Levegő Munkacsoport

Particle pollution caused by household heating with solid fuels and possible measures for its reduction

by

Gerda Gavenaite

student of Kaunas University of Technology (Lithuania)

and

Guillermo Lozano Hurtado

student of Rey Juan Carlos University (Spain)

interns of Clean Air Action Group (Budapest, Hungary)

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Introduction

Historically, the use of solid fuels has been warming our lives. Nowadays, the tradition continues. Wood, coal and waste are used by millions of homes around the world as heating fuels and as a disposal way for garbage. Furthermore, it is not expected that the use of biomass energy will decrease in the global rural population for at least a century, and some studies indicate it may increase. In Europe as a result of climate policies biomass will be one of the main fuels for such practices. The solid fuels can cause several problems for the environment and human health by releasing toxic pollutants during combustion. The most important are: soot, black carbon (BC) and particular matter (PM) as well as hazardous compounds adhered to solid surfaces such as dioxins and furans.

The contribution of household heating to air pollution is significant. For example, in Central Europe 21% of outdoor particulate matter with an aerodynamic diameter of less than 2.5 micrometres (PM2.5) can be traced to residential heating with solid fuels in 2010 (WHO, 2015). In Hungary, this proportion was 77% in 2014.

Several studies analysed the consequences of the use of solid fuels in households and the best burning practices that can improve indoor and outdoor air quality in the last years. Still nowadays, the population has not a clear idea about how to use their heating systems in a correct way or choosing the best option available in the market or which burning practices are banned in their countries. The lack of knowledge has conducted to bad practices that are worsening air quality and cause several problems to the environment and health systems as well contributing to climate change. In this study the main points of these studies are covered in order to help raise public awareness and consciousness and to analyze the current situation in a comprehensive manner.

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List of figures and tables

Explanation of soot and black carbon

Soot can be obtained from various surfaces such as chimney flues or soot boxes. It can be collected on filters placed in the pathway of emissions. The aerodynamic properties, that is, whether the particles settle or remain airborne, are determined by particle mass and size. Changing flue temperature also influence chemical reactions on particle surfaces. Flue temperatures cool as a function of distance from the combustion source, and the partitioning of organic compounds between the vapor phase and particulate phase is affected. Therefore, different collection sites will sample soot particles with different characteristics, even if the fuel source is the same. Black carbon (BC) — or carbonaceous compounds in general — are a constituent of particulate matter(PM) dispersed in the air, and they are a major component of soot.

The terms black carbon and soot often have been used interchangeably; however, black carbon is physically and chemically distinct from soot. More than 97% of black carbon black consists of elemental carbon arranged as aciniform particulate. For both black carbon and soot, other elements and chemical compounds are associated with the particulate carbon. Soot has much greater percentages of ash than black carbon. There has been concern about the adsorbed organic compounds because of potential biologic activity. Black carbon is distinctly different from soot, and when discussing potential health effects, care must be taken to differentiate between the two types of carbon-based particles.

Black Carbon and soot differ in the following characteristics:

- Physical parameters, such as particle size and surface area;
- Carbon content and form of particulate carbon;
- Overall composition of organic carbon and organic elements;
- Total amount and types of organic compounds obtained from solvent extracts

Particle pollution, also called particulate matter or PM, is a mixture of solids and liquid droplets floating in the air. Some particles are released directly from a specific source, while others form in complicated chemical reactions in the atmosphere. Particulate matter is made up of a number of components, including acids (such as nitrates and sulphates), organic chemicals, metals, and soil or dust particles. For purposes of air quality and health studies, PM is typically measured in two size ranges: PM10 and PM2.5.

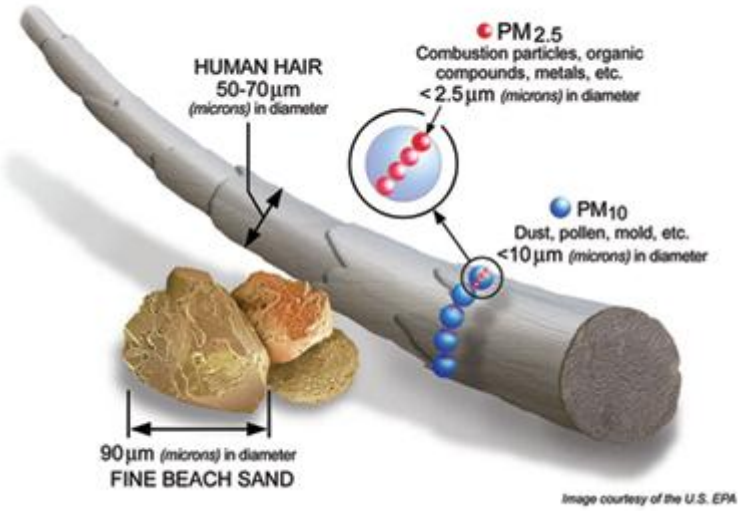


Figure 1: Size comparison between particle matter, hair and fine beach sand

Source: United States Environmental Protection Agency.

Climate effects

Black carbon has a unique and important role in the Earth's climate system because it absorbs solar radiation, influences cloud processes, and alters the melting of snow and ice cover. A large fraction of atmospheric black carbon concentrations is due to anthropogenic activities. Concentrations respond quickly to reductions in emissions because black carbon is rapidly removed from the atmosphere by deposition. It has a unique combination of the following physical properties:

- It strongly absorbs visible light;
- It is refractory; that is, it retains its basic format very high temperatures;
- It is insoluble in water, in organic solvents including methanol and acetone, and in other components of atmospheric aerosol;
- It exists as an aggregate of small carbon sphere.

