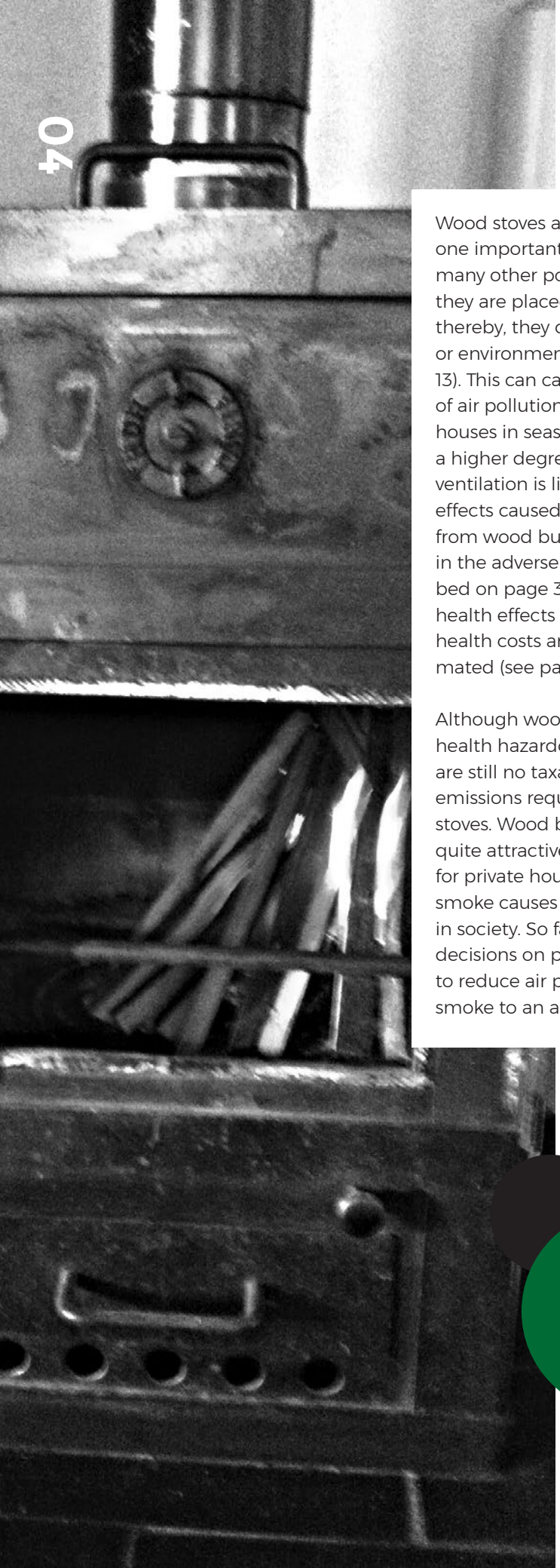



**Figure 1:** Lost lives of living in EU caused by outdoor particle pollution.

Source: The European Environment Agency

**Pollution from residential burning of mainly wood causes about 60,000 premature deaths every year in the EU.**



Wood stoves and fireplaces are, in one important way, different from many other pollution sources as they are placed inside houses and, thereby, they can pollute the indoor environment directly (see page 13). This can cause very high levels of air pollution with particles inside houses in seasons where people to a higher degree stay indoors and ventilation is limited. Adverse health effects caused by indoor air pollution from wood burning is not included in the adverse health effects described on page 3. Hence, the adverse health effects and the connected health costs are thereby underestimated (see page 23).

Although wood burning is the most health hazardous heat source, there are still no taxation or any strict emissions requirements for wood stoves. Wood burning is therefore a quite attractive form of heat source for private housing although the smoke causes severe adverse effects in society. So far (February 2022), decisions on political regulation to reduce air pollution from wood smoke to an acceptable level or give municipalities the possibility to ban smoke from residential areas are yet to come.

Air pollution from wood burning is therefore one of the dominant and remaining air pollution issues in Denmark, despite that wood burning only covers a few percentages of the national energy consumption and is unnecessary in a modern wealthy society where cleaner heat sources are available and abundant. It can only be assumed that the high use of wood stoves and lack of regulation from a political hand is due to ignorance of the hazardous air pollution from wood burning on both a public and political level.

The significant decrease in wood consumption in recent years could imply that our communication of the adverse health effects and climate impacts connected to wood smoke has made Danes choose cleaner heat sources over wood burning. To continue this development, we have chosen to update this publication on wood burning. *Enjoy!*

**High levels of air pollution with health hazardous particles often occur inside houses with wood burning.**

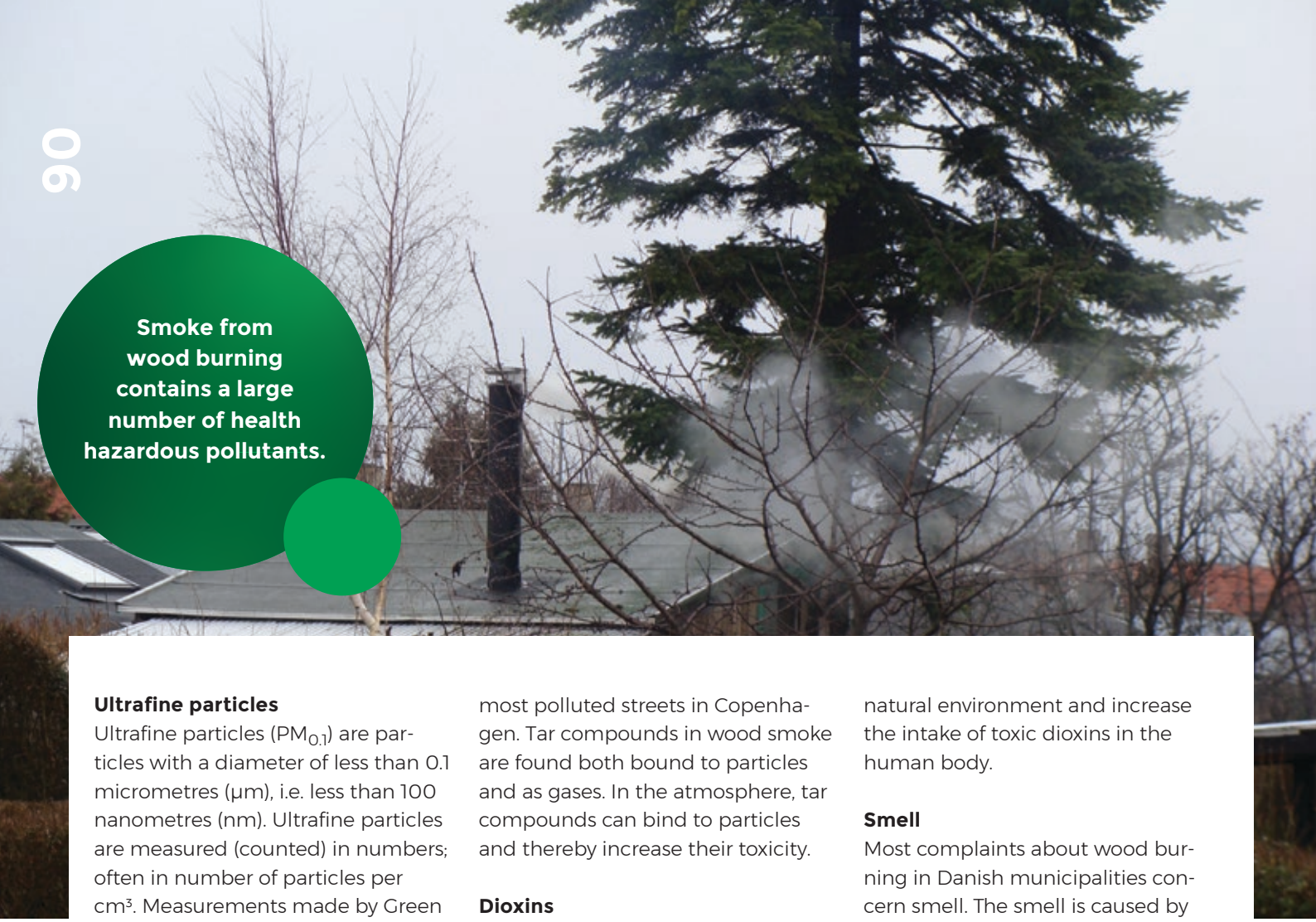
# POLLUTANTS

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 wood 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 by the surrounding air. Hence, it is crucial to dilute and thereby cool the smoke to 25-30˚C to obtain proper 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 recognise 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/m³). Fine particles from wood smoke make up about half of the 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. Hence, 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 adverse health effects 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 23).

**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/m³). Soot particles from wood smoke make up half of the total Danish soot particle emissions. Just like fine particles, soot particles have a long lifetime in the atmosphere and are therefore transported over long 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. New wood stoves emit around twice as many soot particles compared to older stoves (see page 25).



**Smoke from wood burning contains a large number of health hazardous 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 $cm^3$. Measurements made by Green Transition Denmark 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 19). Furthermore, indoor pollution with ultrafine particles from wood burning can be severe (see page 13).

### Tar compounds

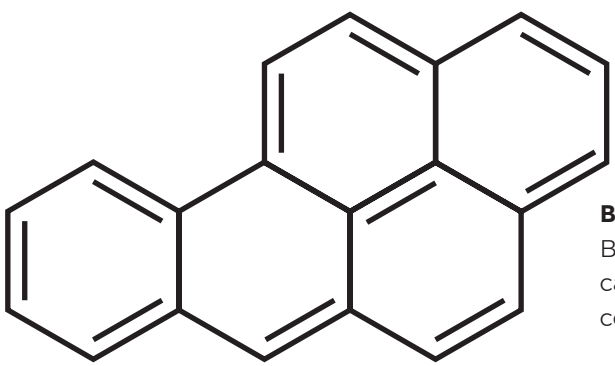
Tar compounds (PAH: polycyclic aromatic hydrocarbons) are an organic substance group consisting of polycyclic aromatic rings. Tar compounds from wood smoke make up approximately 60% of total Danish emissions. Particularly the tar compound benz(a)pyrene is of interest, since the substance is carcinogenic 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, 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 50% 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 the intake of toxic dioxins in the human body.

### 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 half of the total Danish emissions of harmful fine particles; although wood burning only covers about 2% 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 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 new wood stoves are shown under ideal operational conditions; in other words, in reality emissions are most likely significantly higher. In comparison, the particle emission from a truck is shown (all newer trucks today have particulate filters). From the figure is seen that particle emissions from new wood stoves are so high that emissions from other heat sources (and trucks) seem negligible compared to wood burning. It is also seen that particle emissions from wood burning can be reduced by more than 99.8% by using cleaner heat sources like heat pumps, etc.

