Emissions from burning plastics in domestic fireplaces, household stoves and boilers with special focus on persistent organic pollutants

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A literature review

Prepared for Arnika and CES
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“The European Union is made up of 27 Member States who have decided to gradually link together their know-how, resources and destinies. Together, during a period of enlargement of 50 years, they have built a zone of stability, democracy and sustainable development whilst maintaining cultural diversity, tolerance and individual freedoms. The European Union is committed to sharing its achievements and its values with countries and peoples beyond its borders”.

Contents:

Introduction

Pollution from domestic sources has become the focus of increasing research and regulatory attention in recent years. This is mainly because major efforts towards the reduction of certain emissions to air in the industrial sector have been successful[1,2]. Emissions of Persistent Organic Pollutants ('POPs') - most notably polychlorinated dibenzo-p-dioxins/polychlorinated dibenzofurans ("PCDD/PCDF" or, more commonly simply "dioxins") and Polycyclic Aromatic Hydrocarbons (PAH's)[3] have been particularly important because of the serious health and environmental impacts.

Overall emissions of dioxins to air have decreased considerably and the European inventory, for example, estimates that emissions of dioxin to air from legally operating waste incinerators fell from 4,000 grammes/year in 1985 to between 178 and 232 grammes/year in 2005[4]. The consequence is that domestic emissions to air now form a much higher proportion of the total emissions than was previously the case.

As a result of this reduction of industrial emissions it is now commonly claimed that domestic burning of waste has far higher emission factors than waste incineration. The European Commission, for example, say that "*One kg of waste openly burned may cause the same amount of dioxin emissions as 10 tonnes of waste burned in a modern incineration plant*"[5]. Reports from the Czech Republic claim that the emissions of dioxin from domestic combustion in a single village are similar to those from large incinerators[6].

These claims are rather misleading as the emission factors relate only to air emissions[7] and far more dioxins in modern incinerators partition to the ash residues than are emitted to air. These residues are commonly landfilled in sites which are not protective of the environment[8]. In some countries, such as the Czech Republic, it is common practice to use residues from incineration in construction projects[9]. The Stockholm Convention applies to emissions of POPs to all media and it is important that this is applied in practice when discussing different technologies and abatement techniques. Failing to properly address the

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1 At least in part – and sometimes almost entirely - by capturing the dioxins in the emissions to air in filters and thus increasing the dioxin content of flue gas residues which are subsequently landfilled.

2 BiPRO. (2009). *Information exchange on reduction of dioxin emissions from domestic sources ref: 070307/2007/481007/MAR/C4*. European Commission

3 PAHs are defined as POPs under the UNECE POPs Protocol – although they are not POPs under the Stockholm Convention. The consequence is that in Europe they are treated in a similar way to Stockholm POPs under the EU POPs legislation (Regulation 850/2004, as amended).

4 Quass, U., Fermann, M., & Broker, G. (2004). The european dioxin air emission inventory project - final results. *Chemosphere*, *54*(9), 1319-1327

5 European Commission. (2009). *Reduction of dioxin emissions from domestic sources*. European Commission

6 Horák, J. & Hopan, F. (2009). Může jedna vesnice vyprodukovat tolik dioxinů jako velká spalovna odpadu? (In Czech - can one village produce as much dioxins as a large waste incinerator?). *Topenářství Instalace*, (6), 36-38.

7 In the case of the Horák paper there also seems to be an underestimate of the emissions from incinerators when compared with the Czech PRTR reporting.

8 Macleod, C., Duarte-Davidson, R., Fisher, B., Ng, B., Willey, D., Shi, J. P., Pollard, S. (2006). Modeling human exposures to air pollution control (APC) residues released from landfills in England and Wales. *Environment International*, *32*(4), 500–509.
Macleod, C., Duarte-Davidson, R., Fisher, B., Ng, B., Willey, D., Shi, J. P., . . . Pollard, S. (2007). Erratum to "Modelling human exposures to air pollution control (APC) residues released from landfills in England and Wales" [environment international 32 (2006) 500-509]. *Environment International*, *33*(8), 1123-218
Weber, R., Watson, A., Forter, M., & Oliaei, F. (2011). Review article: Persistent organic pollutants and landfills - a review of past experiences and future challenges. *Waste Management & Research*, *29*(1), 107-121. doi:10.1177/0734242x10390730

9 Petrlik, J. & Ryder, R. (2005). *After incineration: The toxic ash problem April 2005 <http://Www.Ipen.Org,>*. Prague – Manchester: "Keep the Promise, Eliminate POPs!" Campaign and Dioxin, PCBs and Waste Working Group of the International POPs Elimination Network (IPEN)

issue can lead to simple diversion of POPs from air to soil rather than their elimination as required by the Convention. The practical implications are that the failure to address emissions to all media is likely to focus solutions on emission abatement and scrubbing rather than substitution of the original pre-cursors.

There is enormous variability in the emissions of PAHs from domestic sources and the emission factors are subject to high levels of uncertainty. There are indications, however, that in some countries with high reliance on biomass and coal for domestic heating and cooking residential emissions might be the amongst the largest emission sources of PAHs.

There remains a live debate about the relative importance of emissions of POPs from domestic sources but whether they are the largest source or not. The available evidence certainly indicates that waste combustion in domestic conditions can be a significant generator of dioxins and, particularly, of PAHs. These emissions should therefore be reduced and eliminated where possible – not least because the WHO-recommended maximum intake level for dioxins is still exceeded by up to 50% of the population[10]. Furthermore smoke from the use of coal, wood, biomass for domestic cooking and heating has been associated with a variety of health outcomes including lung cancer [11]. Around 3 billion people are exposed to smoke from domestic combustion worldwide and whilst most of the impacts are likely to be related to combustion in more primitive conditions than in most of Europe the annual global health burden of indoor air pollution from solid-fuel use, is estimated to be 2 million deaths and > 33 million disability-adjusted life years[12].

According to the European Commission domestic sources with potential for high emissions of dioxins include[13]:

- Heating and cooking with coal, wood or other biomass such as peat and straw in simple ovens
- Domestic combustion of waste or treated wood
- Backyard waste burning of waste

The report is one component of projects aimed at reducing emissions from these sources in the Czech Republic and other Central and East European Countries with particular emphasis on domestic combustion in fireplaces, stoves and boilers and where waste is burned with coal or biomass[14]. The literature review is therefore based on publications relevant to European countries where such data has been published. In some cases studies carried out in comparable conditions in other parts of the world have been used to supplement these.