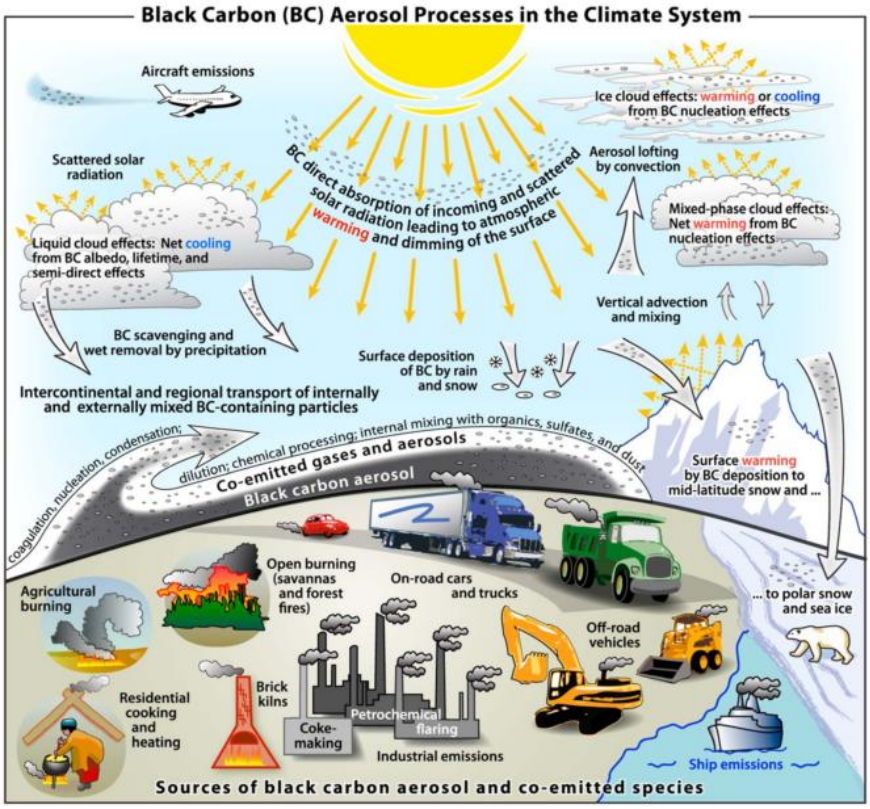


Figure 1: Schematic overview of the primary black-carbon emission sources and the processes that control the distribution of black carbon in the atmosphere and determine its role in climate system. *Source: T.Blond, S. Doherty, 2013.*

The US Environmental Protection Agency (EPA) in their study "Black carbon and its effects on climate" (2012) reported that these particular emission influences climate through multiple mechanisms:

Most combustion occurring on Earth (both anthropogenic and natural) involves carbon-based fuels, mainly fossil fuels (coal, oil, and natural gas), biomass (mostly wood and crop residues), and biofuels (e.g. ethanol). Complete combustion of a carbon-based fuel means all carbon has been converted to CO2. Once ignited, the fuel must be well mixed with oxygen at a sustained high temperature for this to occur. Incomplete combustion emits various materials in both gas and particle form, depending on the combustion conditions (e.g. oxygen availability, flame temperatures, and fuel moisture) and the type of fuel burned (e.g. gas, liquid, or solid).

Climate related effects vary across regions, EPA report shows summary of the impact in particular regions.

Table 1: Climate related effects of black carbon in various regions

USA	Asia	Artic
– Temperature estimates of average warming from BC in the Northern Hemisphere range from 0.29ºC to 0.54ºC. In the western US, BC deposition on mountain glaciers and snow produces a positive snow and ice albedo effect, contributing to the snowmelt earlier in the spring. – Early snowmelt reduces the amount of water resources which normally would be available later in the spring and summer, and may contribute to seasonal droughts.	– South and East Asia have some of the world's highest estimates of radiative forcing. – Over the Himalayan region, atmospheric BC was estimated to result in up to 0.6ºC of warming. – Precipitation and temperature gradient modifications can lead to shifts of regional circulation patterns such as a decrease in the Indian and Southeast Asian summer monsoon rainfall and a north-south shift in Eastern China rainfall.	– BC deposited on snow results in warming of roughly 0.4 to 0.5°C, varying by season. – Atmospheric BC was estimated to contribute roughly 0.2°C in spring, 0.1°C in summer, and nearly zero in autumn and winter. – BC may increase snowmelt rates north of 50°N latitude by as much as 19-28%. – Soot deposition in the Alaskan Arctic tundra created snow free conditions five days earlier than model runs without BC deposition.

Source: Feng Y., (2009) Air pollution, greenhouse gases and climate change.

The black carbon climate forcing from the direct effect and snowpack changes cause the troposphere and the top of the cryosphere to warm, inducing further climate response in the form of cloud, circulation, surface temperature, and precipitation changes. In climate model studies, black-carbon direct effects cause equilibrium global warming that is concentrated in the Northern Hemisphere. The warming response to black-carbon-in-snow forcing is greatest during local spring and over mid-to-high northern latitudes. In terms of equilibrium global-mean surface temperature change, the BC total climate forcing estimate over the industrial era would correspond to a warming between 0.1 and 2.0°C. Note that not all this warming has been realized in the present day, as the climate takes more than a century to reach equilibrium and many co-emitted species have a cooling effect, countering the global-mean warming of BC (Bond et al, 2013).

Health effects

WHO (World Health Organization) in its 2014 report announced that in 2012 about 7 million people worldwide died prematurely from air pollution, and in Europe almost 600 thousand people.

Outdoor air pollution is associated with 3.7 million deaths worldwide (in Europe, 482 thousands), and indoor air pollution with 4.3 million deaths (in Europe, 117 thousand). An important statistic for this report are the 61,000 deaths attributable to ambient air pollution from residential heating with wood and coal in Europe per year.

In October 2013, International Agency for Research on Cancer (IARC) declared that there is sufficient evidence of carcinogenicity in humans due to PM2.5 and PM10 emission.

Every person has different reaction to PM pollution, effect on health depends of several factors:

- Particle size;
- Pollution concentration in the air;
- Composition of the particles;
- Duration of the impact (short or long term);
- Individual sensitivity

Short term health effect on particular matter may cause:

- Inflammatory reactions in the lungs
- Respiratory tract illness symptoms
- The negative impact for heart and blood vessel system
- Increasing number of hospitalizations and deaths

Long term health effect:

- Asthma, bronchitis, emphysema flare-up
- Flounder cardiac activity
- Uneven lung function which can lead to lung cancer
- Shorter period of lifetime mostly because of heart and blood vessel illnesses.

Table 2: Health effects of fine particulate air pollution

Lungs	Heart	Blood	Brain
- Inflammation - Oxidative stress - Increased respiratory problems - Lung function decline	- Heart attacks - Heart and blood vessel disorders - Increased heartbeat rate;	- High blood pressure; - Hypoxemia (low blood oxygen)	- Stroke
PM impact on children			
- Newborn and baby deaths (because of breathing disorder) - Lower newborn body weight; - Negative effect on the development of lungs; - Asthma flare-up - PM is associated with premature childbirth, pregnant women and their unborn babies are more affected by air pollutants.			