**Fine particle emissions from Danish heat sources compared to trucks**
(g particles per GJ heating)

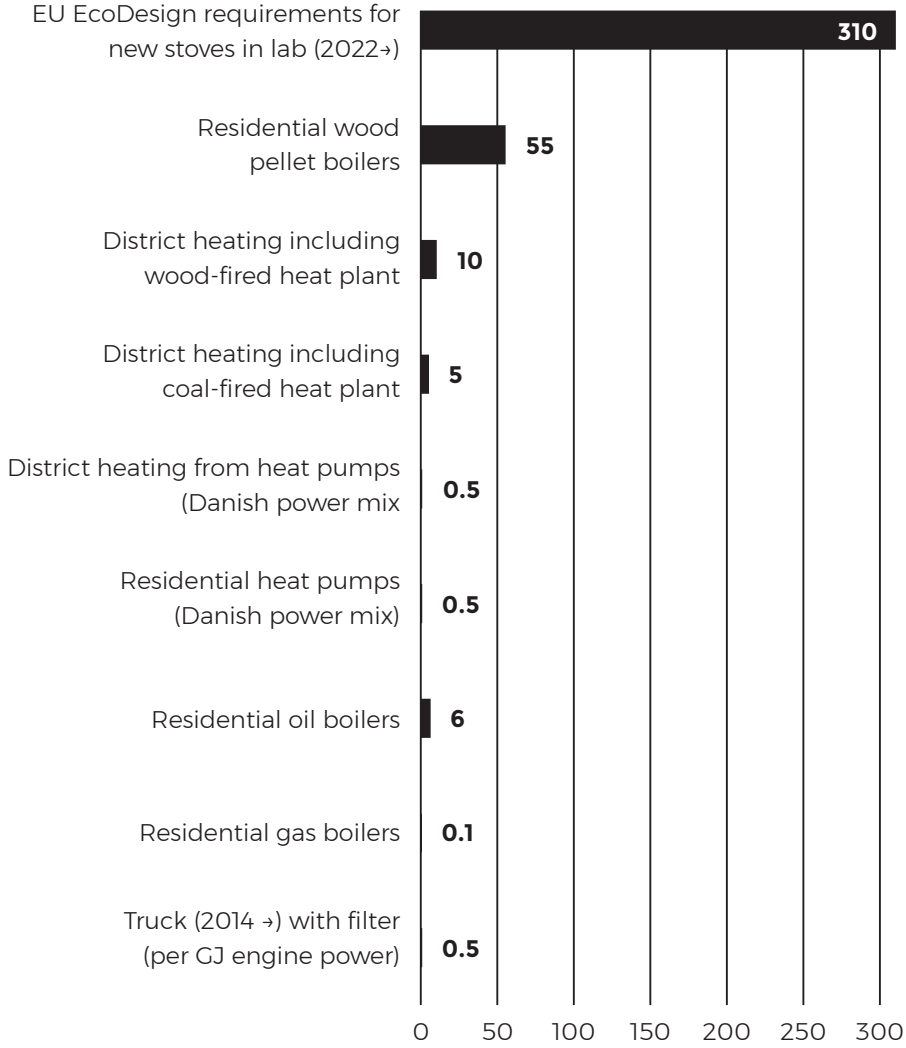
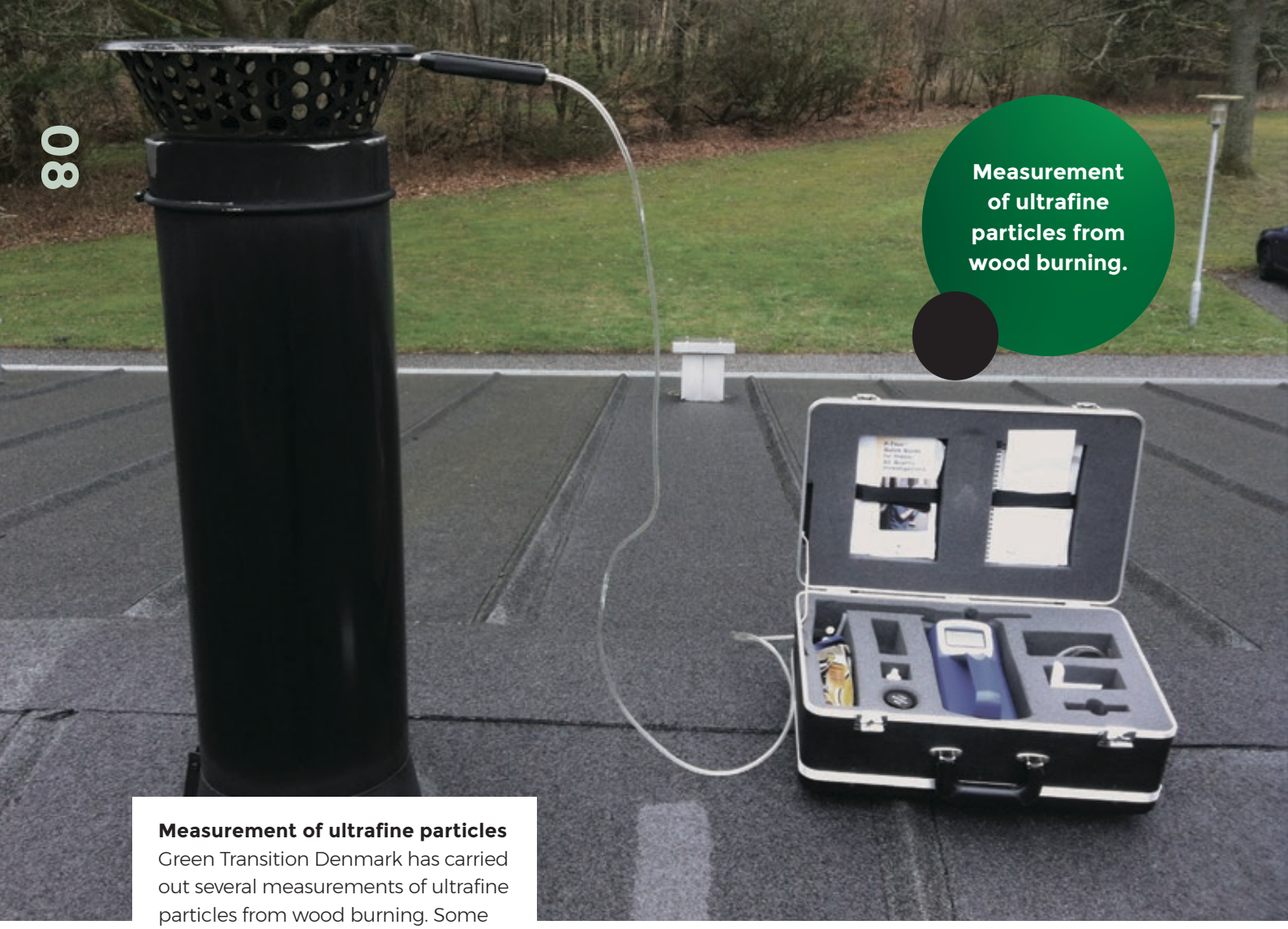



**Figure 2:** Particle emission from different heat sources. For comparison is shown the emission from a truck. The emission from district heating and heat pumps includes the emission from power plants (PP).

**It is not logical that a wood stove fulfilling the strictest Ecodesign requirements from 2022 emits around 650 times more particles than a truck.**

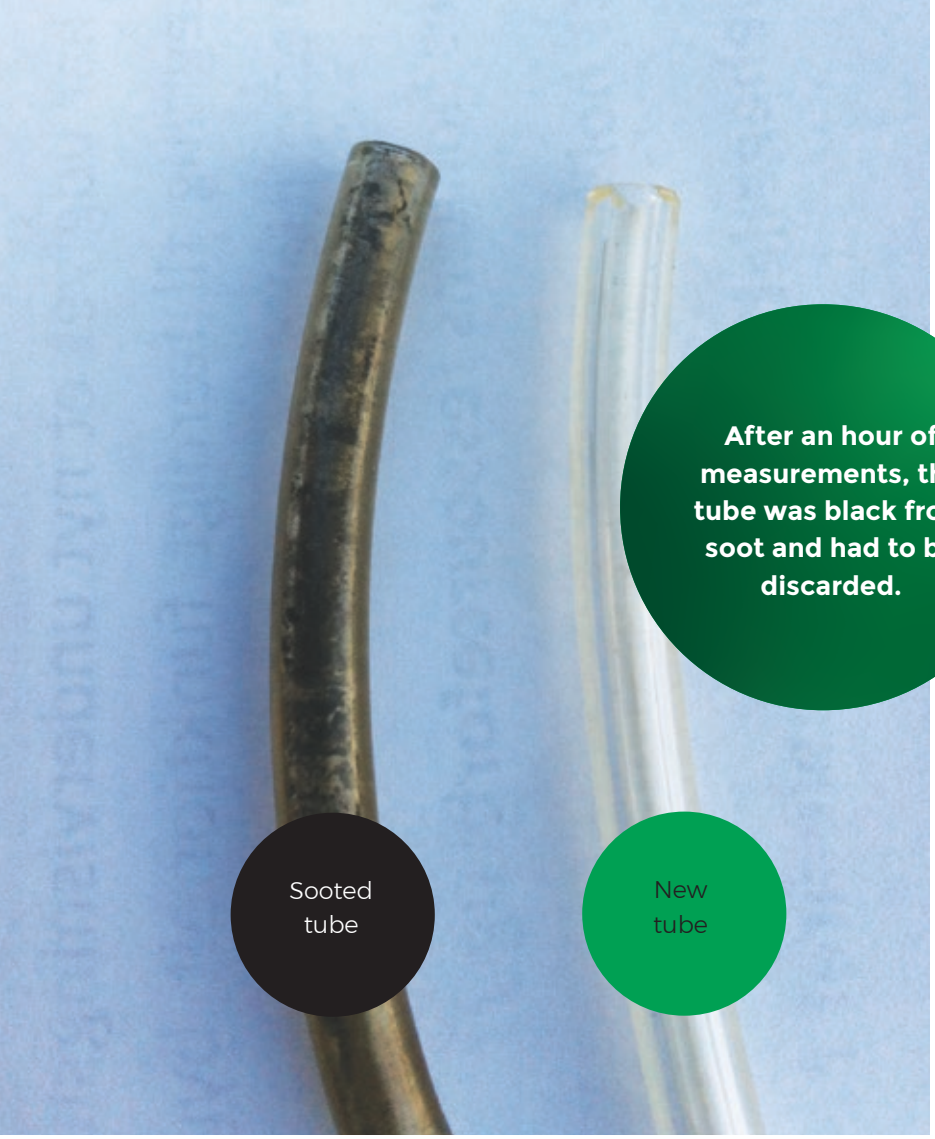


Measurement of ultrafine particles from wood burning.

**Measurement of ultrafine particles**
Green Transition Denmark 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 25% 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 1 kg 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 666,000 particles per cm³ (corrected for removal of 25% 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 were markedly higher than what the P-Trak was able to measure and thereby significantly higher than illustrated in the figure where the graph merely flattens at the exceedances of the measurement limit. Afterwards, sawdust briquettes were used for firing (1 kg), 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.