It became clear at an early stage in this review that in comparison to emissions of POPs from municipal waste combustion, literature reports on emissions from small-scale biofuel and other domestic heating sources are scarce[15]. The review by BiPRO for the European Commission[16] reported 90 studies relating to the (then) current state of knowledge on dioxin releases from domestic sources. Only a small number of these were relevant to the specific concerns relating to the co-combustion of plastics or waste in domestic

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[10] European Commission. (2009). *Reduction of dioxin emissions from domestic sources*. European Commission

[11] Hosgood, H. D. ,. I., Boffetta, P., Greenland, S., Lee, Y. -C. A., McLaughlin, J., Seow, A., et al. (2010). In-Home coal and wood use and lung cancer risk: A pooled analysis of the international lung cancer consortium. *Environ Health Perspect*, *118*(12)

[12] WHO (2009). *Global health risks : Mortality and burden of disease attributable to selected major risks.* Geneva, Switzerland: World Health Organization

[13] European Commission. (2009). *Reduction of dioxin emissions from domestic sources*. European Commission

[14] Mainly wood but whilst peat burning is unusual in much of the CEE region it is still common in Belarus.

[15] Hedman, B., Näslund, M., & Marklund, S. (2006). Emission of PCDD/F, PCB, and HCB from combustion of firewood and pellets in residential stoves and boilers. *Environ Sci Technol*, *40*(16), 4968-4975. doi:10.1021/es052418

[16] BiPRO. (2009). *Information exchange on reduction of dioxin emissions from domestic sources ref: 070307/2007/481007/MAR/C4*. European Commission

situations. This represents an important gap in the scientific literature given the apparent significance of domestic sources in the dioxin inventories relied upon by the European Commission and other policy makers. Ironically their consultants, BiPro, comment that "*Dioxin emissions are currently not a driving force for environmental policy in the domestic sector*".

Combustion Equipment and Fuels:

According to the UNECE Guidebook, the relevant types of appliances for domestic combustion can be characterised as:

Fireplaces - usually very simple combustion chamber, with or without front door, in which fuels are oxidised to obtain thermal energy, which is transferred to the dwelling mainly by radiation.

Stoves - simple appliance in which fuels are combusted to obtain thermal energy, which is transferred to the interior of the building by radiation and convection

Boilers - any technical apparatus in which fuels are oxidised in order to generate thermal energy, which is transferred to water or steam

More full definitions and descriptions are included in Annex 1.

These appliances burn mainly solid fuels including hard coal, brown coal, patent fuels, brown coal briquettes, coke, charcoal, peat, solid biomass fuels. In the case of stoves and, especially, boilers, natural gas or liquid fuels (kerosene, gas oil, gas/diesel oil, residual oil, residual fuel oil etc) may be used as alternative fuels [17].

Household wastes, possibly including plastics, if burned with solid fuels may be used either continuously, intermittently or for start-up. Co-combustion of coal and wastes is usually practiced in residential stoves and an average of between 5 and 10 times higher emission factors according to Kubica[18].

Both biomass and fossil fuel are used extensively for domestic heating, especially in developed countries and in countries with economies in transition. Coal, light fuel oil and natural gas are the main sources of fossil fuel used for domestic heating and fossil fuels are burned in devices ranging from "small stoker fired furnaces" to "*highly sophisticated boiler/burner systems for central heat generation in large multi unit residential buildings*" (UNEP, 2005). Coal and biomass are also burned on residential grates and stoves which also range in sophistication from very basic to those with advanced air control and catalytic flue gas treatment.

Combustion for domestic heating generally takes place in two types of boilers (UNEP, 2005):

Central heating systems - Coal is still commonly used as a fuel in some CEE countries but these systems increasingly use oil or gas[19] in a large furnace to heat water, which then is circulated through the building

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[17] *EMEP/CORINAIR Emission Inventory Guidebook, Version 4 (2006 Edition) Technical Report No 11/2006. Available From Http://reports.eea.europa.eu/EMEPCORINAIR4/en/page002.html.* (2006).. European Environmental Agency

[18] Kubica, K., Paradiz, B., & Dilara, P. (2007). *Small combustion installations: Techniques, emissions and measures for emission reductions*. Joint Research Centre Scientific and Technical Reports, EUR. It is interesting to note that the source for this was indicated to be Grochowalski yet the cited original work, in Polish, did not appear to relate to domestic emissions. Nonetheless Grochowalksi has published several papers attributing high levels of ambient dioxin concentrations to residential incineration of waste in stoves burning black coal. See, for example, Grochowalski, A., Chrząszcz, R., & Wybraniec, S. (1995). Determination of PCDFs/PCDDs in ambient air from Cracow city, Poland. *Organohalogen Compounds* , *21*, 321-326

[19] The Polish NIP, for example, says "*combustion processes, in particular in individual furnaces, undergo gradual modernization and treatment of exhaust gases from coal-fired boiler houses is improving, with small, high-efficiency oil- or*

to release its heat in decentralised radiators[20]. These modern systems are typically highly efficient and fairly clean burning leaving little to no residue for disposal.

Individual stoves - mostly burn solid fuels and mainly coal. These are located in each room of the building or inside the wall to provide direct access to several rooms at the same time. The stoves consist of fairly small furnaces but provide a system for air to circulate inside the stove around the furnace. These systems are typically older, less efficient and less clean burning. Also bottom ash resulting from the inert content of the fuel is generated and must be disposed of. Some of these systems are also capable of burning oil or gas (UNEP, 2005).

Data on total usage of the various fuel option in the range of residential combustion appliances is generally poor and relies heavily on unvalidated estimations.

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gas-fired boiler houses being built". This shift to oil and gas is an action point in the Czech NIP which emphasizes "*Focus on the decreasing POPs emissions conditioned especially by the increase of the natural gas proportion in the households*"

[20] underfloor heating is becoming more popular as an alternative to radiators

Inventories and Emission Factors

Inventories for emissions of dioxins are not normally derived from direct measurements but are usually calculated based on statistical data of fuel consumption - activity rates ('AR') – which are then multiplied by emission factors (EFs). Thus the total emissions of a pollutant are calculated on the basis:

$$E_{pollutant} = AR_{fuelconsumption} \times EF_{pollutant}$$

where

$E_{pollutant}$ = the emission of the specified pollutant,

$AR_{fuelconsumption}$ = the activity rate for fuel consumption,

$EF_{pollutant}$ = the emission factor for this pollutant.

The EFs indicate the amount of dioxins released when a given amount of fuel goes through the combustion process and the two most widely recognised sources are the UNEP Dioxin Toolkit and the Emission Inventory Guidebooks published by the European Environment Agency for which the UNECE's Task Force on Emission Inventories and Projections has responsibility for the technical content of the chapters. The latest version of the UNECE guidance was published in 2009[21] and uses the default emission factors published in 2006 [22] for PCDD/PCDF emissions from hard coal of 800 ng I-TEQ/GJ with a 95%ile confidence range of 300 – 1,200 ng I-TEQ/GJ. For biomass the default emission factor was 700 ng I-TEQ/GJ with a 95%ile confidence range of 500 – 1,000 ng I-TEQ/GJ.