Source: C. A. Pope, D. W. Dockery, 2006, Health Effects on Fine Particulate Air Pollution: Lines that Connect

Worldwide, the contribution of different risk factors to disease burden has changed substantially, with a shift away from risks for communicable diseases in children towards those for non-communicable diseases in children and adults. New evidence has led to changes in the magnitude of key risks including ambient particulate matter pollution (Lancet et al., 2012). Table 3 shows risk factors according to illnesses in 2010 (Lancet et al., 2012) where we can recognize impact of household air pollution from solid fuels, to ambient particular matter pollution.

Table 3: Health risk factors of particulate matter pollution

Ranking legend
1–5 6–10 11–15
16–20 21–25 26–30
31–35 36–40 >40

Risk factor	Global	High-income Asia Pacific	Western Europe	Australasia	High-income North America	Central Europe	Southern Latin America	Eastern Europe
High blood pressure	1	1	2	3	4	1	2	2
Tobacco smoking, including second-hand smoke	2	2	1	2	1	3	3	3
Alcohol use	3	3	4	4	3	2	4	1
Household air pollution from solid fuels	4	42	..	..	..	14	23	20
Diet low in fruits	5	5	7	7	7	5	6	5
High body-mass index	6	8	3	1	2	4	1	4
High fasting plasma glucose	7	7	6	6	5	7	5	10
Childhood underweight	8	39	38	37	39	38	38	38
Ambient particulate matter pollution	9	9	11	26	14	12	24	14
Physical inactivity and low physical activity	10	4	5	5	6	6	7	7

Source: Risk factors according to illnesses in 2010. Lancer et al.

Roadmap 2050, EU strategy to decarbonisation

Climate change is a problem, which plays out over long timescales. If the emission of greenhouse gases were to cease today, global temperatures would continue to increase by decades, and sea-level continue to rise for centuries (Munasinghe & Swart, 2005). While we can already see climate change impact, the main risks are expected to be occur in the near future. Because of this reason, countries around the world are exploring the options of future scenarios to sustainable development.

In July 2009, the leaders of European Union and the G8 announced an objective to reduce greenhouse gas emission by at least 80% below 1990 levels by 2050. Such an effort appears necessary in order to avoid a temperature increase of more than 2ºC which would create a severe climate change hazards (Hubler & Lochel, 2013). The European Commision published a communication on how to be achieved a low-carbon economy in Europe, in line with the energy security, environmental and economic goals of the European Union, which is mainly called "Roadmap 2050" (European Commission, 2011).

Roadmap 2050 suggests milestones which are 40% emission cuts by 2030, 60% by 2040, and 80% by 2050 below 1990 levels. Since this paper shows the necessity to reduce emission of

household heating, the paper focuses on emissions from buildings that can be almost completely cut by around 90% in 2050.

EU strategy on Heating and Cooling: Decarbonizing our buildings

Heating and cooling represent around half of the EU energy consumption (European Commission 'An EU Strategy on Heating and Cooling, 2016). The main idea of the decarbonization on buildings is to cut costs and deliver EU greenhouse gas emission reduction under the climate agreement which was reached in COP21 climate conference in Paris.

To achieve our decarbonisation objectives, buildings must be decarbonized. This entails renovating the existing building stock, along with intensified efforts in energy efficiency and renewable energy, supported by decarbonized electricity and district heating (European Commission 'An EU Strategy on Heating and Cooling, 2016). The main challenge that EU face is to switch from fossil fuels to low-carbon fuels. Biomass will play a key role in that environmental policy. Therefore, the management, assessment and reduction of compounds and gases associated with biomass burning practices (PM, black carbon...) could be essential for climate system in the next years.

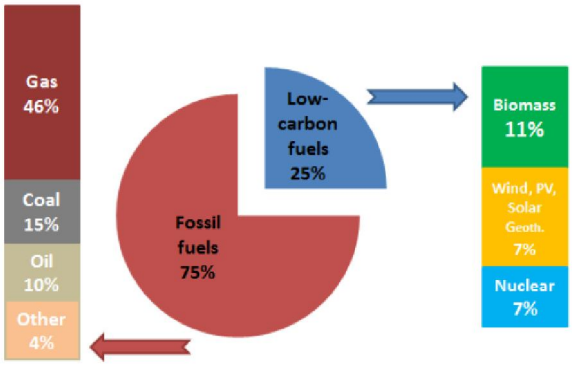


Figure 3: Switching from fossil fuels to low-carbon fuels

Source: European Commission 'An EU Strategy on Heating and Cooling, 2016'

According to ‘EU Strategy on Heating and Cooling 2016’, almost half of the EU's buildings have individual boilers installed before 1992, with efficiency of 60% or less. 22% of individual gas boilers, 34% of direct electric heaters, 47% of oil boilers and 58% of coal boilers are older than their technical lifetime.

Decisions on replacing old appliances are typically made under pressure, when the heating system breaks down. Comparison of prices between solutions, as well as information on how their existing system performs, is not easily available for most consumers. This leads them to continue using older, less efficient technologies.

In some parts of Europe, up to three quarters of outdoor fine particulate matter pollution is attributable to household heating with solid fuels (including coal and biomass). The Commission has initiated infringement procedures on ambient air quality against several Member States, referring two cases regarding persistently high levels of fine particulate matter to the European Court of Justice in 2015. The Commission warns about the negative impact on air quality from the use of coal (lignite) and boilers and stoves with poor emission standards for heating as healthier solutions are available, easily accessible and more efficient and cheaper in the long run.

European Commission suggests member countries initiatives to reduce PM emission into the atmosphere. One of the good practices can be considered ‘Eco design and labeling requirements’ for space and water heaters. The initiative was taken in 2015. At the same time, emissions of air pollutants will also be reduced (European Commission ‘An EU Strategy on Heating and Cooling, 2016). In wood burning section we can find an extended resume of such regulation.