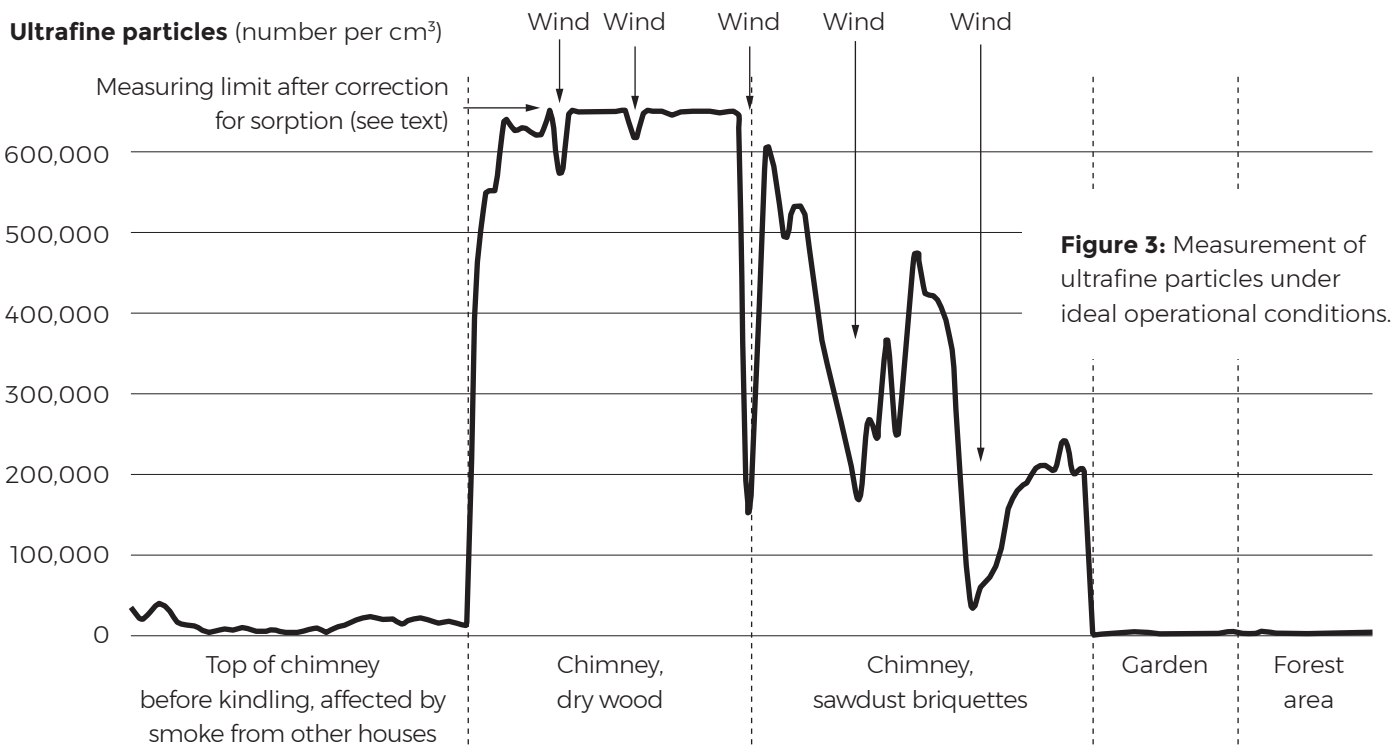



**Figure 3:** Measurement of ultrafine particles under ideal operational conditions.

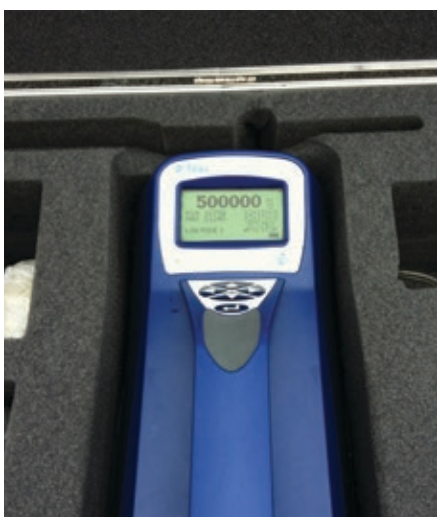
| Measurements | Average pollution (particles per $cm^3$) |
|---|---|
| Chimney exhaust, dry wood | > 587,850 |
| Chimney exhaust, sawdust briquettes | 291,300 |
| Garden (no smoke) | 2,500 |
| Forest near house (no smoke) | 2,500 |
| Small diesel truck with new filter | < 1,000 |

**Table 1:**
Emission of ultrafine particles

The averages of the different measurement situations 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**




**Forest near house**

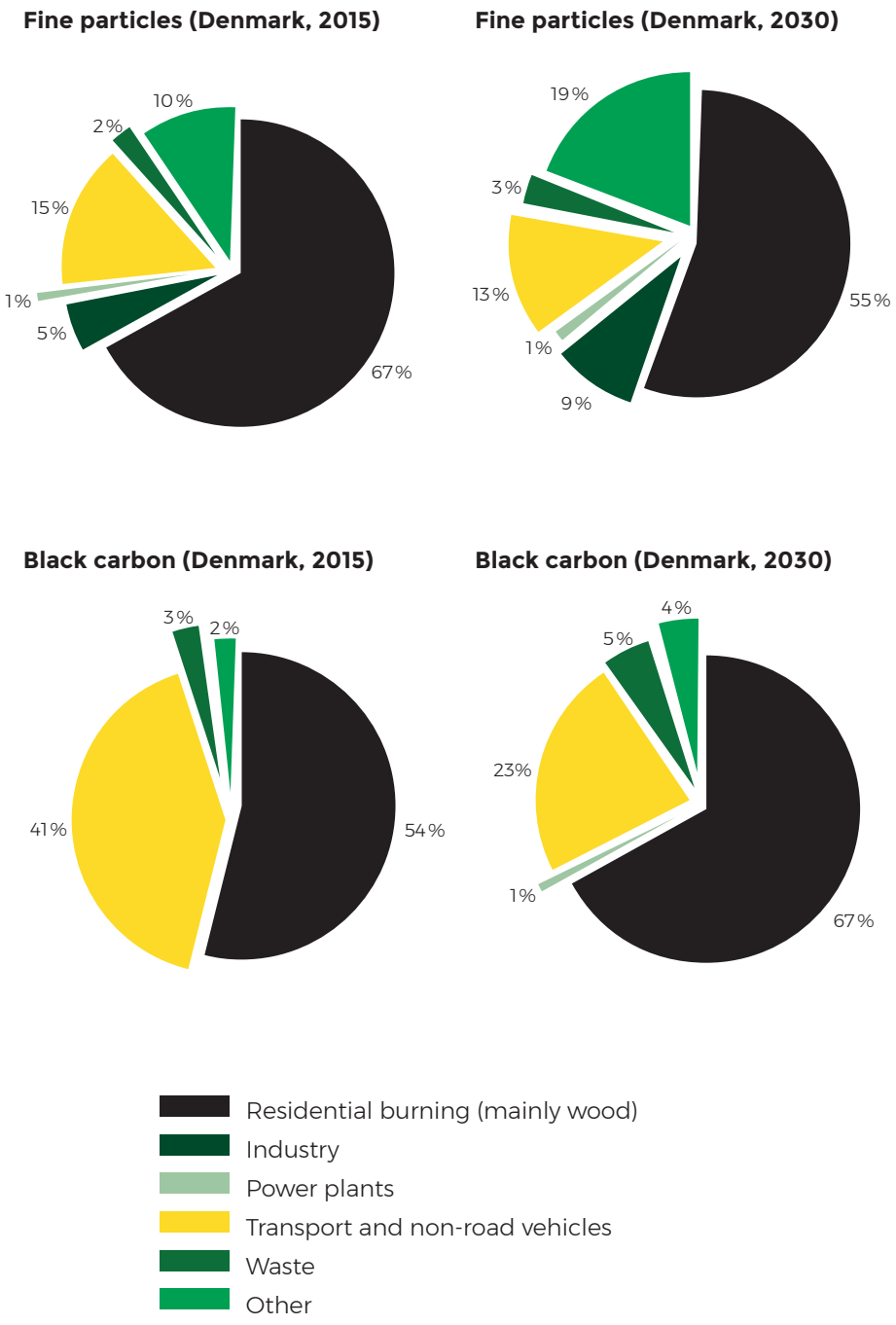

**Truck exhaust (with filter)**

# 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 maximise 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 although 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 minimise pollution from residential burning in the EU.

**Table 2:** Fine particle and black carbon emission estimates.

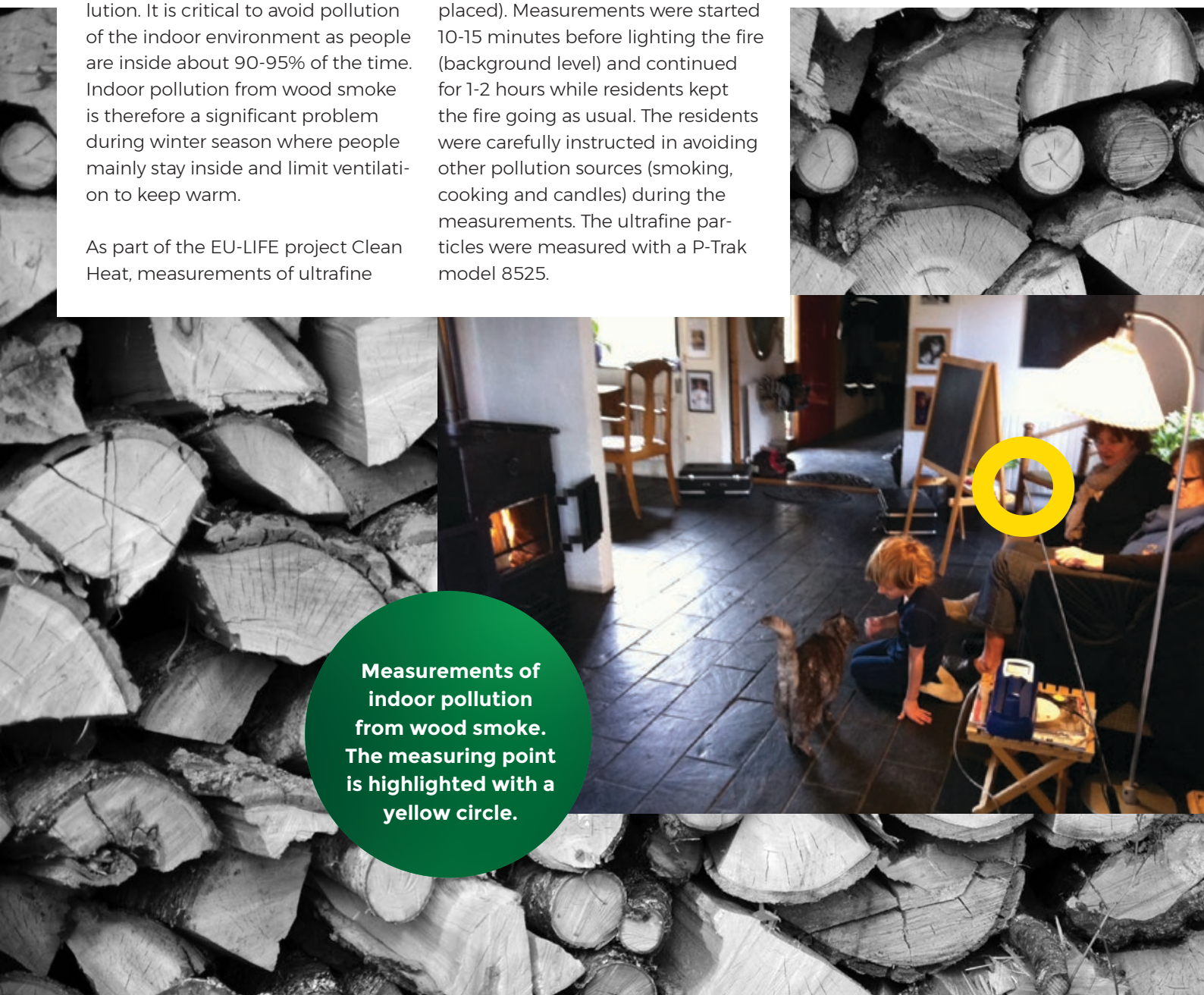
| | | 2015 | | | | 2030 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fine particles | | Black carbon | | Fine particles | | Black carbon | |
| | | Tonnes | % | Tonnes | % | Tonnes | % | Tonnes | % |
| **EU 27** | Residential burning | 654000 | 46% | 152290 | 56% | 454880 | 41% | 111380 | 69% |
| | 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 investigations made by the Danish Building Research Institute (Aalborg University), particles from wood burning can cause significant particle pollution in houses where wood stoves are used. Even new eco-labelled wood stoves can cause very high levels of indoor pollution. It is critical to avoid pollution of the indoor environment as people are inside about 90-95% of the time. Indoor pollution from wood smoke is therefore a significant problem during winter season where people mainly stay inside and limit ventilation to keep warm.