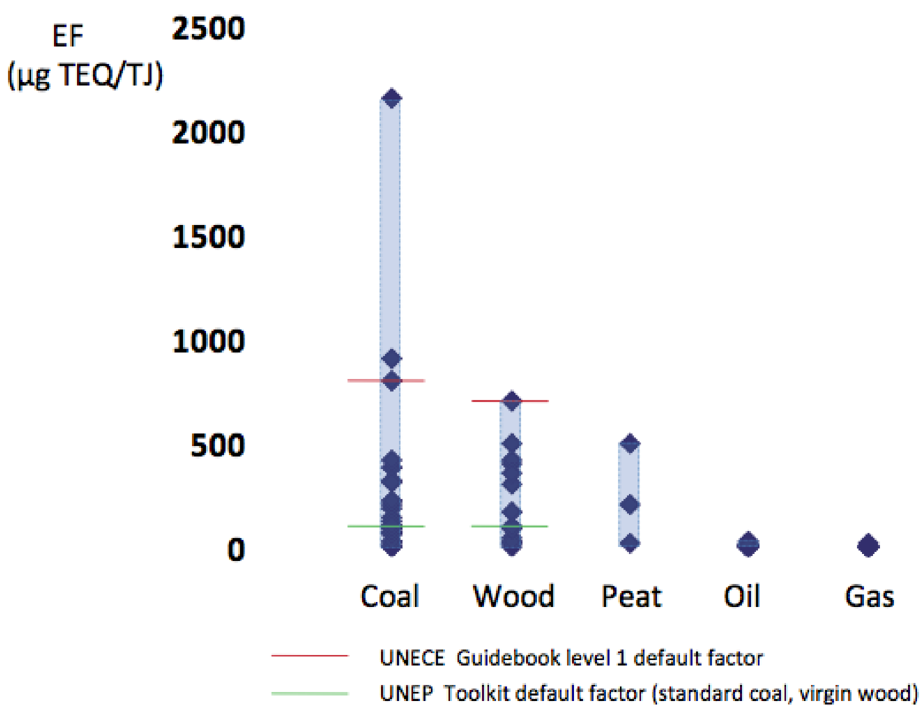
UNECE Guidebook Default EF ng I-TEQ/GJ	1A4bi Residential	Fireplace	Domestic Stoves	Advanced stove	Small boiler (<50 kWth)	Advanced manual boiler <1 MW	Medium size boiler (50kW - 1MW)	Pellet stove <1 MW	Medium size boiler (1 -50 MW)	Advanced automatic boiler
Coal	800	500	1000	500	500	200	400		100	40
Coal briquettes			300*		200		100		2	
Wood	700	800	800	300 (and fireplace)	500	300	500	50	200	30
Liquid fuels	10	NA	10		10		10		10	
Gaseous fuels	0.5	1.V	1.V		NA		2		2	

21 *EMEP/EEA Emission Inventory Guidebook, Technical Report No 9/2009. Available From Http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009.* (2009). *EMEP/EEA emission inventory guidebook, technical report no 9/2009. Available from http://Www.Eea.Europa.Eu/publications/emep-eea-emission-inventory-guidebook-2009*. European Environmental Agency

22 *EMEP/CORINAIR Emission Inventory Guidebook, Version 4 (2006 Edition) Technical Report No 11/2006. Available From Http://reports.eea.europa.eu/EMEPCORINAIR4/en/page002.html.* (2006).. European Environmental Agency

Specific default EFs for different types of domestic appliances in the UNECE Guidebook

The Second Edition of the UNEP dioxin toolkit (UNEP, 2005) is an important tool that has been prepared to assist in the implementation of the Stockholm Convention. Because of controversy over a number of emission factors, notably those relating to biomass, it has not yet been adopted by the Conference of the Parties and is currently being updated with lower emission factors for biomass and open burning which will change the balance between "industrial" and "non-industrial". These revisions are likely to impact upon the combustion of wood and the co-combustion of wastes. In spite of the controversy over the emission factors in the toolkit the default emission factors relevant to this review are significantly lower than used by UNECE:



Ranges of emission factors (EFs, blue dots) applied by European Member States to estimate dioxin emissions into the air from domestic combustion Ref EC2009

This makes an enormous difference to the estimates of total emissions.

In determining emission factors for the various source categories UNEP assumed that combustion devices were "reasonably well-operated and maintained…in order to maximize heat output". In practice higher emissions may be found in use where appliances are operated less effectively but there is very limited data to assess this.

Emissions to air were considered by UNEP in all cases and in the case of coal combustion, residues were also considered as a potential release vector.

For the UNEP toolkit four groups of emission factors were derived from studies undertaken in Austria, Belgium, Denmark, Germany, The Netherlands, Poland, Sweden, Switzerland, and the UK. The emission factors established by UNEP on the assumption that only the coal burned leads to PCDD/PCDF releases associated with the disposal of ash, were:

Classification	Emission Factors - µg TEQ/TJ of Fossil Fuel Burned Air	Concentrations - ng TEQ/kg Ash Residue
1. High chlorine coal-fired stoves	15,000	30,000
2. Coal fired stoves	100	5,000
3. Oil fired stoves	10	NA
4. Natural gas fired stoves	41030	NA

Releases to air are the predominant vector for fossil fuel combustion. For coal, two classes of emission factors are proposed since there are two distinct ranges of PCDD/PCDF emissions reported in the literature. The default emission factor for coal fired stoves was derived from "mean values reported between 1.6 and 50 µg TEQ/t of coal burned, which is reported from most European countries".

UNEP claimed that the values reported for domestic coal combustion "*are fairly consistent between 1 and 7 µg TEQ/t of coal burned*" (UNEP, 2005). Thus, an average value of 3 µg TEQ/t was chosen for typical coal. Based on an average heating value of 30 MJ/kg for coal, a default emission factor of about 100 µg TEQ/TJ was calculated.

UNEP note much higher values of 910 µg TEQ/t were reported in an Austrian study. Emission factors in the same range (between 108.5 µg TEQ/t and 663.9 µg I-TEQ/t) were reported by Kubica in 2004 for small residential stoves when coal from Poland was burned. These high values may be due to the high chlorine content which ranges from traces to 0.4 % and maxima up to 1.5 % of chlorine. UNEP used an average of 400 µg I-TEQ/t of coal burned and with an average heating value of 25 MJ/kg for bituminous and similar coal to calculate a class 1 default emission factor of 15,000 µg TEQ/TJ. Obviously use of these very high, and very uncertain, emission factors can give the impression that coal burning alone is a major dioxin source. The values in the literature do not support the use of such high emission factors as averages and they should be applied with caution in exceptional circumstances. They may, however, be more relevant for situations where waste is being burned which can add chlorine to the waste stream and is well known to be associated with higher dioxin formation. The Stockholm BAT/BEP guidance notes, for example, that "it is important to avoid waste loads containing high chlorine content and/or bromine content, whether inorganic such as salts, or halogenated organics such as PVC (Lemieux et al. 2003).

The co-incineration of waste is, however, common practice in solid fuel- fired appliances. It should be strongly discouraged through policies and awareness campaigns. Many studies show that combustion of chlorine containing waste such as PVC, leads to increased formation of unintentional persistent organic pollutants as shown in Table 7 (Gullett et al 1999). A regulation specifying standard fuels could be implemented. This is also valid for such fuels as treated wood, waste oil, transformer oil, plastics and other combustible waste".