Wood burning

Wood burning is not as clean as we can think. This practice releases several indoor and outdoor hazardous compounds. The quantity and toxicity depends of the technology used, how we use it, the maintenance, the type and characteristics of fuel and geography. Actually it is not expected that the use of wood will be reduced in Europe in the coming years. The main reason is the climate policies. However, it is necessary inform the population about risks associated with wood burning, encourage the government in order to develop strong policies in which incentives play a key role to substitute old devices by state-of-art technologies and promote

campaigns in order to increase the awareness and consciousness related with good burning practices and other useful instruments to improve the indoor and outdoor quality air.

Chemical compounds released

Wood (and other biomass) smoke contains not only BC but also gaseous air pollutants linked with a range of potential health outcomes like CO, NOx and VOCs, gaseous and particulate PAHs, as well as other organic compounds. Combustion of biomass that contains chlorine, for example, which has been treated or transported via saltwater, can also emit chlorinated organic compounds.

Apart from BC, one compound has special interest. Wood smoke is the third largest source of dioxins. European Commission reveals wood burning practices as one of the major sources of polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF), two precursors of dioxins and furans, respectively (Berdowski et al. 1997). It is one of the most intensely toxic compounds known to science. More details one can find in the chapter on Waste burning.

We can find some examples detailing the toxicity of these practices. Burning 10 lbs of wood for one hour releases as much PAHs (polycyclic aromatic hydrocarbons) as 6,000 packs of cigarettes. Toxic free-radical chemicals in wood smoke are biologically active 40 times longer than the free radicals in cigarette smoke. The inhalable particulate pollution from one woodstove is equivalent to the amount emitted from 3,000 gas furnaces producing the same amount of heat. The very small size of wood particles makes them seven times more likely to be inhaled than other particulate pollution as "*Utah Physician for a Healthy Environment"* reported.

The contribution of wood burning indicates that wood combustion accounts for 20–30% of local heating-season ambient PM2.5 levels althought this varies greatly by location.

Table 4: The contribution of wood burning to total outdoor PM2.5 pollution

Region	PM2.5 from residential heating (%)		PM2.5 from residential heating (µg/m3)	
	1990	2010	1990	2010
Central Europe	11.1	21.1	3.5	3.4
Eastern Europe	9.6	13.1	2.0	1.4
Western Europe	5.4	11.8	1.3	1.7
High income North America	4.6	8.3	0.9	1.1
Central Asia	9.9	8.3	2.4	1.6
Global	3.0	3.1	0.9	0.7

Source: Residential heating contribution to outdoor PM2.5 and burden of disease, selected regions, 1990 and 2010 (Amann et al., 2011; IIASA, 2014; EC JRC, 2014).

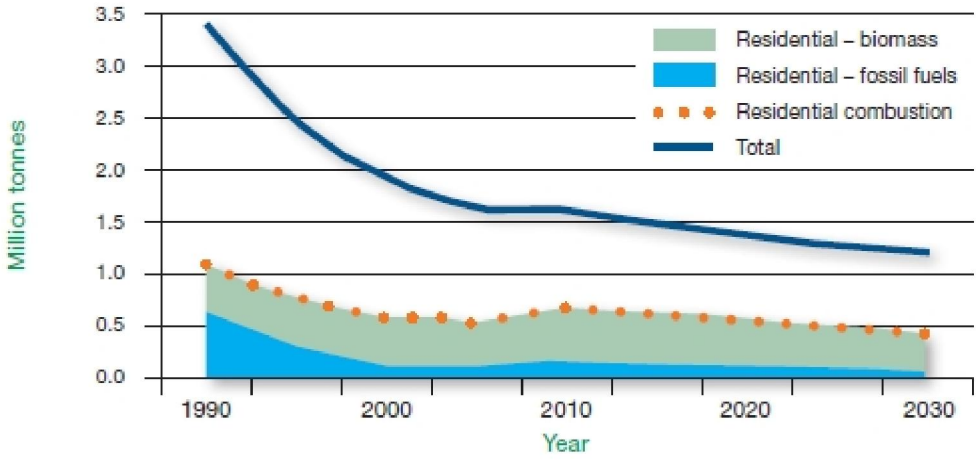
Future in Europe

It is not expected that wood use for heating in Europe will be reduced in the next years. Europe is not an exception, in the United States wood burning grew by 34% in the period between 2000 and 2010, especially low-and middle-income households. The relative contribution in EU-28 of PM 2.5 and BC from use of biomass for heating will increase although declining in absolute terms. This scenario is strongly related with current climate policies. The European Union´s main target is to reduce fossil fuel use. Further problems associated with wood burning strategies are:

- Necessity of stronger economic incentives in order to replace old solid fuel heaters by state-of-art technologies with higher efficiency and less emissions per unit of fuel used.
- There are not enough social campaigns addressing the problems associated with such practices. Lack of awareness and consciousness is widespread among the population. Still Nowadays people still have little knowledge about the current legislation in their countries, the best choices available in the market or good burning practices.

A moderate increase in the use of wood will not result in higher amount of toxic pollutants such as PM2.5 or BC due to increased efficiency. However, with the current legislation, it is expected to maintain similar levels.

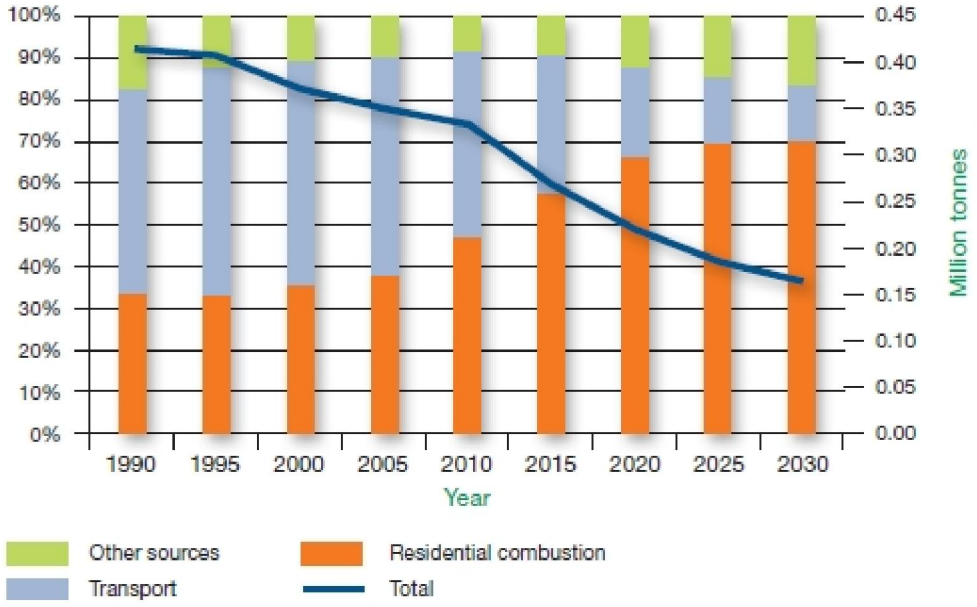
Table 5. Emissions of PM2.5 from residential sources in the EU-28, 1990–2030.