As part of the EU-LIFE project Clean Heat, measurements of ultrafine particles were performed in 20 typical Danish houses with wood stoves. Both new eco-labelled and old wood stoves connected to old and new chimneys were included. Measurements were performed 2-3 m from the wood stoves (where the sofa or the coffee table were often placed). Measurements were started 10-15 minutes before lighting the fire (background level) and continued for 1-2 hours while residents kept the fire going as usual. The residents were carefully instructed in avoiding other pollution sources (smoking, cooking and candles) during the measurements. The ultrafine particles were measured with a P-Trak model 8525.



**Measurements of indoor pollution from wood smoke. The measuring point is highlighted with a yellow circle.**

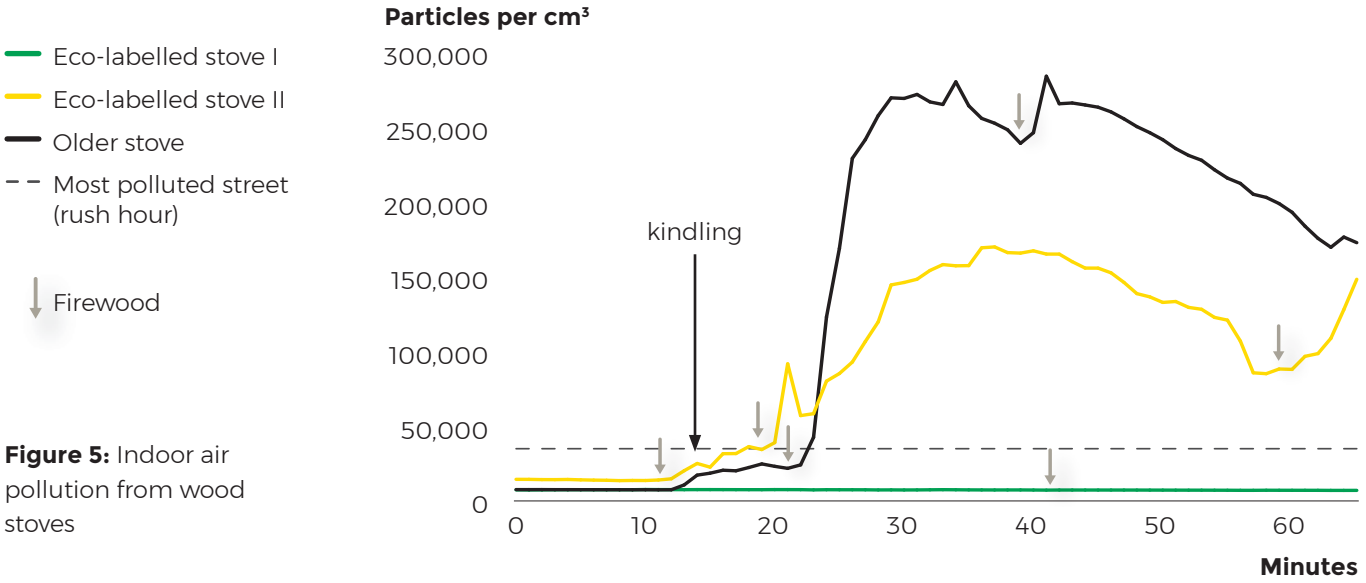



**Figure 5:** Indoor air pollution from wood stoves

In 20% of the houses (4 houses), no significant increase in air pollution was detected (compared to background levels) during measurements. In 80% of the houses (16 houses), a significant increase in air pollution was detected in the living room. In six of the houses, the particle pollution increased by up to a factor 10 above background level during the measurement period. In the latter 10 houses, the particle level increased by more than a factor 10. In the most severe cases the particle level inclined to more than 50 times as high as the background level, which is 8-10 times above the particle pollution detected on the most polluted street in Denmark during rush hour (figure 5).

No coherence between type/age of the wood stoves and chimneys and the indoor pollution levels were seen. Even the new eco-labelled wood stoves connected to well-insulated chimneys caused a significantly high level of indoor particle pollution.

The cause of the indoor pollution is most likely due to one or more of the following:

1. Particles escaping through the stove door (when logs are added).
2. Leaky joints in the stovepipe or wood stove (when hot and expanding).
3. Sudden air intake through the chimney down into the living room.
4. Dust that is burned on the surfaces of the stove (characteristic smell).

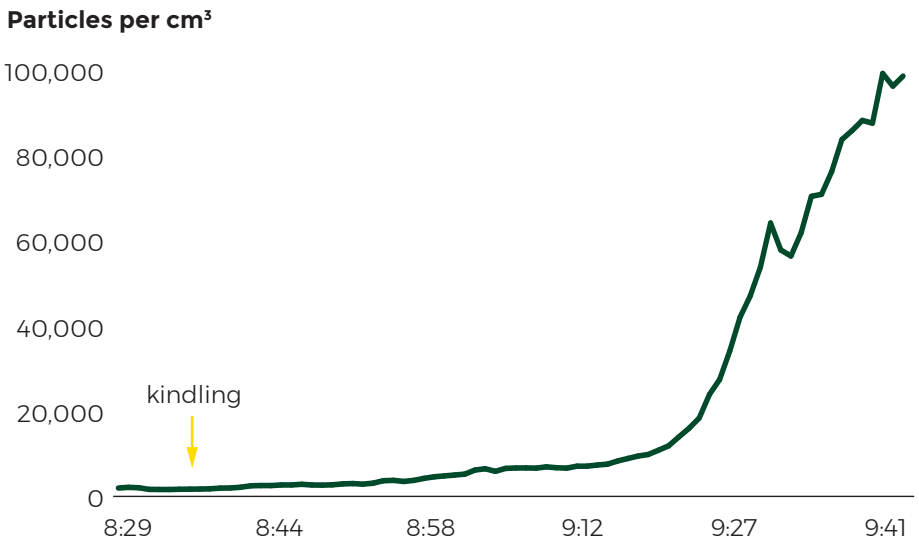
At the end, in two of the houses, measurements were made in other rooms (e.g. bedrooms). The particle pollution had easily spread from the living room and caused high levels of air pollution in the adjoining rooms with open doors. It is of high importance to inform people about the risk of high levels of indoor pollution from wood stoves as many people are uninformed about how severe the indoor pollution can be.

Well-functioning chimneys with high ventilation are believed to be the reason for low or no levels of particle pollution measured indoors in some of the houses when the fire was going.

**Wood stoves can cause serious indoor air pollution with toxic smoke.**

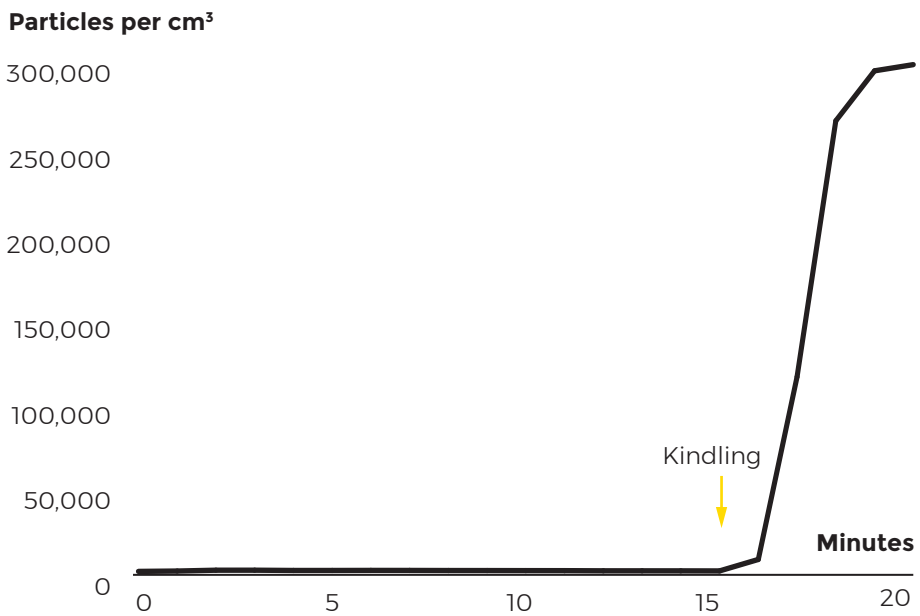

**Hotel measurements**
In the unpolluted areas of the Slovakian mountains, two identical hotel rooms next to each other were rented; both rooms had modern wood stoves. For one room, a fixed amount of dry wood with integrated small ignition blocks was included and placed in the stove. In the morning before lighting the fire, the same low levels of particles were measured in both rooms. At 8:35 am the fire was lit in one room with ongoing measurements. After lighting the fire, both rooms were left, and returned to around 9:45 am. In the room with a stove not in use, the particle level was pretty much unchanged. However, in the room with the stove in use, the particle level had increased about 60 times (figure 6). This shows that even dry wood used in a modern wood stove can cause high levels of indoor pollution although the door of the wood stove remains closed.