Table 7 from the guidance, derived from Gullett[23] shows the Relation of PCDD/PCDF emission factors to the PVC content in burned material:

[23] Gullett, B. K., Lemieux, P. M., Lutes, C. C., Winterrowd, C. K., & Winters, D. L. (1999). PCDD/F emissions from uncontrolled, domestic waste burning. Organohalogen Compounds, 41, 27-30. Gullett, B. K., Lemieux, P. M., Lutes, C. C., Winterrowd, C. K., & Winters, D. L. (2001). Emissions of PCDD/F from uncontrolled, domestic waste burning. Chemosphere, 43(4-7), 721-725

PVC content [%]	0	0.2	1	7.5
Average Emission factor in I-TEQ/kg (ng)	14	80	200	4,900
Range I-TEQ/kg (ng)	2 - 28	9 -150	180 - 240	3,500 - 6,700

The default emission factor for class 3 and 4 4 as defined by UNEP (see Table on previous page) are low and not relevant to this review.

PCDD/PCDF in the fly ash residue of coal combustion has been analysed and concentrations between 4 and 42,000 ng TEQ/kg ash were reported by Dumler-Gradl[24]. For a first estimate, an emission factor of 5,000 ng TEQ/kg ash should be used in the Toolkit. UNEP found no emission factors for the high chlorine coals from Poland but suggested that as a first approximation the upper values of the measured data from Dumler-Gradl[25] could be used for class 1(High chlorine coal-fired stoves) residues. The chlorine content of these coals is upto about 1.5%.

The toolkit approach has been critiqued in detail by Costner [26] and is currently in the process of major revision. For open burning, for example, which was one of the most contentious areas many of the emission factors are being substantially reduced. The open burning of waste, perhaps most relevant to many of the emission factors discussed in this review, is being dramatically reduced and the emissions to land and in residues have practically been eliminated from the calculations :

6b Waste burning and accidental fires		Emission factors – µg TEQ/t of material burned									
	Classification	Air		Water		Land		Product		Residue	
		Old EF	New EF	Old EF	New EF	Old EF	New EF	Old EF	New EF	Old EF	New EF
1	Fires at waste dumps (compacted, wet, high C_{org} content)	~~1000~~	300	ND	ND	~~[600]~~	10*	NA	NA	600	NA
2	Accidental fires in houses, factories (per burn event)	400	400	ND	ND	[400]	400	NA	NA	400	NA
3	Open burning of domestic waste	~~300~~	40	ND	ND	~~[600]~~	1*	NA	NA	600	NA
4	Accidental fires in vehicles (µg TEQ per vehicle)	~~94~~	100	ND	ND	[18]	18	NA	NA	18	NA
5	Open burning of wood (construction, demolition)	60	60	ND	ND	[10]	10	NA	NA	10	NA

From the presentation: Progress on Toolkit group 6 Open Burning Processes by Heidi Fiedler[27]

Activity Rates:

[24] Dumler-Gradl, R., Thoma, H., & Vierle, O. (2005). Research program on dioxin/furan concentration in chimney soot from house heating systems in the bavarian area. *Organohalogen Compounds*, *24*, 115-118
[25] Dumler-Gradl, Op-cit
[26] Costner, P. (2008). Comments and recommendations for UNEP's standardized toolkit for identification and quantification of dioxin and furan releases, edition 2.1, December 2005 prepared on behalf of IPEN October 2008.
[27] Sixth Toolkit Expert Meeting, Geneva November 2011

Activity rates for fuels are based on national energy statistics, and provide reliable consumption data for coal, oil and gas. However, data for wood combustion are much less reliable because not all wood that is combusted is commercially traded. Data concerning the burning of waste are typically very rough estimates due to the often illegal nature of this activity.

Major difficulties include the unknown amounts of the different fuel types burned in single-room heating stoves or open chimneys – not least because there are strong indications in the literature that these are more important emission sources than central heating appliances (Geueke et al., 2000; Moche and Thanner, 1998, 2000) (BiPRO, 2009).

The available data for domestic heating in the Czech Republic based on data from the 2011 Census[28] shows that the approximate split between different systems is (in percentage of households):

- 35% - large/medium scale disrict heating
- 40% - natural gas
- 8% - electricity
- 9% - coal, coke, brown coal briquetes (approx. 346,000 households)
- 8% - wood (approx. 293,000 households).

It is clear that a significant minority of the population use heating methods of concern to this report and the breakdown of fuel consumption for the Czech Republic reflects this. Although the usage of coal has fallen from 2006 there are indications that it is now increasing again in response to rises in alternative fuel prices:

Spotřeba paliv a energií v domácnostech, ČR (TJ)

Rok	Autor dat	Kvalita údaje	Hnědé uhlí tříděné	Hnědouhelné brikety	Černé uhlí tříděné a černouhelné kaly a granulát	Koks	Biomasa	LPG	Zemní plyn	Elektřina	CZT	Ostatní	Celkem
2006	MPO	konečný údaj	26 883	3 066	3 254	1 100	46 498	1 332	106 216	54 712	50 570	640	294 271
2007	MPO	konečný údaj	19 594	2 902	2 887	687	53 992	951	94 778	52 725	47 626	830	276 972
2008	MPO	konečný údaj	17 243	3 458	1 734	687	51 519	928	94 985	52 930	47 971	1 090	272 545
2009	MPO	předběžný údaj	17 243	4 610	1 864	1 100	50 376	928	95 576	52 873	46 654	1 397	272 621
2010	MPO	předběžný údaj	18 810	4 610	2 641	687	56 174	232	110 830	54 101	50 165		298 250

Spotřeba paliv a energií v domácnostech, ČR (% množství energie obsažené v jednotlivých zdrojích)

Rok	Autor dat	Kvalita údaje	Hnědé uhlí tříděné	Hnědouhelné brikety	Černé uhlí tříděné a černouhelné kaly a granulát	Koks	Biomasa	LPG	Zemní plyn	Elektřina	CZT	Ostatní
2006	MPO	konečný údaj	9,1	1,0	1,1	0,4	15,8	0,5	36,1	18,6	17,2	0,2
2007	MPO	konečný údaj	7,1	1,0	1,0	0,2	19,5	0,3	34,2	19,0	17,2	0,3
2008	MPO	konečný údaj	6,3	1,3	0,6	0,3	18,9	0,3	34,9	19,4	17,6	0,4
2009	MPO	předběžný údaj	6,3	1,7	0,7	0,4	18,5	0,3	35,1	19,4	17,1	0,5
2010	MPO	předběžný údaj	6,3	1,5		0,2	18,8	0,1	37,2	18,1	16,8	

Domestic fuel use in the Czech Republic[29]

[28] Koloničný, J., Horák, J., Petránková, J., & Ševčíková, S. P. (2011). Kotle malých výkonů na pevná paliva

The Polish NIP indicates that the municipal and housing sector is the dominant source of PCDD/F emissions "*as the main fuel used in this sector is hard coal*" with an annual consumption of 9 million tonnes. The NIP calculates that with household furnace emissions at the rate of 18mg TEQ PCDD/F/Gg of carbon, this is equivalent to emission of 162g TEQ/year which is 50.4% of the total dioxins into the air countrywide. This sector is also claimed to be responsible for 17.3% of HCB releases and 59.4% of PCB releases. The conclusions of the NIP are that "*emissions from household furnaces in total emissions of all pollutants listed in Annex C to the Convention still undisputedly have the dominant share* (sic)"[30] – a conclusion which does not reflect the high level of uncertainty associated the emission factors.