EU-28 is countries belonging to the EU after July 2013; current legislation scenario as in Amann et al. (2014), using the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model (Amann et al.,2011).

Source: Residential Heating with wood and coal: health impacts and policy option in Europe and North America, WHO (2015).

Table 6: Baseline BC emissions from the common major sources in the EU-28, 1990–2030



EU-28 is countries belonging to the EU after July 2013; current legislation scenario as in Amann etal. (2014), using the carbonaceous particles module (Kupiainen and Klimont, 2007) of the GAINS model (Amann et al., 2011).

Source: Residential Heating with wood and coal: health impacts and policy option in Europe and North America, WHO (2015).

New legislation

Several European countries have developed in the last years a variety of new regulations for the improvement in efficiency and/or emission limits standards. In addition, incentives were available for purchasing new devices. Nevertheless, old wood burners are still in market from these countries with lack of regulation for such components. This scenario can hamper the internal market. Old devices are cheaper than new ones. Moreover, a European common target would be difficult without common rules for the participant countries. Because of that, and replying to the fact that some countries have stated developing new legislations the previous years, European Commission has elaborated a new policy related to solid local fuel space heaters and boilers particularly those that use various forms of woody biomass fuel (wood logs, pellets and biomass bricks), to create proposed ecodesign emissions limits. Energy efficiency and emission regulations are currently being developed for solid fuel space heaters (ENER Lot 20) and solid fuel boilers (ENER Lot 15) under the ecodesign directive (European Commission, 2009). From 1 January 2022 emissions of particulate matter (PM) from solid fuel local space heaters (SFLSH) shall not exceed the values presented in Table 7.

Table 7: Emission standards for solid fuel local space heater (SFLSH) proposed by the European Commission.

Device / **Limit Standards, not to be exceeded**	**Open fronted SFLSH**	**Closed fronted SFLSH**	**Closed fronted SFLSP using wood compressed in form of pellets**
PM 2.5	50 mg/m3	40 mg/m3	20 mg/ m3
Organic compounds	120 mgC/m3	120 mgC/m3	60 mgC/m3
CO	2 000 mg/m3	1 500 mg/m3	300 mg/m3
NOx	200 mg/m3 (biomass only)	200 mg/m3 (biomass only)	200 mg/m3 (biomass only)

Source: Standards limits for solid space heaters. Ecodesing directive (European Commission, 2009)

Compared to a business-as-usual scenario it is expected that the proposed Regulation together with the Commission Delegated Regulation on energy labelling will save about 183 PJ (about

4.4 Mtoe) per year by 2020 (EU-27). In terms of generation capacity, this would be equivalent to 12 coal power plants. The related CO2 emission reductions of are around 5.8 Mt, particulate matter emissions will be reduced by 16.8 kt/year, organic gaseous compounds will be reduced by 4.3 kt/year and carbon monoxide will be reduced by 248.6 kt/year by 2020.

Administrative measures and results

One successful intervention in Launceston, Tasmania, combined fuel switching (via replacement of wood stoves with electricity) with community education and enforcement of environmental regulations (Johnston etal., 2013) to reduce the proportion of households heating with wood from 66% to 30%. Wood heating accounted for 85% of PM emissions at the beginning of the 13-year study; mean wintertime PM10 concentration dropped by 39% (from 44 to 27 μg/m3) with the interventions. This improvement in air quality was associated with reductions in annual mortality, after adjustment for general regional improvements in health that were charted in a nearby location (Hobart) over the course of the study.

Best practices

1. **How to burn**

Toxic compounds may form during burning practices regardless of the composition of the material being burnt. This is a result of incomplete combustion. High efficiency combustion, however, will result in a much smaller amount of organic compounds such as benzene (catcinogenic) or dioxins and an increase in inorganic salts such as potassium sulfates, chlorides and carbonates and zinc, depending on the type of biomass (Larson & Koenig, 1994; Lighty, 2000). Under ideal burning conditions, meaning 100% efficiency, all the wood is converted to CO2. A modern stove or fireplace is not the only aspect that affect the efficiency. The way we burn, how we take into account the characteristics of our devices and other circumstances before we use our wood are important as well. In the following text good burning practices are exposed. It is also useful to ask the manufacturer or the retailer at the sale point.

- Ensuring adequate air flow. When used correctly to optimize airflow, pellet stoves produce a much lower level of BC and polycyclic aromatic hydrocarbons (PAHs) than conventional wood stoves (Eriksson et al., 2014). For example, pieces of wood can obstruct the flow of incoming air if these are bigger as the device. In example using bigger pieces of wood as the manufacturer recommend. An adequate quantity of oxygen ensures a more complete combustion of fuel avoiding or reducing the release of not only

gaseous pollutants but solid pollutants containing PCDD/PCDF, and the formation of secondary hazard compounds such as CO.

- There should be enough space in the firebox for optimal airflow. This measure and the one mentioned before also prevent a bad mix between the gas given off by the fire and air. High turbulence (chaotic movement of the air) give as result better combustion of the compounds released by the combustion, improving the quality of the outcome air.
- Sufficient residence time is necessary in order to have a complete combustion.
- Avoid excess of fuel. The efficiency is reduced when we burn more wood that the optimal quantity. This depends on the device.
- Minimal disturbance of the glow bed is necessary.