**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 means to 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.




**Neighbours wood smoke in the bedroom**

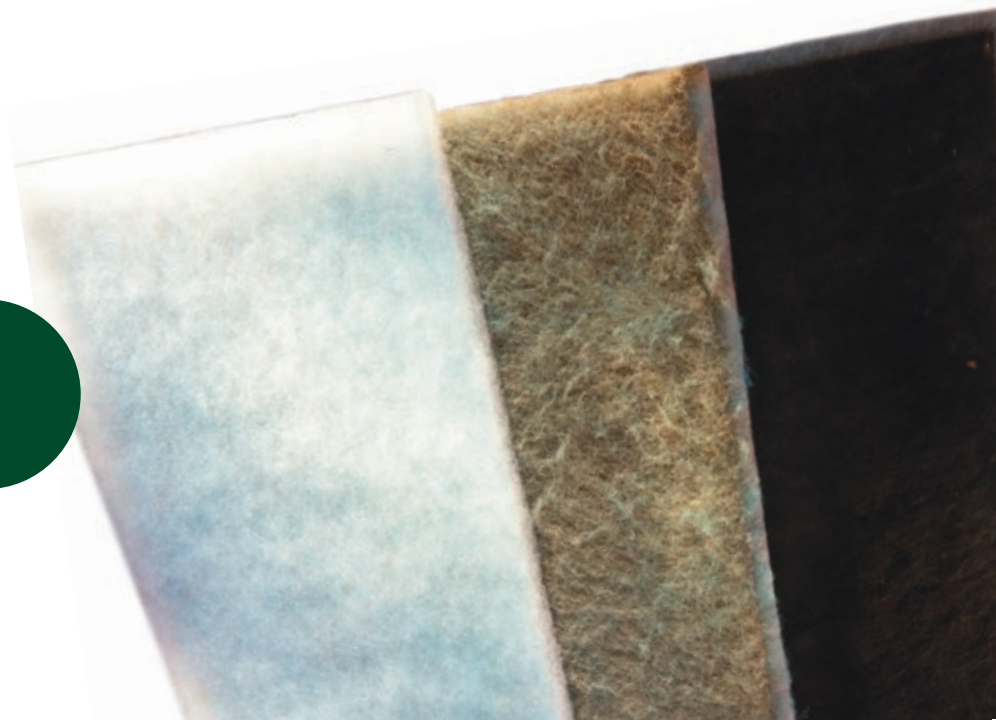
New and energy-renovated houses often have mechanical ventilation installed to improve indoor air quality. The mechanical ventilation is supposed to improve indoor air quality by leading fresh pre-heated air into the house while leading indoor air out of the house. However, in residential areas with wood burning, the neighbours´ wood smoke can enter the house through the mechanical ventilation system and thereby directly pollute the air inside the house. This is a serious risk as the intake of the mechanical ventilation system is typically placed on the roof at similar height of the chimney on the neighbouring roof.

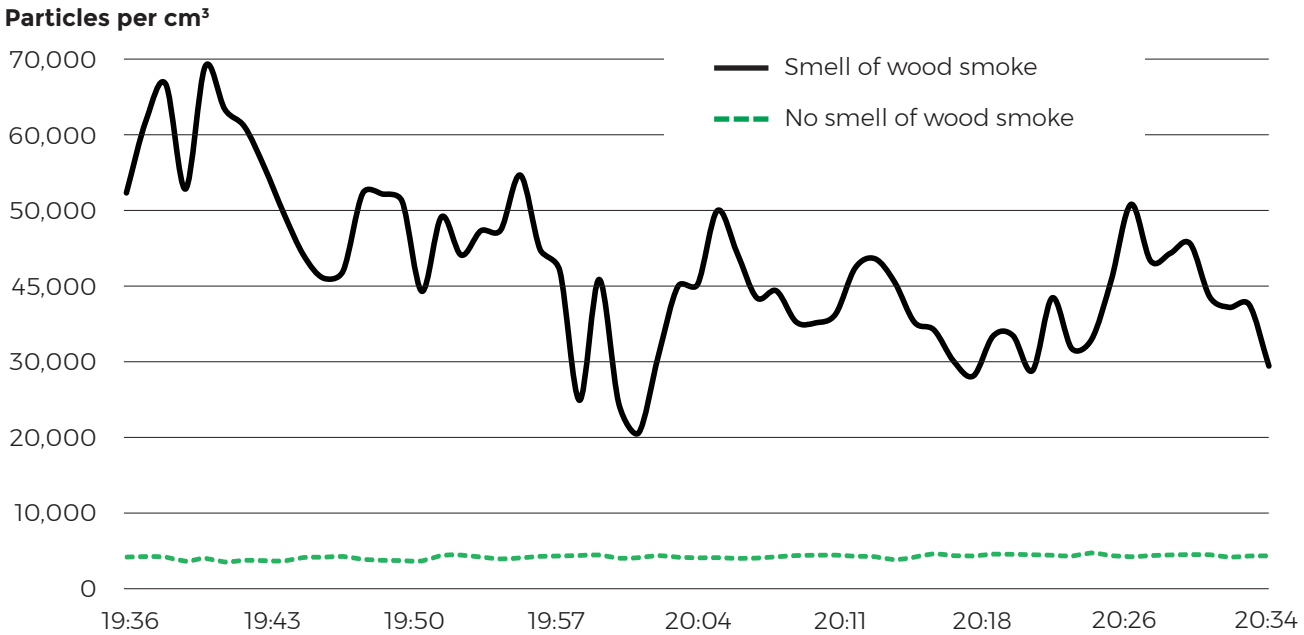
Green Transition Denmark regularly receives inquiries from residents in new houses that clearly smell that smoke from their neighbours' chimneys is ventilated into their new house through the mechanical ventilation. When the winter season is over, clear signs of these episodes are seen on the intake ventilation filters, which are often black from soot (photo below).

Green Transition Denmark has performed a screening of the pollution with wood smoke entering the houses (photo above) through the mechanical ventilation (Nilan Comfort Ventilation System with a 300 standard filter) in a newer house from 2011 in an area with district heating and wood stoves in Copenhagen. The distance between the nearest chimney and the intake of the ventilation system on the roof was about 18 m and measurements were performed in a room about 10 m from the ventilation inlet. The measurement equipment was a P-Trak (Model 8525 Ultrafine Particle Counter) from TSI, and calibration was made prior to/after measurements. Measurements were performed for one hour with and without smell of wood smoke from the air led in by the mechanical ventilation system.

**Mechanical ventilation**

**Left: New filter.**
**Middle: Filter in ventilation discharge with grey dust from the house.**
**Right: Filter in ventilation intake with soot from wood burning.**






In figure 8, the results of the measurements are shown. The same level of pollution was detected in the whole house (including kids' rooms and bedrooms) as was seen 10 m from the ventilation inlet. Pollution levels of 40-50,000 ultrafine particles per cm³ were detected. For comparison, the average pollution on H.C. Andersens Boulevard (the most polluted street in Denmark) reaches levels around 20-25,000 particles per cm³ during rush hour. Needless to say, wood burning from neighbours in residential areas can cause significantly higher levels of pollution inside new houses with mechanical ventilation than is seen on the most polluted street in Denmark during rush hour. And contrary to H.C. Andersens boulevard, people stay in their houses for much longer and are thereby exposed for long periods to high levels of carcinogenic and health hazardous particles coming from the neighbours' wood stoves.

The screening shows that significant indoor pollution from wood smoke in houses with mechanical ventilation can happen when the outdoor air is polluted by smoke and the intake air smells of smoke. Standard filters in the ventilation system are not sufficient to remove the pollution. Further and more detailed measurements of indoor pollution from wood smoke should be conducted in houses with mechanical ventilation. Additionally, the retention of particles from wood smoke in various ventilation filters ought to be investigated. Moreover, a ban on wood burning within the vicinity of 100 m of houses with mechanical ventilation should be considered. Green Transition Denmark hope to find funding for these investigations in the near future.

**Figure 8:** Ultrafine particles in the intake of the mechanical ventilation on an evening with and without the smell of wood smoke in the ventilation inlet.

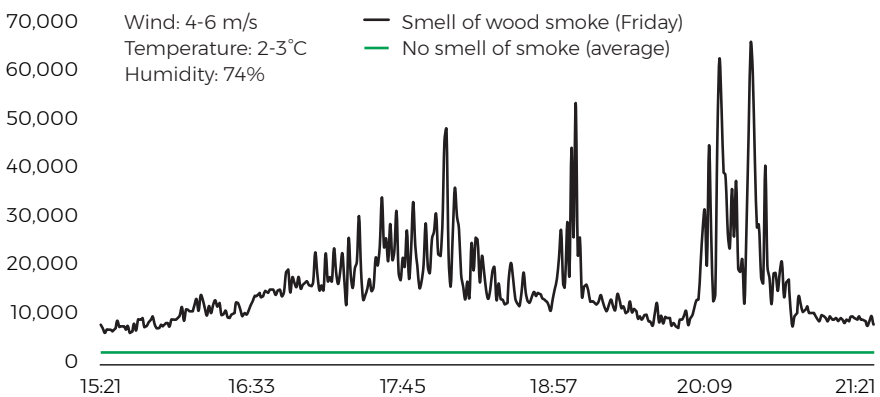
# OUTDOOR POLLUTION

Green Transition Denmark has carried out many measurements of air pollution in residential areas as 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.