The Czech NIP[31] is more forthright about these uncertainties saying: "*In the Czech Republic, similarly to other countries of the EU….what concerns the non-industrial sources (solid fuel combustion in households, household waste combustion, fires, accidents etc.) then their contribution cannot be accurately estimated*" (sic) .

The European Inventory and the Community Implementation Plan for the Stockholm Convention:

The European Community Implementation Plan for the Stockholm Convention[32] ('CIP') complements the national plans of the EU Member States and was adopted on 9th March 2007[33].

The foundation stone for the CIP is a new dioxin inventory largely based on a report for the European Commission by consultants BiPRO [34]. In relation to domestic sources of dioxins the CIP says:

"The contribution of domestic sources to certain POP emissions is becoming increasingly important in relative terms. It was estimated that these sources may contribute with as much as 45 % of total emissions of PCDD/F to air in the EU (BiPRO, 2006). Domestic sources include residential heating with wood and coal; open burning of waste and co-combustion of waste for heating purposes".

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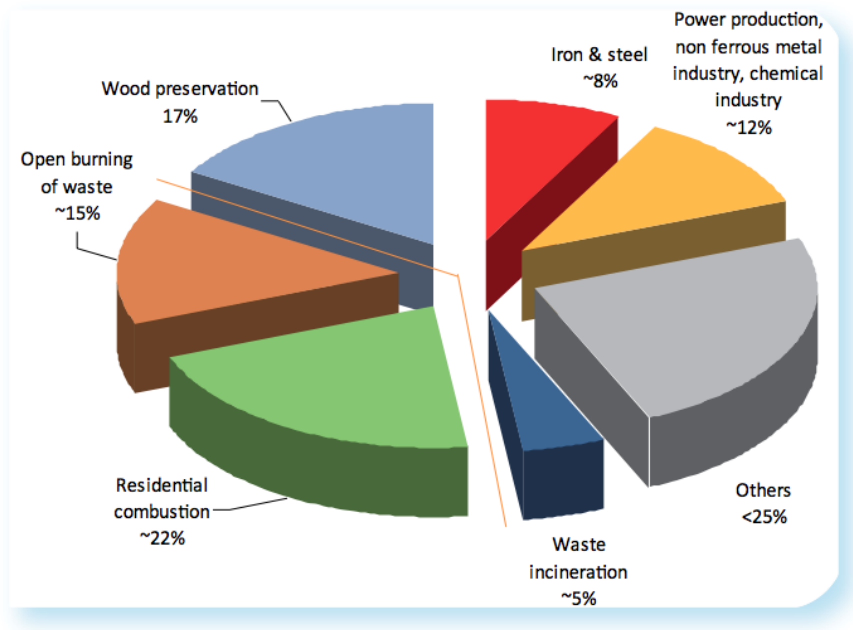
[29] Source http://issar.cenia.cz/issar/page.php?id=1711
Note that: Hnede uhli - bown coal
Hnedouhelne brikety - brown coal briquetes
Cerne uhli ..... - black coal
Koks - coke
Bimasa - biomass
LPG - Liquified Petroleum Gas
Zemni plyn - natural gas
Elektrina - electicity
CZT - central heating systems
Ostatni - others
Celkem - Total
[30] And: "The main source of dioxin emissions into the air from fuel combustion processes is the housing sector using individual furnaces and heating boilers fired with coal fuels and biomass and using kitchen furnaces fired with such fuels to prepare meals and drinking water. The problem of PCDD/F emissions from this sources is important not only due to their share in total dioxins and furans emissions in Poland (over 36%) but also due to the generally inadequate waste incineration and co-incineration conditions in furnaces and ovens."
[31] Czech Republic (2006). The national implementation plan for implementation of Stockholm Convention in the Czech republic. Brno
[32] Commision of the European Communities (2007). Community implementation plan for the Stockholm convention on persistent organic pollutants - Commision staff working document SEC(2007) 341, 9.3.2007. Brussels.

[33] http://ec.europa.eu/environment/pops/index_en.htm
[34] BiPRO (2006, July 25). Identification, assessment and prioritisation of EU measures to reduce releases of unintentionally produced/released persistent organic pollutants REFERENCE:O7.010401/2005/419391/MAR/D4 FINAL REPORT. Brussels: Beratungsgesellschaft für integrierte Problemlösungen for the European Commission.

There is undoubtedly significant uncertainty about the actual contribution made by these domestic sources. Whilst a range of figures have been used most estimates still represent a large proportion of the total emissions to air. A later report by the same consultants, for example, includes a pie chart from the European Commission website indicating 22% from residential combustion with a further 15% from open burning:



Major sources for atmospheric dioxin emissions in the European Union in the year 2006 [BiPRO, 2009 with the original source attributed to: http://ec.europa.eu/environment/dioxin/reduction.htm]

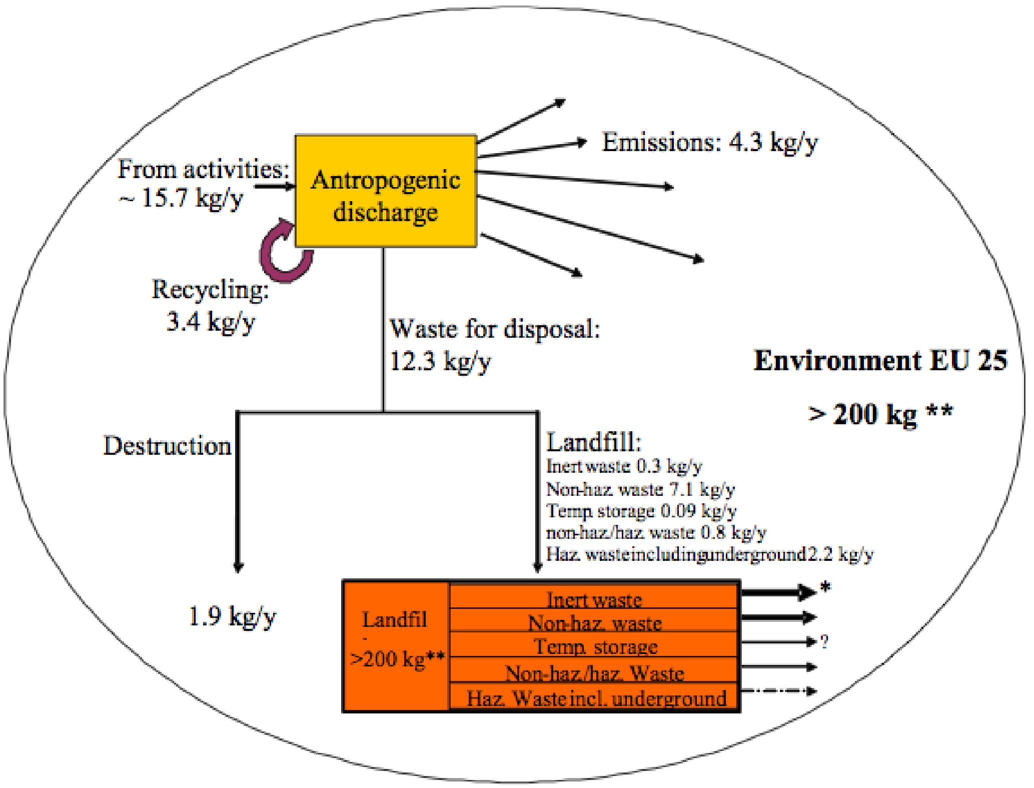
The 2006 BiPRO report upon which the EU Community Implementation Plan was based is an unusual scientific/policy report – it covers a wide range of technical and political issues and contains over 355 pages yet it does not appear to contain even a single properly referenced citation. Few clues are given as to sources of the information the consultants have relied upon and this makes it extremely difficult to use effectively as it is difficult to fully understand the context of the information presented or to give appropriate weight to the credibility of the conclusions - or even recommendations. As the report forms the basis for the implementation of many important aspects of the Stockholm Convention in the EU this is a serious concern.