2. Material

- Burning wood with household waste will increase hazardous compounds such as dioxins, furans and others. In chapter on waste burning there is detailed information about such practices.
- Only burn clean, dry, seasoned, untreated wood, or sea-salt laden driftwood in your heating device. Firewood must be prepared at least for a year. It should be stored in a dry wind-proof location, not basements or garages. In addition, material burnt often includes not only natural wood but also wood wastes coated and treated with different chemical compounds including organochlorines (dioxins precursor). Wood residues (waste and industrial) often contain various types of contaminants (chromated copper arsenate, pentachlorophenol, creosote, adhesives, resins, paint and other surface coatings) that are released in variety of forms to indoor and outdoor space.

  Comparative emission factors were derived from studies carried out in different European countries for the combustion of treated versus untreated wood and are given in the table below.

Appliance type	Emission factors: µg TEQ/TJ of biomass burnt to air	Concentration: ng TEQ/ kg ash residue
Contaminated wood/biomass-fired stoves	1,500	1,000
Virgin wood/biomass-fired stoves	100	10

TJ = terajoule = 1 x 10^{12} joule.
µg TEQ/TJ = µg of toxic equivalents.
Emission factors for releases with residues are given on the basis of measured concentrations in the ash and are not related to the heating value of the fuel.
Source: UNEP 2005

- Where available, seasoned hardwoods (instead of softwoods) should be used in wood-burning stoves and fireplaces. Hardwoods burn hotter and form less creosote (an oily, black tar that sticks to chimneys and stovepipes, posing a fire hazard).
- Painted scrap wood or wood treated with preservatives are never to be burnt, because they could release highly toxic pollutants.
- Environmentally friendly alternatives: Renewables such as solar heat and geothermal energy, including efficient heat pumps, are recommended. Renewable or biomass based district heating from combined heat and power plants can also be an eco-friendly solution. In urban regions, surplus heat from industry may be used for heat supply (Deutsche Umwelthilfe, The Danish Ecological Council, 2016).

3. Maintenance and best technology

Emissions from modern combustion appliances for wood logs may increase ten-fold if they are not operated appropriately or frequently maintained, and most of them are not. The maintenance is an obligatory measure for the optimal performance of the wood burner. Revisions should take place periodically. It is the only manner to keep air outputs without impurities for an optimal air flow. In addition, such measures avoid future problems with stoves and fireplaces. One example is CO, which can sometimes even be fatal, may occur due to indoor emissions of wood combustion products when ventilation of the wood-burning appliance is not managed properly.

To choose the best available option in the market we need to take knowledge about the different features of heating systems. In the text we can find some references to take into account at the time we purchase new device, e.g. in “New legislation” we found emission standards for new devices placed in market settled by European Union from 2022, this limits can bring us an idea in order to make differences between high-pollutant and low-pollutant devices. Below further advices are stated:

- Eco-design boilers and space heating systems have the lowest carbon emission and give more rational distribution of costs. Life-cycle costs are often higher in devices with less efficiency and high consumption.
- Regularly clearing out the flues, chimney, exhaust vent pipes and ashtrays is necessary. In addition, take into account that they are properly connected and in good condition, and chimney flue is open during operation. Ensure that the heat exchanger is not cracked. Revise manufacturer´s guidelines for installation and working in order to have a performance as the manual indicates. It is highly recommendable to pay once per year

(at the beginning of the heating season) a qualified person or company to do this kind of work.

- ❖ Install new industrially manufactured home heating equipment that meet specific energy demand for space to reduce not only air pollution, but also expenses.
- ❖ Eco-design standards to small sources would reduce soot emissions by nearly 50% in 2020, by 80% in 2030 and by more than 90% in 2050. About 70% of these emission reductions emerge from stoves.
- ❖ Consider non-wood options. Natural-gas-fired stoves and fireplaces are much cleaner than those that heat with wood. Fireplaces can be retrofitted to use natural gas instead of wood. Pellet and corn stoves also tend to be significantly cleaner than wood stoves.
- ❖ Proper dimensioning and particle separators: If a new stove is to be purchased, proper dimensioning and a smart integration in an overall heating concept is strongly required (e.g. buffer storage for excess heat). In addition, further development efforts have to be taken to improve combustion and exhaust cleaning technology. Especially for smaller appliances, there aren't many exhaust cleaning solutions and those offered in the market often do not deliver the emission reduction promised (Deutsche Umwelthilfe, The Danish Ecological Council, 2016).

4. Voluntary measures

- ❖ Limit your use of fireplaces, especially on smog days it decreases indoor and outdoor pollution.
- ❖ Building efficiency and energy renovation: The soundest measure is to minimize the heat consumption of houses by better insulation. Whether wood burning is a supplementary heat source (stove) or the primary heat source (boiler), the energy renovation of the home will effectively reduce the amount of wood burned and the related air pollution (Deutsche Umwelthilfe, The Danish Ecological Council, 2016).

Coal burning

Coal has been used for residential heating for centuries. In the 1960s coal and coke (a coal derivative) were the residential heating fuels of choice in Germany (84% of energy use in the residential sector) and France (68%), and were second only to oil in Denmark (33%) and Canada (22%). By the 1980s, however, residential coal/coke use was virtually nonexistent, accounting less than 0.5% in Canada, Norway and Sweden. In the Netherlands coal was the major heating fuel in the 1950s and 1960s but disappeared from use by the mid-1970s, primarily due to domestically available oil and natural gas resources (Dzioubinski & Chipman, 1999). In the USA 55% of homes used coal/coke for space heating in 1940, but this fell to 12% in 1960, below 5% in the early 1970s and below 1% from the early 1980s (Schipper et al., 1985; United States Census Bureau, 2011). One study estimates that reductions in the use of bituminous coal for household heating in the USA from 1945–1960 decreased winter all-age mortality by 1% and winter infant mortality by 3%, saving nearly 2000 lives per winter month, including 310 infant lives (Barreca et al., 2014).

Highlights of coal burning

According to Center for Climate and Energy Solutions (C2ES) a large number of environmental problems are associated with the production and combustion of coal. One significant impact is acid mine drainage, where acidic run-off is formed through a chemical reaction between water and sulfur-bearing rocks. This run-off contaminates creeks and rivers, and, because it diffuses easily, can be difficult to contain. Another significant impact is the practice of mountaintop mining. As the tops of mountains are removed to reveal coal seams, the sediment and waste becomes valley fill, impacting water quality and resulting in the loss of headwater ecosystems, or the species and environmental processes that are native to river sources.