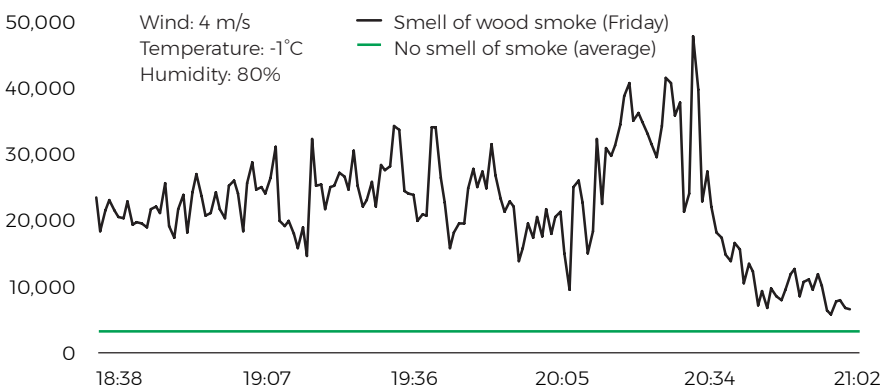
Measurements were carried out in residential areas with smell of wood smoke (air pollution) and in the same areas at locations (or at times of the day) with no smell (background). Thereby, it can be estimated how much pollution from wood burning increases local air pollution. The measurements were carried 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 9 are results from measurements in residential gardens where a clear smell of smoke from wood burning was observed (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, measurements were made inside during ventilation with open windows and 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 9:**
Pollution from wood burning in Copenhagen
Particles per cm³




Pollution from wood burning in Frederikssund.
Particles per cm³



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

**Figure 10:**
Air pollution from wood burning in an allotment society in Copenhagen

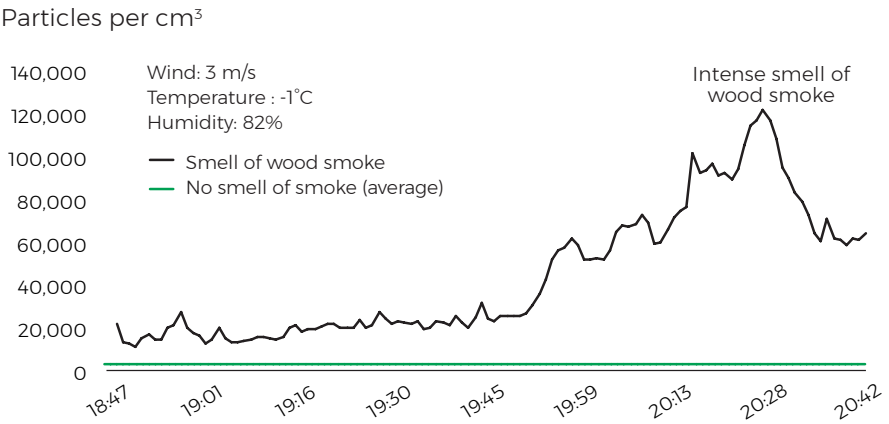



Figure 10 shows a measurement from an allotment society in Copenhagen where wood burning is used as supporting heat source in the winter. For comparison are shown background concentrations in a residential area a few hundred meters away. Background concentrations could not be measured in the allotment 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 25,000 particles per cm³ 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.

Open burning of waste is not included in the official Danish pollution statistics. Adverse health effects and costs connected to this pollution therefore have to be added to the effects 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 waste.

# 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 limits.

In Danish cities, millions of euros are used every year to replace slightly polluted soil with clean soil before establishing daycare institutions. Afterwards, the 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; despite that the smoke is emitted at inhalation altitude at times where families often stay nearby, thus breathing in extensive amounts of harmful smoke. Preparation of food on an electric barbecue is more environmentally friendly; just as it is easier to stabilise the preferred temperature and thereby achieve more 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 cm³.**

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


Brønshøj-HusumAvis 2. SEKTION

Grill, bål og hygge i haven

# ADVERSE HEALTH EFFECTS

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 are the dominant cause of adverse health effects. 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 adverse health effects 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 adverse health effects. The contribution to adverse health effects from tar compounds, dioxins and heavy metals, however, is included indirectly when adverse health effects 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 adverse health effects 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; the values in table 3 are therefore underestimated if this is taken into account.

**One third of all premature deaths connected to Danish pollution sources are caused by wood burning.**

**Table 3:** Adverse health effects due to outdoor air pollution with fine particles from Danish wood burning

| | Denmark | Europe |
|---|---|---|
| Premature deaths | 300 | 600 |
| Lost life years | 3,150 | 6,300 |
| Sick days | 300,000 | 600,000 |

Source: Estimated from DCE, Aarhus University, 2019.
All fine particles are assumed equally harmful.
Cases in Europe include cases in Denmark.

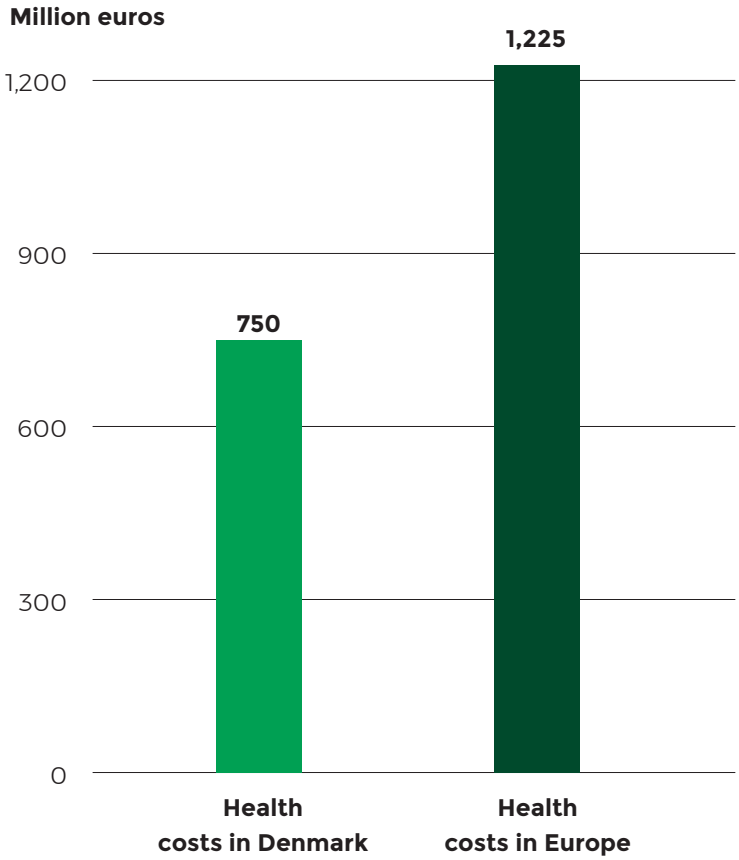



**Figure 11:** Health costs related to outdoor air pollution with fine particles from Danish wood burning

Source: Estimated from DCE, Aarhus University, 2019.
Costs in Europe include costs in Denmark. It is assumed that all particles are equally harmful.

Figure 11 shows health costs related to outdoor air pollution from Danish wood burning under the assumption that all particles are equally health hazardous. Thereby, pollution from wood burning causes around 40% of total costs associated with air pollution from pollution sources in Denmark; wood burning is thus the most expensive environmental problem.

The calculation of adverse health effects does not include adverse effects 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, adverse health effects 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 of the very serious diseases have not been included in the calculation of adverse health effects, for instance low birth weight and low IQ among children, reduced lung function among children, strokes, diabetes, etc. The calculated adverse health effects and associated costs in figure 11 related to air pollution from Danish wood burning are thereby underestimated.

Recent studies from World Health Organisation document adverse health effects 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 adverse health effects 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 years.

**In Copenhagen, one hour of wood burning in an older stove costs 5.5 EUR in adverse health effects from outdoor pollution according to the Danish national Economic Council.**

# CLIMATE IMPACT

**Wood is not $CO_2$ neutral**
Politicians have decided to consider wood burning as carbon neutral because trees take up the same amount of $CO_2$ during their lifespan as is released while being burned. In recent years however, most of the scientific society is agreeing that wood burning is not $CO_2$ neutral even when new trees are replanted and take up $CO_2$. On the contrary, wood burning will create more global warming than burning fossil energy as it takes decades for a new tree to absorb the emitted $CO_2$ and because wood burning emits high amounts of soot particles, which contributes significantly to global warming as well.

**Count the rings**
When wood is burned in a wood stove, more $CO_2$ is emitted per heat unit than by burning coal. One kg of $CO_2$ from firewood gives the exact same global warming as one kg of $CO_2$ from coal – the climate does not make distinctions. According to the Intergovernmental Panel on Climate Change (IPCC), we only have 10-20 years to avoid the threatening global warming and fulfil the Paris Agreement. Hence, we urgently need to reduce all $CO_2$ emissions.

Burning wood is the fastest way to emit $CO_2$ from trees and must be limited as much as possible. If you count the tree rings in a piece of firewood, you will typically find 30-50 rings. A new tree therefore needs 30-50 years to take up the $CO_2$ that is emitted when the wood is burned. During those 30-50 years, the released $CO_2$ contributes to global warming.

Living and dead wood is the natural $CO_2$ storage. If a dead tree is left in nature, it becomes part of the natural $CO_2$ cycle and is slowly composted (and releasing $CO_2$) at the same time as a new tree grows and take up the released $CO_2$. This way there is a balance, but this balance is distorted when the wood is burned, and $CO_2$ is released immediately. That is why wood burning needs to be prevented. Instead, wood should be used for building materials and products with a long lifespan and be left in nature to the benefit of animals (see page 27).

The direct climate impact from wood burning in private houses exceeds the climate impact if the same houses were heated by fossil fuels (figure 12 on next page). However, the solution is neither burning wood nor fossil fuels. Green transition is building/renovating to energy efficient houses, which are heated by heat pumps, geothermal energy, and excess heat from industries in the energy systems of the future where electricity is produced by wind, solar and hydro power.

At the same time, inexpensive wood makes it unattractive for house owners to insulate their houses, change windows, etc. Low-cost wood for heating thereby prevents the green transition to a climate neutral society with good air quality.


**Burning firewood causes adverse climate impacts and low-cost firewood makes it unattractive to perform energy renovation of residential houses.**

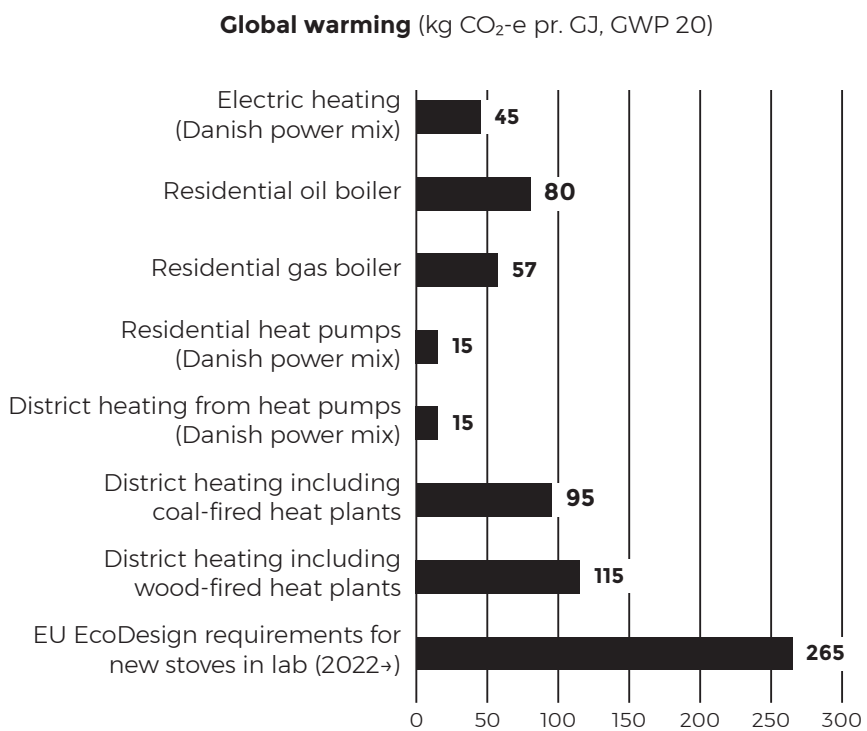
**Wood burning is the opposite of a green transition, which is all about changing to emission free heat sources.**

**Soot particles harm the climate**
The IPCC has classified soot particles (black carbon) as being harmful to the climate having a global warming potential (GWP) of 3,200 over a 20-year period. Practically, that means that one tonne of soot particles causes the same global warming as 3,200 tonnes of $CO_2$.