The inventory presented by BiPRO suggests that the main sources of emissions of dioxins to air in the EU-25 are:

- Residential combustion (~ 30%)
- Open burning of waste (backyard burning) (~15%)
- Wood preservation (~15%)
- Iron and steel industry (~ 8%)
- Power production, non-ferrous metals, chemical industry (~ 5% each)

It should be noted that emissions to air are estimated to represent only about 20% of the total emissions of dioxins - the majority of dioxins are found in residues and the CIP says that the most important sectors for discharge of PCDD/PCDF via residues are municipal solid waste (35%), municipal solid waste incineration (16.5%), power production (18.6%), the ferrous metal industry with electric arc furnaces (10.3%) and sinter plants (8.4%).

The CIP graphically illustrates the inventory using a figure from the BiPRO report:



* The thickness of the arrow lines shall represent the release potential from the different landfill options
** The accumulated amounts of PCDD/PCDF in environment and landfills are estimated (note: they are equal by coincidence)

A full explanation or justification for the high emissions attributed to wood combustion, in particular, should have been made and included in the BiPRO review.

The new BiPRO inventory relied largely on national reporting to EMEP. The collated data suggests that emissions to air for the EU25 are[35]:

Sector	Estimated emission of PCDD and PCDF to Air (g TEQ/y)	Data base	Emission factor (µg TEQ/t)	Range EF
Total waste incinerator	270	Based on country reporting to EMEP	~ 5	Not available
MSWI	20	Calculation based on concentrations and toolkit emission factor (good FGT)	0.5	0.5 - 1.3
Total metal	400	Based on EPER 2001 (EU 15)	1.IX	Not available
Iron & steel	207	Extrapolation from UK EMEP reporting	1.VII	0.1 - 10
Sinter	500	Based on POP waste study	2.V	0.3 - 20
EAF	170	Based on POP waste study	2.IV	
Coke production	20	UNEP toolkit	0.3	0.3 - 3
Primary copper	0.03	UNEP toolkit	0.01	
Secondary copper	80	POP waste	80	5 -800
Secondary aluminium	60	POP waste	28.IX	Toolkit 0.5 - 150
Secondary zinc	2.5	POP waste	2.VI	0.3 - 100
Lead	1	Country reporting	0.5	0.5 - 80
Cement	11	Country reporting	0.05	0.05 - 5

[35] Table 5-3 page 59

Lime	2	Toolkit (good dust abatement)	0.07	0.02 - 10
Pulp and Paper	7	Country reporting	0.1	0.06 - 4.5
Chemical Industry	~ 160	Extrapolated from EMEP data	0.1	0.0003 - 0.95
Refinery	6	Country reporting	0.1	0.06 - 1.3
Fertizilers	1	EPER		
Pharmaceuticals	10	EPER		
Power production fossil fuels	350	Based on country reporting to EMEP	0.24	-0.01 - 1
Power production biomass	1.7	POP waste	0.3	0.06 - 13
Residental combustion	1.300	Based on country reporting to EMEP	50	0.002 - 225
Road transport	60	Country reporting	0.2	0.00 - 3.5
Marine transport	1.7	Based on country reporting	0.25	0.1 - 4
Air transport	1	Country reports EMEP	0.1	
Railroad transport	10	Based on country reporting to EMEP	2.IX	
Open burning	800	Based on UNEP Toolkit	300	60 - 1000
Agricultural waste	52	Country reporting	5	0.5 - 30
Crematoria	7	Based on country reporting to OSPAR	5	0.4 - 90
Animal carcasses	130	Extrapolated from BE data		0.3 - 500
Wood preservation	1000	Country reporting on creosote/PCP		
Shredder	2		0.1	0.02 - 3.3

Taking residential combustion as just one example to illustrate the difficulties that follow from an attempt to examine slightly deeper into the date presented in this table: We can see that the table indicates that residential combustion was by far the largest single source of emissions to air at 1,300 g of the 5,644 total[36] or 23%[37] .

It is anomalous how the ratio of emission factors given in the table is 0.002 – 225 i.e. a ratio of 112,500 from max to min which is inconsistent with the 'cross check' which claims a range of 'concentration data from literature' (uncited) between 100 to 7,000 g TEQ/y i.e. a ratio of only 70 from max to min. Clearly the 'cross check' did not use the full range of emission factors given in the range of emission factors in Table 5-3.

The emission factors used in the European Inventory covered a range from 1 to 500 µg I-TEQ/t based on levels of fuel's contamination. Obviously assumptions based on either end of this range can make a very large impact on total emissions:

Clean wood	**Slightly contaminated (without PCP)**	**Strongly contaminated (with PCP)**
1	50	500

It is worth noting, as a comparison with the 23% contribution from residential combustion claimed by BiPRO, that a study by Lee[38] for the UK Department of the Environment, Food and Rural Affairs measured a

[36] a total which was not included in the report

[37] It is not clear why BiPRO listed it as >30% in Figure 5-2 –was this an error? Similarly it is unclear how Figure 5-3 finds it to be c.1,500 thus adding an additional 200g (more than the entire claimed emissions from the chemical industry) to the inventory table. A 'cross check' from the toolkit indicates that the emissions should be 200g and this was claimed by BiPRO to be validation yet the factor claimed to have been used of 50 ug/t is the toolkit average factor based on 'slightly contaminated bio-mass'!