The American Lung Association and the Clean Air Task Force (CATF) claims that 13,000 people die each year from coal pollution--down from 24,000 in 2004, when less pollution regulation was enforced. In addition to the premature deaths, CATF estimates that every year

coal pollution is responsible for 12,000 emergency room visits, 20,000 heart attacks, and over 200,000 asthma attacks
Coal is the most carbon intensive fossil fuel. According to the United Nations Environment Program, coal emits around 1.7 times as much carbon per unit of energy when burned as does natural gas and 1.25 times as much as oil. Coal typically requires a higher ignition and combustion temperature and has a higher content of sulfur and nitrogen than wood and other biomass.
Residential coal combustion is a source of SO2 and NOx as well as toxic pollutants adsorbed (adhering to the surface in an extremely thin layer) or absorbed to PM. Globally, the contribution represents 4% of SO2 and 1% of NOx emissions. Even with good combustion sulfur and other toxic contaminants are not destroyed.
Coal mining requires an estimated 70 to 260 million gallons of water every day.

In China (where residential coal combustion accounts for 7–8% of national SO2 emissions) and some central European countries that use substantial amounts of coal for heating, the proportion can be much higher than average global emissions.

International guidelines and administrative measures

Based on this and evidence that indoor emissions from household combustion of coal are carcinogenic to humans, the latest WHO indoor air quality guidelines strongly recommend against the residential use of unprocessed or raw coal for heating. WHO currently makes no recommendation about the residential use of processed coal but calls for future research to examine the content of, emissions from and exposure to pollutants – including toxic contaminants – from the use of "clean" or "smokeless" coal.

A useful example is found in Dublin. When coal sales were banned health and air quality improvements were tested, these were the results:

- Average concentrations of black smoke (fine PM measured by its blackening effect on filters declined by 70%.
- Non trauma death rates decreased by 5.7%.
- Respiratory deaths fell by 15.5%
- Cardiovascular deaths by 10.3%.

- About 116 fewer respiratory deaths and 243 fewer cardiovascular deaths were seen per year in Dublin after the ban (Clancy et al., 2002).

In a subsequent reanalysis the original authors concluded that the statistical approach did not adequately control for a downward long-term trend in mortality, and that the results were therefore not statistically significant; however, the reanalysis still showed a significant decrease in respiratory mortality (Dockery et al., 2013). However, in the study is showed an improvement in other Irish cities when the ban entered into force. Reduction in morbidity and mortality were found, and this numbers are higher in case of people affected by respiratory diseases. WHO indoor air quality guidelines for household combustion now strongly recommend against the use of unprocessed or raw coal as a household fuel.

Solid waste burning

Solid Waste, another term for trash or garbage, is often burned in communities. The composition may vary, however in many cases it is recyclable material. The waste often contains plastic and other synthetic materials that produce particularly dangerous air pollution when they are burned alone or mixed with coal or wood and without being treated or filtered. They release hazardous compounds resulting in harmful consequences for the human health: respiratory ailments, stress on human immune systems and potentially causing cancer. In addition, pre-natal problems can occur. A case study from 2012 concluded that garbage burning at home is an important risk factor for low birth weight. The names of these hazardous compounds are: PCB´s (polychlorinated biphenyls), dioxins, particulate matter, volatile organic compounds, carbon monoxide, hexachlorobenzene and ash.

In addition, pollutants can travel long distances and deposit in water and soil, contaminating water for human consumption and crop fields.

Start from yourself

Reduce: Find ways to reduce the quantity and volume of goods that are brought into the community that will need to be disposed of in the landfill, such as packaging and plastic bags. Choose long lasting items that will not need to be replaced frequently.

Reuse: Find ways to put used items to other uses or make used items available to others. Choose reusable items rather than disposable ones. Switch to cloth bags rather than plastic bags for groceries.

Compost: Organic waste such as yard trimmings and food scraps can be used for composting. By asking for information in local institutions, local communities, specialized shops or even in internet we can obtain high quality fertilizers for ourselves or third persons.

Recycle: Set up recycling and backhaul programs that will keep goods from going to landfills or for burning. Compost household food waste.

Properly dispose of waste: Don't litter or dump illegally. Use a waste collection service or take your waste to a transfer station, convenience center, or local landfill.

Check with your local institutions to learn about collection service and drop-off sites in your community

According to the data from chemical analysis performed in Poland, residential sources may emit stack gases containing about 3 times higher concentration of PCB than industrial sources (excluding manufacturing industries), about 2 times higher concentration of hexachlorobenzene (HCB) and 25 times higher concentration of PCDD/PCDF. The main reason for these high concentrations of PCDD/PCDF, PCB and HCB

is the co-combustion of domestic wastes with hard coal or wood, generally in simple kitchen stoves or heating boilers (Lassen et al. 2002, 2003)

Dioxins are the most toxic compound for human health and therefore, the most important. Open burning of household waste creates significant amounts of dioxins due to the low combustion temperatures, poor air distribution, and the presence of chlorine, which is found in almost all household waste components. Negative health effects occur even at low levels, and have been linked to serious health problems in humans. These include cancer and adverse developmental and reproductive effects.

Its effects are bioaccumulative. They pass through the food chain. Dioxins are taken by crops and feed animals or humans accumulating in our body-fat and thus mothers pass it on directly to their babies via the placenta.

PCB, particulate matter, sulfur dioxide, hexachlorobenzene and volatile organic compounds are part of waste smoke. Not only the people responsible for waste burning practices are in risk, but people living around it. These compounds can damage your lungs, nervous system, kidneys, and liver. The effects may be intensified in people with respiratory diseases.

The ashes are made by a such variety of compounds. Lead, mercury and arsenic are some examples. They contaminate garden plants and crops. They go through the food chain until humans. In addition, children that usually play in recreational gardens can be injured by ingestion; touching contaminated plants and then putting the dirty hands in their mouth.

Waste burning takes place also in residential burn barrels, open dumps, burn units, and landfills. Different reasons can explain these practices. In the past, backyard burning may have been the only way that many local settlements could get rid of their waste. Nowadays, we have enough resources in order to not continue with these historical practices. Actually, the population might see waste burning as an easier way to remove garbage than hauling it to drop-off centers. Consciousness about the associated risks can help tackle this problem. Avoiding paying for regular waste collection service is another reason. In some cases, people are paying for take-away of waste of small size, and they dispose illegally the garbage of big size by methods such as burning or deposition prohibited landfills. This practice is chosen when it is needed to pay for the volume of trash collected. Nevertheless, the environmental and health costs are much higher in medium- and long-term.