Figure 12 shows the climate impact from a new eco-labelled wood stove compared to other heat sources. The new eco-labelled wood stove is the heat source that contributes most to global warming when the impact of the emitted climate-damaging compounds ($CO_2$, soot particles, methane, nitrous oxide) are included. In particular, new wood stoves severely harm the climate as they emit far more soot than old wood stoves (on the contrary, old wood stoves emit more fine particles).

Green transition is about changing to emission free heat sources, which requires not to burn resources (fossil fuels, wood, etc.). Instead, we need energy efficient buildings heated by heat pumps (as part of the district heating system in cities, and private heat pumps in rural areas). Wood burning is thus the opposite of a green transition.

**Figure 12:** Direct climate impact from heat sources (kg $CO_2$-e per GJ heat, GWP 20)



**Leaving dead wood in a corner of your garden highly benefits nature.**

# NATURE DAMAGES

In Denmark, 10 different types of forest exist, and half of all Danish species are somehow connected to a forest ecosystem. According to the latest national survey, the state of nature is highly unfavourable. The poor condition of the forests is the primary reason for the decline of nature in Denmark. The lack of dead trees (wood) is one of the main reasons for the low biodiversity in the forests as dead wood is a vital part of the forests' ecosystem. A production forest contains 5-6 $m^3$ of dead wood per ha whereas natural forests contain 30-40 times more. It is necessary to leave more dead wood in the forests for the benefit of nature instead of burning it off and bring harm to the climate and public health.

In most gardens, parks, and meadows, etc., there is a severe shortage of dead wood and many animals therefore have difficulties in finding food, hideouts, and habitats. Here, it is also necessary to improve the capacity of dead wood to be part of the natural cycle. Instead of burning the wood, it should be left or piled up for an insect hotel in the corner of our gardens creating a habitat for hedgehogs, toads, insects and many other animals that have difficulties in finding good habitats in our well-kept and broomed gardens.

# TECHNICAL SOLUTIONS

**An electric fireplace gives exactly the same cosy atmosphere, but without health hazardous air pollution.**

Air pollution from wood burning can be significantly reduced through a wide range of measures. Below is a prioritised description of the most efficient measures. The key conclusion is that air pollution and the harmful effects to public health, the climate, and nature from wood burning can be eliminated by performing energy renovation and changing to environmentally friendly heat sources, and it can be reduced if particle filters are installed on wood stove installations.

**1) Energy renovation**
The most environmentally friendly and energy efficient measures are to optimise the heat consumption of your house by changing windows, insulation, etc. When your house is energy efficient, the wood stove is no more needed as supplementary heat source. In addition, heat consumption from the primary heat source decreases, the indoor environment is improved, and the value of the house increases. Regardless of using wood burning as a secondary heat source (wood stoves) or as primary heat source (boilers), energy-renovating your house will efficiently lower the extent of wood burning and the connected air pollution – and the need for heating will be reduced, which will further decrease the costs of changing to an environmentally friendly heat source.

**2) Environmentally friendly heat**
Both the health hazardous and climate-damaging pollution is significantly lower for environmentally friendly heat sources. In particular, district heating in cities and heat pumps in rural areas are the foundation of the green transition, and in particular in the future scenario, where district heating to a much higher degree is based on heat pumps, and electricity is produced from wind, solar and hydro power balanced by flexible power import/export.

Creating a cosy atmosphere will in the future be from using modern electric fireplaces, which is widely used in the US and has gradually gained a foothold in many European cafés, hotels, etc. The cosy atmosphere is identical to the traditional wood burning, but without the health hazardous and climate-damaging air pollution – and without the risk of indoor air pollution (cf. page 13). Alternatively, find other ways to create a cosy atmosphere; most people already do fine without a wood stove.

**3) Flue gas cleaning**
Flue gas cleaning with efficient filters might remove the health hazardous particle pollution from wood smoke including the soot particles that cause severe climate impacts; however, particulate filters do not prevent the emission of $CO_2$ and the included climate impacts. In addition, the filters must be extremely efficient to reduce the air pollution to an acceptable level: A new wood stove (sold in 2022) fulfilling the strictest EU Ecodesign requirements emits about 5 g of fine particles per kg of wood burned. The new air quality limit for fine particles from WHO is 0.000005 g per $m^3$, which corresponds to polluting 1,000,000 $m^3$ of clean air to the limit when burning just 1 kg of wood in the stove. Such an amount of polluted air would cover an area of 100,000 $m^2$ to an altitude of 10 m. Therefore, to reduce the pollution from new wood stoves to an acceptable level, filters must be 99.9% efficient (to reach same particle pollution level as a newer truck per GJ energy); a purification efficiency of 99.7% would be acceptable for the best new Danish eco-labelled wood stoves. Purification of this level can only be achieved with a condensed flue gas system combined with bag filters or wall-flow filters, which is not yet on the marked.

**4) Good stoves and boilers**
Unfortunately, there are no indications that new wood stoves or boilers will solve the problem as a new good eco-labelled wood stove under optimal conditions emits about 2 g of fine particles per kg of wood burned thereby polluting about 400,000 $m^3$ of clean air to the WHO air quality limit (cf. calculation above). In densely populated residential areas, this level of air pollution is completely unacceptable. In addition, new wood stoves emit almost twice as many soot particles as older wood stoves and thereby contribute even more to global warming.

**5) Optimal stove operation**
In all estimations and assumptions in this booklet, optimal stove operation is presumed; if optimal stove operation is not the case, pollution levels are much higher than stated. However, even new good eco-labelled wood stoves emit unacceptably high pollution levels during optimal laboratory settings (see above). Therefore, optimal stove operation is not a solution, but it is of course less harmful than wrong stove operation.

**New wood stoves fulfilling the new Ecodesign requirements in 2022 pollute about 1,000,000 $m^3$ of clean air to the WHO air quality limit for each kg of wood burned, and contribute significantly to global warming – they are not a solution!**

# EXISTING REGULATION

**Transboundary air pollution must be regulated internationally and reduced locally.**

Air pollution from wood burning in Denmark is indirectly regulated through UN protocols and EU directives and directly through Danish regulation and the Danish Statutory Order on wood stoves, which is partly an implementation of the EU Ecodesign directive. In particular, the new NEC Directive is expected to lead to a reduction of air pollution from wood burning in some member states (but not in Denmark). The EU Ecodesign Directive may however limit national opportunities for reducing air pollution from wood burning e.g. in Denmark.

**Stockholm Convention**
Denmark has signed the Stockholm Convention, which entered into force in 2004, and is thereby obliged to reduce emissions of persistent organic pollutants; Denmark is thereby required to reduce dioxin emissions. Wood burning is presently responsible for the dominant part of the Danish dioxin emissions (cf. page 6), yet no measures have been taken to reduce emissions of dioxin from wood stoves. The levels of dioxin emitted from a new eco-labelled wood stove are so high that it cannot even fulfil the limit value of a waste incineration plant. If wood stoves were simply replaced by environmentally friendly heat sources, Denmark would half the dioxin emission and thereby fulfil the Stockholm Convention; however, the necessary political decisions are yet to be made (see page 31).

**Gothenburg Protocol**
According to the Gothenburg Protocol from 2012, Denmark must reduce emissions of fine particles by 33% by 2020 based on 2005 levels; special attention should be given to the reduction of soot particle emissions. Danish particle emissions however already decreased by 33% partly due to the reduction of wood burning in the past years. Changing old stoves for new ones have however had the opposite effect in regards to soot particle emissions as new wood stoves emit significantly higher levels of soot than old wood stoves.

**NEC Directive**
EU has implemented the 2020 target of the Gothenburg Protocol through the new National Emission Ceilings Directive (NEC Directive). In addition, the EU NEC Directive further requires a 55% reduction in the Danish fine particle emission by 2030 compared to the 2005 emission level; in particular, reducing the emission of soot particles. If the recent reduction in wood consumption continues, this target will be reached by 2030, however changing old stoves with new ones will increase emissions of soot particles and be in breach of the Directive.

**Ecodesign Directive**
EU's Ecodesign Directive sets requirements for energy consumption and adverse emissions from new products on the EU market. From 2022, the Ecodesign Directive introduces an emission requirement for wood stoves of 5 g of particles per kg of wood burned, which corresponds to polluting 1,000,000 $m^3$ (one million $m^3$) of clean air to the new air quality limit (0,000005 g particles per $m^3$) of the WHO. Such an amount of polluted air corresponds to covering an area of 100,000 $m^2$ to an altitude of 10 m, which is highly unambitious. Fortunately, most wood stoves in the Danish market are somewhat better than this.

**Air Quality Directive**
Air quality limit values for fine particles and PAHs 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 as wood burning mainly occur in the winter season; the high winter concentrations are "diluted" by the low summer concentrations in the calculation of annual averages. The air quality limits of the WHO are, however, exceeded for both particles and PAHs in residential areas with wood burning.

**Danish regulation**

Due to our intense information activities, there has been significantly more focus on the health hazardous air pollution from wood burning in Denmark in recent years. From a political side, this has brought several actions e.g. the change-of-ownership scheme where old wood stoves and fireplaces from before 2003 must be replaced or scrapped when a house changes owner. Finally, a bill has been in consultation (in December 2021) where the government and the agreeing parties approve for municipalities to have the opportunity to ban stoves and fireplaces installed before 1st June 2008 in areas with district heating or natural gas.

**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.**

The challenges of the two initiatives are, however, that many wood stoves are exempted, and that changing to new stoves do not solve the problem of the health hazardous air pollution as new stoves emit up to 5 g of particles per kg of wood burned, which pollutes 1,000,000 $m^3$ clean air to the WHO air quality limit when one kg of wood is burned (see calculation above). Additionally, new wood stoves emit twice as many health hazardous and climate-damaging soot particles. Finally, the severe problem of indoor air pollution caused by wood stoves and fireplaces will not be solved by these political actions. An obvious solution is to simply ban heating with solid fuel in urban areas, which will eliminate the pollution from wood burning both indoors and outdoors. Such a ban is already in force in some European cities and is compatible with EU law.

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 Danish EPA has on several occasions added more strict - but still unambitious - requirements to the Order. Hence, the Danish EPA expects that the Order will only reduce pollution from wood burning by approximately 2% compared to business as usual.

Furthermore, the Order states that local authorities can set requirements for higher chimneys, reduced use of units, fuel quality, operational requirements, etc. based upon section 42 of the Danish Environmental Protection Act, i.e. if units cause "unhygienic conditions or significant pollution". Like this, local authorities must evaluate whether the pollution is "significant" or not, however that is quite difficult as local authorities are not equipped with measuring equipment and the Order is thereby only symbolic. However, a court ruling on wood smoke in Guldborgsund municipality states that pictures of intense visible smoke is enough to document "significant pollution" as the smoke contains health hazardous substances.