[38] Lee RG, Coleman P, Jones JL, Jones KC, Lohmann R (2005) Emission factors and importance of PCDD/Fs, PCBs, PCNs, PAHs and PM10 from the domestic burning of coal and wood in the U.K. Environ Sci Technol 39:1436-1447

range of emissions from the domestic burning of coal and wood in the UK and found that the proportion of the total inventory was very small in relation to dioxin and PCB emissions. They concluded that "*total emission from the domestic burning of coal and wood (at ca. 7 g TEQ/a), or just 2% of total emissions*" :

Estimated Inputs from the Domestic Burning of Coal and Wood to the U.K. Atmosphere and Potential Contribution to the National Inventory

	Est total emissions		U.K. NAEI [c] for 1998	% due to domestic burning	other estimates
	coal	wood			
amount (t/a)	2.40E+06	7.21E+05			
Σ PAHs (t/a)[a]	420	31	2685	17%	90% (5)
BaP (t/a)[a]	3.VII	0.9	13	36%	
ΣPCBs (kg/a)	21	0.5	2840	0.1%	
ΣCl$_{4-8}$DD/Fs (g/a)	555	36	40100	1%	
ΣTEQ (g/a)[b]	7.II	0.1	401	2%	12% (2)
ΣPCNs (kg/a)	1.VI	0.09	284	1%	
PM$_{10}$ (kt/a)	25	5.VII	210	15%	

a) EF for coal and PM10 from ref. 5 b) van den Berg et al., ref 16 c) Ref 33

The BiPRO inventory is rather different from the original 'final' European Stage II Dioxin inventory[39] though slightly closer to the update published in 2004[40]. This suggests that non-industrial sources generated between 952 and 2,257 grammes[41] of the total inventory of 1,963 to 3,752 grammes of dioxin emissions. Between 116 and 187 grammes were estimated to arise from the illegal domestic incineration of household waste; between 82 and 337 grammes from the residential combustion of coal and lignite in boilers, stoves and fireplaces and between 523 and 969 grammes from the residential combustion of wood in boilers, stoves and fireplaces. This was therefore estimated to be by far the largest source of dioxin emissions. Together the emissions from domestic solid fuel combustion (wood and coal) were therefore assessed to make up more than 60% of all non-industrial PCDD/F emissions:

These data, by contrast with the BiPRO results, are for the EU$_{17}$ rather than EU$_{25}$. It appears that the results closest to the BiPRO inventory are the 2005 maxima - although there are some major unexplained changes including the preservation of wood 118 – 310 g in Quass and 1,000 g in BiPRO: Fossil fuel power plants 350 g in BiPRO vs. 50 -67 in Quass etc. These may in part be explained by the rather high emissions in the new countries [42] but a more clear breakdown is essential to allow informed consideration of the results and to avoid the need for such speculation.

Comparison of year 1985 maximum emission estimates with year 2005 estimates for all considered source types

SNAP			1985 upper estimate	2005		Reduction/increases (%)		Trend	90% reduction likely?
				Min	Max	Max	Min		
01	Power plants	Fossil fuels	666	50	69	-92	-90	↓↓↓↓	Yes
0202	Res. Combustion: boilers, stoves, fireplaces	Wood	989	523	969	-47	-2	↓	No

[39] Quass, U., Fermann, M. W., & Broker, G. (2000). Steps towards a European dioxin emission inventory. *Chemosphere*, *40*(9-11), 1125-1129
[40] Quass, U., Fermann, M., & Broker, G. (2004). The european dioxin air emission inventory project - final results. *Chemosphere*, *54*(9), 1319-1327
[41] All values in grammes here are ment in g TEQ/year.
[42]

0202	Res. Combustion: boilers, stoves, fireplaces	Coal/lignite	900	82	337	-91	-63	↓↓↓	No
0301	Combustion in industry/boilers, gas turbines, stationary engines		238	39	78	-84	-67	↓↓↓	No
030301	Sinter plants		1650	387	470	-77	-71	↓↓↓	No
030308	Secondary zinc production		450	20	20	-96	-96	↓↓↓↓	Yes
030309	Secondary copper production		29	15	17	-49	-40	↓↓	No
030310	Secondary aluminium production		65	21	60	-68	-7	↓↓	No
30311	Cement		21	14	50	-32	+137	↔	No
030326	Other: metal reclamation from cables		750	40	50	-95	-93	↓↓↓↓	Yes
040207	Electric furnace steel plant		120	141	172	+17	+43	↑	No
040309	Other: non-ferrous metal foundries		50	38	72	-25	+44	↔	No
040309	Other: sintering of special materials and drossing facilities		200	1	1	-100	-100	↓↓↓↓	Yes
060406	Preservation of wood		390	118	310	-70	-20	↓↓	No
0701	Road transport		262	41	60	-84	-77	↓↓↓	No
090201	Inc. of domestic or municipal wastes	Legal combustion	4000	178	232	-96	-94	↓↓↓↓	Yes
090201	Inc. of domestic or municipal wastes	Illegal (domestic) combustion	200	116	187	-42	-6	↓	No
090202	Inc. of industrial wastes	Hazardous waste	300	16	45	-95	-85	↓↓↓	No
090207	Inc. of hospital wastes		2000	51	161	-97	-92	↓↓↓↓	Yes
090901	Cremation: Inc. of corpses		28	13	22	-55	-23	↓↓	No
1201	Fires		382	60	371	-84	-3	↓↓	No
Total of sources considered (g I-TEQ/year)			13690	1963	3752	-86	-73	↓↓↓	No
Industrial sources (g I-TEQ/year)			10539	1011	1495	-90	-86	↓↓↓	No
Non-industrial sources (g I-TEQ/year)			3151	952	2257	-70	-28	↓↓	No

Unfortunately it is also not possible to work out the break down the distribution between air, water and land of each of the POPS effectively in the process specific notes in the BiPRO report.

No justification is given for the choice of emission factors by BiPRO even when wide ranges are presented in the summary tables. More appropriate emission factors for burning agricultural residues and open burning of waste would be those proposed by Costner :

Dioxin Emission Factors with Strongest Scientific Support to Date

	Emission factor for releases to air	Emission factor for releases to land	Emission factor for releases to residues
ng TEQ/kg			
Forest fires, grassland and moor fires	0.125 - 0.5	0.02 - 0.05	
Agricultural residues, open burning	0.5 - 0.8	0.02 - 0.05	
Domestic waste, open burning			
No PVC content, 0%	4.4 - 14		0.3
Moderate PVC content, 0.2% or less	17 - 79		0.3 - 343

High PVC content, 1.0 - 7.5%	200 - 5,000		343 - 892
Landfill/open dump fires	23 - 46		120 - 170

The emission factors for coal and wood are discussed further below.