Administrative measures

The government should improve measures against waste burning practices, especially in households. Economic punishments are not the only way to stop them. It should carry out educational campaigns, from young to old people, informing about the risks associated.

Below, we describe the examples of some countries taking measures against wood burning.

Firstly, the Stockholm Convention on Persistent Organic Pollutants. It was entered into force in 2004. Since then, new conventions and agreements have been made. Actually, is signed by 152 countries and the number of parties are 180. One of the main targets was to ban any waste burning inside households. The convention has guidance to improve biomass burning practices in devices. It is called *"Best available techniques and best environmental practices to minimize emissions of chemicals listed in Annex C"*. For more information the annex can be found in Literature (number 3). Moreover, open burning was regulated.

The Irish government, by Sections 32 and 39 of the Waste Management Act, banned the burning of any waste by householders. Actually burning household waste in Ireland can incur a fine of up to €3,000 or 12 months in prison upon summary conviction in a District Court. Examples of prohibited places where it is not permitted to burn household and garden waste are:

- In a barrel or exposed pile in the yard or garden
- On a bonfire
- On an open fire, range or other solid fuel appliance
- In a mini-incinerator

Any kind of waste incinerator is banned. The only exception is *uncontaminated* agricultural waste (free of dangerous substances, preservatives or other artificial impregnation or coating) and must be notified to local authority. This exception will be ceased on 1 of January 2018.

There is also a voluntary measure in Ireland. By the program "See something? Say something" any person who witnesses illegal burning practices can report the incident to the local authority by a simple call

In México fines are from 600 pesos (30 €) until 25000 pesos (1253 €).

In the USA Forsyth County strictly enforces North Carolina's statewide ban against burning garbage, penalizing first-time offenders with fines ranging from $100 to $10,000.

➢ Country examples

Danish public awareness raising

Public engagement is well rooted in the everyday lives of Danish citizens. People are well informed about energy efficiency measures to change old technologies with the renewable energy assets.

In 2012 Danish Ministry of Environment started informational campaign "Stop Smoking Guide for Stoves" the main goal of which was to advice inhabitants. It included flyers, websites and movies.

Figure 4: Stop Smoking Guide for Stoves (2012). Flyer

Lithuanian Air pollution management program:

Kaunas city air pollution management program 2011-2014

Objective – to determine the influence of individual household heating on Kaunas city air quality, and to prepare proposals for better air quality control.

Suggestions:

In accordance with existing laws create new regulatory rules to control emissions (regulation of zoning, restrictions in increased pollution areas, for new inhabitant's requirement to remove outdated boilers in new property, communication between municipality and inhabitants to stop heating during days when air pollution exceeds the norms);

Investing in initiatives for replacing old boilers to the new (example of the Polish program "Eco Grant");

Development of district heating (in many national strategic plans the centralized energy supply is one of the priority measures to reduce the environmental impact of air pollution)

Citizen education **(**daily information on air quality is publishes on the website of Kaunas city, workshops on ambient air quality problems and ways of resolving them with NGOs, daily information on air quality on the city public transport screens)

Figure 5: Displaying the results of air pollution measurements on Kaunas city-public transport vehicles

Economic instruments

The Lithuanian Environmental Investment Fund function is to manage greenhouse gas emissions by financing objects which includes individual households.

More than one million euro was set to individual housing modernization which would reduce energy costs at least 20%.

The project REIMBURST up to 30% of a specified cost which will be needed.

Denmark

Denmark implemented a system of emissions limits for stoves and boilers in 2008. The law applies to both new and existing wood stoves and boilers installed after June 1, 2008. There are different, less stringent requirements for stoves only intended to heat a single room. The Environment Ministry also exempts straw-fired boilers in rural areas from particle emission limits. The law allows municipalities to restrict residential wood burning in small local areas based on community complaints; though there is no record that such a restriction has ever been implemented.

In 2008, Denmark introduced a scrapping payment for old wood boilers (i.e. those installed before 1980), based on the Danish environmental Ordinance (from December 2007). Individuals received a grant of up to 530 Euros if they replaced an old wood boiler with a new boiler that fulfilled the emission limit values set down in the ordinance, or used an alternative heat source.

This program led to the replacement of an additional 3 500 boilers, approximately doubling the number of boilers that would have been replaced in a usual 1-2 year period. Because old wood boilers are the most polluting heat source per GJ heat, the payment plan produced an immediate reduction in emissions—the net effect of which depends on the type of replacement heat source installed. Over the 1-2-year duration of the program, the scrapping payment is estimated to have achieved a total reduction of 1500 tons PM2.5, and 500 tons BC. Despite these short-term gains, the program was heavily criticized by some within the environmental community for not requiring that payment recipients shift to an even cleaner heating source, such as district heating or heat pumps.

Conclusions

Firstly, Clean Air Action Group urges that the regulations prohibiting waste burning by households must be enforced. The widely spread practice of household waste burning is polluting the air with a wide variety of harmful compounds. Improvement of awareness and consciousness about risks associated is needed and this study shows that this is necessary and possible.

Secondly, coal burning is one of the most pollutanting ways to heat our home. WHO strongly recommend to not use raw or unprocessed coal. Both of them have been associated with carcinogenic effects in human health. In addition, WHO calls for future research for "Clean" or "smokeless" coal. Therefore, we strongly recommend to switch coal devices to renewables and clean energies such as geothermal or solar, or inclusively using district heating based on renewable or biomass energy that use combined heat and power plants is a good choice.

Our last solid fuel, wood. Improving the way we burn wood, replacing old devices with state-of-the-art fireplaces, stoves and boilers, encouraging public institutions with strong incentives in order to replace them are some solutions that this study covered. Wood will be heating our houses for the next years. Europe targets in renewable consumption encourage it. Therefore, guidance for better use of wood burning devices, consciousness about the best technology, and awareness of risks associated with wood burning are essential.

Last but not least, measures such as better insulation of houses and low-consumption habits reduce the necessity of using heating fuels, thus improving our air quality as well as our health.

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