# NATIONAL SOLUTIONS

**Table 4:** Average health costs due to emissions from domestic heat sources in Denmark

| | | $PM_{2.5}$ | $NO_X$ | $SO_2$ | $NH_3$ | Costs (euro per GJ house heating) | |
|---|---|---|---|---|---|---|---|
| | Energy[1] | 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 (Plant < 50 MW)** | Coal | 6.5 | 125 | 584 | < 0.1 | 1.3 | 12.8 |
| | 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 air to air, air to water, and soil to water all having average efficiencies around 3.

Air pollution from wood burning will only be eliminated if national politicians take decisions that incentivises the population to use emission free heat sources as part of the green transition.

### Bans

Wood burning covers only 2% of the energy consumption in Denmark and can easily be replaced by cleaner heat sources. An obvious solution is to ban individual heating with solid fuel, which is compatible with EU law. For example, a ban can be made on individual heating with solid fuel in urban areas by 2025, and by 2030 the ban can extend to be national. If a national political agreement cannot be reached for such a ban, then as a minimum, politicians can allow ambitious green municipalities the possibility of banning individual heating with solid fuel to protect their citizens from health hazardous air pollution and reduce global warming; wood smoke is a greater source of particle emission than road traffic in all Danish municipalities. Once a municipality decides on the ban, others will quickly follow as their citizens will also demand breathing clean air in residential areas (just as seen with environmental zones for road traffic).

In both Copenhagen and Frederiksberg municipalities there is political will to avoid wood smoke by bans for the benefit of public health and the climate.

### Taxation

Wood burning is the most health hazardous heat source and thereby the most expensive environmental problem in Denmark. In addition to the health costs shown in table 4, costs due to adverse health effects from indoor air pollution from wood smoke, climate impacts, and nature damages should be added. Nevertheless, wood burning is exempted


from taxation, which means that costs fall on society as externalities. This is both unethical and financially wrong, and anti-competitive, undermining the implementation of energy renovation and clean heat sources. Taxation can correct this market error.

By aligning taxes on wood burning with the taxation of other heat sources and by directly imposing taxes on particle pollution from wood burning corresponding to the associated health costs, incentives for energy renovation and using cleaner heat sources arise.

Taxes may be designed in a relatively simple manner as the energy consumption of air pollution from 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).

The number of operating hours can easily be registered by using 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, e.g., 60˚C, which only occurs when the unit is in use. It would be advantageous to use a remote meter reader to reduce costs for reading and controlling use, and to minimise cheating.

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 can be controlled and reported by the chimney sweeper during the yearly mandatory chimney inspection. According to the Danish technology company C.B. Svendsen, such a meter can be manufactured at a very low cost. The principle would be the same as payment for consumption of electricity, heating, gas, and water. In 2016, the Danish Economic Council made a detailed report showing that taxation of wood burning using this method is the most optimal and can save several hundred Danish lives as well as around 500 million euros of health costs a year.

In summary, taxation can reduce air pollution by 80-100% depending on the design and magnitude of the taxation. The taxation is in full compliance to the polluter pays principle and the EU directives.

**Information**

More and more Danes become aware of the environmental and climate issues associated to wood smoke, which is why the wood consumption is decreasing; a development that needs to continue. The green transition will only succeed if we all make an effort. The solution is a continuous flow of information about wood smoke as no one intentionally wishes to harm their family, neighbours, the climate, or nature.

It is imperative to achieve public understanding of the reasons for a ban on wood burning and/or taxation of wood burning; just as most people have an understanding of why a no smoking policy is applied at public daycare institutions and many private companies as well as the high taxation on cigarettes.

There is a high share of wood stove producers in Denmark, therefore the authorities are quite reluctant to inform the population about harmful impacts of wood smoke; typically, it is “la-la information” about optimal stove operation not solving the pollution challenge at all. There is a need of detailed information on the severe adverse health effects and climate impacts from wood smoke to motivate most of the Danish population to change to cleaner heat sources. A task that could be performed by the municipalities.

**Although wood stoves cover only 0.5% of the energy consumption in Copenhagen, wood burning emit a much higher level of particles every year than all the traffic in the city put together. A ban is obvious!**

# LOCAL SOLUTIONS

So far no ambitious 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. 31). Local solutions are important if 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. 36). Therefore, local authorities should carry out information campaigns. Such campaigns should focus on local air pollution from wood burning and associated adverse health effects. Campaigns should point out that local wood burning have an adverse impact on local air quality – both outdoors and indoors – 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/heat pumps as environmentally friendly alternatives to the pollution from wood burning. Also, electric fireplaces used to create a cosy atmosphere (cf. p. 28) 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 company could inform about environmentally friendly heat. A dealer of electric fireplaces 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 air pollution from wood burning and measurements of air pollution from wood burning made 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 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 stoves.

**Efficient regulation**

Many Danish municipalities have a number of opportunities of using the Statutory Order on wood stoves (cf. p. 31) 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 legitimise 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. 31). 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. 31) - 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.**

## "WOOD BURNING IS CARBON NEUTRAL"

Wood burning is often market 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 (www.dapo.dk). However, as described previously, wood burning emit significantly higher levels of $CO_2$ and more soot particles than other heat sources, thereby contributing significantly more to global warming than even fossil heat sources. Fossil energy sources is however not an alternative to wood burning. Instead, heat pumps (also in district heating), geothermal sources, solar energy and excess heat from the industry are. In the future, heat pumps will be based on wind, solar, and hydro power. That should eliminate the harmful wood smoke from densely populated residential areas. Further, a ban on and/or taxation of wood burning will stimulate energy renovation. Initiatives that are all important parts of the green transition.

## "MODERN WOOD STOVES DO NOT POLLUTE"

It is often said in the public debate that modern wood stoves "hardly" cause any pollution during optimal operation as the particle emission is "quite low" (e.g. on the website of the Danish stove industry www.dapo.dk). Good Danish eco-labelled wood stoves emit approximately 2 g of particles per kg wood burned during optimal test conditions in laboratories. The new air quality limit of the WHO for particles are 0.000005 g per $m^3$ air, which corresponds to polluting 400,000 $m^3$ of clean air to the air quality limit when just burning one kg of wood; that is unacceptably high. A five-year-old truck emits 250 times less particles as all newer trucks have efficient particle filters installed. Additionally, modern eco-labelled wood stoves have shown to cause particle pollution inside houses that are many times higher than along the most polluted streets in Denmark; important details that the wood stove industry "forget" to mention.

# GREEN WASHING

Green washing of wood stoves often happens.

## "WOOD BURNING IS ENVIRONMENTALLY FRIENDLY

The wood stove industry and dealers as well as chimney sweepers often market wood burning as environmentally friendly. In an advertisement brought in the Danish magazine Mediaplanet the wood stove industry claims that wood stoves are "a cheap and environmentally friendly heating source"; despite that, according to authorities and all scientific investigations, wood smoke is the most expensive environmental problem in Denmark (cf. page 3). Wood burning emits much more fine particles than road traffic and accounts for a high share of the Danish emissions of particles, soot, PAHs and dioxins (cf. page 5-6) - despite that wood burning only covers around 2% 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.

## "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 indicate that this might be true for acute adverse health effects, but almost all deaths related to particle pollution from wood burning are caused by long-term exposure (chronic exposure) to low levels of particle pollution where 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 along with the fact that the alternative to wood burning is not diesel, but energy renovation, district heating or heat pumps. In addition, almost all diesel cars have filters eliminating particle pollution.

# RECOMMENDATIONS

Air quality in Denmark can only be significantly improved if serious efforts are made on an international level to limit the unacceptably high levels of air pollution, and political actions are taken to reduce pollution on a national and local level.

## FOR THE EUROPEAN COMMISSION

Green Transition Denmark recommends that the Commission:

1) Introduces particle emission limit values (including particle number limits) for stoves and boilers being the same limits per kWh as for new trucks (Euro standards).

2) Harmonises particle measurements from stoves and boilers by methods that include condensable particles (e.g. Norwegian methods with smoke temperatures of 28˚C) per energy unit (joule) or per standard fuel unit (kg dry wood).

3) Implements all new air quality limits from the World Health Organization as binding air quality limits in the EU from 2025.

## FOR NATIONAL GOVERNMENTS

Green Transition Denmark recommends that governments:

1) Ban individual heating with solid fuel by 2025 in cities and by 2030 nationally.

2) Allow municipalities to ban individual heating with solid fuel in cities by 2025 and in the whole municipality by 2030.

3) Put high taxation on pollution from wood burning to motivate the change to cleaner heat sources.

4) Provide detailed information on the severe adverse health effects and climate impacts from wood burning.

5) Transfer the air pollution area from the Ministry of Environment to the Ministry of Health to bring the adverse health effects of wood smoke into focus.

6) Implement a change-of-ownership scheme that permanently bans heating with solid fuel on the lot when a house changes ownership.

7) Work towards ambitious air quality limits at an EU level, which as a minimum aligns with the new air quality limits of the WHO from 2025.

8) Work towards implementing ambitious requirements for wood stoves in the EU Ecodesign Directive (same emission limit values for new wood stoves as for new trucks in EU).

## FOR LOCAL AUTHORITIES

Green Transition Denmark 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

Green Transition Denmark recommends that homeowner associations:

1) Inform locally about air pollution from wood burning and how wood smoke pollutes locally in your neighbourhood.

2) Make a principal decision in your homeowner association (even if it may not be enforceable) that wood burning is not allowed in your neighbourhood.

# FURTHER INFORMATION

**Links**
Clean Heat project page: www.clean-heat.eu
Doctors and Scientists Against Wood Smoke Pollution: www.woodsmokepollution.org

**Project partners**
Green Transition Denmark: www.rgo.dk
Deutsche Umwelthilfe: www.duh.de
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, 2021: WHO global air quality guidelines, https://www.who.int/publications/i/item/9789240034228

Aarhus University, 2021:
Annual Danish Informative inventory report to UNECE
https://dce2.au.dk/pub/SR435.pdf

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

**Many people do not know that they produce high amounts of hazardous air pollutants by residential burning – even if they have a new eco-labelled stove operating under optimal conditions.**
**Information about – and strict regulation of – air pollution from residential burning is the way to cleaner air.**

**Residential wood burning in Copenhagen emits more particles than all road traffic in the city every year even though residential wood burning only covers about 0.5% of the energy consumption in the city.**

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 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 air pollution from other pollution sources, the pollution from wood burning has not decreased significantly over the past 30 years in Denmark because tax exemption has turned wood burning into an economically attractive solution at the expense of more environmentally friendly heat sources.

Emphasis in this booklet is on pollution from wood burning, the associated adverse health effects and health costs. In addition, focus is on climate impacts of soot particles and $CO_2$ from wood burning. Finally, attention is drawn to the many technical solutions, the political decisions, and local initiatives that may give incentive to implement these solutions thereby reducing the health and climate damaging air pollution from wood burning. The booklet gives many examples on Danish actions and put these into an international perspective.

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

GREEN TRANSITION DENMARK

clean heat

Deutsche Umwelthilfe