The BiPRO review of emissions from domestic heating and combustion concluded:

- The main domestic sources of dioxins are heating and cooking with solid fuels and burning of waste.
- The compilation of information on current knowledge on EFs showed that existing EFs are associated with considerable uncertainty and that the development of detailed EFs in the field of solid fuels might be difficult to achieve as differences in on-the-ground combustion conditions are the predominant parameter for resulting emissions, and conditions of the standardised measurements used for determination of EFs are hardly ever met.
- Considering that considerable amounts of MSW are illegally combusted even in countries, with strict enforcement traditions, highly specific EFs may give the illusion of a precision in emission estimates that does not exist.
- Dioxin emissions are currently not a driving force for environmental policy in the domestic sector but emission reduction potentials are high and even simple means can reduce emissions by up to 80%.
- Reduction of dioxins from domestic sources is achieved by direct measures such as a ban of domestic waste burning. Such a ban would be desirable in all Member States.
- Other policies such as those related to climate change and clean air contribute to the reduction of domestic dioxin emissions.
- Awareness raising and education on the potential health and environmental effects of dioxins is crucial for public acceptance and application of measures that reduce dioxin emissions.
- Information exchange, coordination and harmonisation of emission data in estimating national dioxin emissions are necessary to obtain more reliable and comparable inventories. Per capita fuel consumption, fuel type used and climatic conditions vary considerably within the EU.

The final report provided detailed information to individually assess the reduction potential for domestic dioxin sources in each Member State.

Published Guidance

Stockholm Convention BAT/BEP guidance Guidelines on best available techniques and provisional guidance on best environmental practices

The Stockholm Convention's "Guidelines on best available techniques and provisional guidance on best environmental practices" ("BAT/BEP Guidelines") [43] indicate that "open burning may still be a last resort where there are no alternative disposal or recovery methods due to inadequate infrastructure; where sanitary disposal is required to control disease or pests; or in the case of disaster or other emergency (Great Lakes Binational Toxics Strategy 2004)". They emphasise, however, that "household wastes should never be burnt in indoor residential combustion devices such as stoves, fireplaces or furnaces" (see section VI.C of the guidelines).

Residential combustion sources Summary
This section considers the combustion of wood, coal, gas, as well as other organic matter mainly for residential heating and cooking. Combustion takes place in hand-fired stoves or fireplaces or, in the case of larger central heating systems, in automatically fired installations. Studies have shown that significant levels of chemicals listed in Annex C of the Stockholm Convention are released from residential combustion sources. The amount of chemicals released depends primarily on the fuel used (household waste, sea- salt laden driftwood and treated wood are significant sources of PCDD/PCDF) as well as combustion efficiency. The efficiency of combustion depends upon the combustion temperature, how well the gases are mixed, residence time, sufficient oxygen and the fuel properties. Given their large numbers, residential combustion appliances contribute noticeably to overall releases of chemicals listed in Annex C.

The use of efficient combustion of clean, untreated fuels for cooking and heating is of primary importance for reducing the formation and release of chemicals listed in Annex C. Strategies to minimize releases of chemicals listed in Annex C from residential combustion sources include public education, awareness and training programmes on the proper use of the appliances, use of appropriate fuels and the health impacts from uncontrolled residential combustion. The abatement technologies commonly used in industrial settings are not generally available for smaller residential heating and cooking appliances. However, the use of well-designed stoves with good operation can be effective in reducing chemicals listed in Annex C, with the important added benefit of improving indoor air quality.
Best available techniques include enclosed low emission burners with ducted flues and the use of dry, well-seasoned wood. For countries or regions where these fuels and appliances are not available, best available techniques and best environmental practices for residential combustion include ensuring separation of household waste from fuel to avoid burning of such waste in cooking and heating appliances. In all countries the use of treated wood or sea-salt laden driftwood and the use of plastics as a firelighter or fuel should be avoided.
Cooking and heating with wood is a common and significant practice in all countries of the world. Any action for reducing the emissions of chemicals listed in Annex C from residential combustion will also have to take into consideration local social, cultural and economic factors. Case studies from Australia and New Zealand are provided to highlight this.

Comparative PCDD/PCDF emission factors from the combustion of clean and contaminated wood

[43] Stockholm Convention (2007, May). *Guidelines on best available techniques and provisional guidance on best environmental practices relevant to article 5 and annex C of the Stockholm convention on persistent organic pollutants - adopted at COP 3, May 2007*. Geneva, Switzerland

Comparative PCDD/PCDF emission factors from the combustion of clean and contaminated wood

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

a) TJ = terajoule = 1 x 10^{12} joule

The BAT/BEP guidelines note that "Measurable levels of tetrachlorodibenzo-p-dioxins (TCDD) have been found in chimney soot and in bottom ash from wood-burning stoves and fireplaces. Chimney deposits from residential wood burning have been found to have PCDD/PCDF congener profiles similar to those in flue gases from municipal waste incinerators. This indicates that wood used in residential combustion appliances may be highly contaminated, and inappropriate materials such as plastics may also be used as fuel sources".

This is hardly surprising because, as the guidelines note, "there is little control over emissions from residential sources. Most stoves and fireplaces are poorly operated with inadequate oxygen levels and low turbulence of burning gases (due to overloading or use of over-large wood feed items). In such circumstances combustion releases not only gaseous pollutants but solid pollutants containing PCDD/PCDF, which constitute releases to land".

The potential problems are summarised in tabular form:

Appliances	Fuel	Typical potential problems
Central furnaces Room heaters Fireplaces	Natural or liquefied petroleum gas	Cracked heat exchanger Not enough air to burn fuel properly Defective/blocked flue Maladjusted burner
Central furnaces	Oil	Cracked heat exchanger Not enough air to burn fuel properly Defective/blocked flue Maladjusted burner
Central heaters Room heaters	Wood	Cracked heat exchanger Not enough air to burn fuel properly Defective/blocked flue Green or treated wood
Central furnaces Stoves	Coal	Cracked heat exchanger Not enough air to burn fuel properly Defective grate Defective or blocked flue Low-quality coal High moisture content of fuel
Ranges Ovens	Natural or liquefied petroleum gas	Not enough air to burn fuel properly Maladjusted burner Misuse as a room heater
Room heaters Central heaters	Kerosene	Improper adjustment Wrong fuel (not K-1) Wrong wick or wick height Not enought air to burn fuel properly

Stoves Fireplaces	Wood Coal	Not enough air to burn fuel properly Defective/blocked flue Green or treated wood Cracked heat exchanger or firebox Inappropiate fuel such as residental refuge
Water heaters	Natural or liquefied petroleum gas	Not enough air to burn fuel properly Defective/blocked flue Maladjusted burner

(extracted from CPSC, USEPA & American Lung Association, 2004, *What You Should Know about Combustion Appliances and Indoor Air Pollution. CPSC Document 452,* Consumer Product Safety Commission)

Plastics, chlorine and the possible causes of elevated emissions of POPs

UNECE confirms that the emissions of PCDD/PCDFs are highly dependent on the conditions under which cooling of the combustion and exhaust gases is carried out. Carbon, chlorine, a catalyst and oxygen excess are necessary for the formation of PCDD/PCDF.

The emissions of HCB from combustion processes are very uncertain but, on the whole, processes resulting in PCDD/F formation lead also to HCB emissions.

PCDD/PCDFs are released as a consequence of the de-novo synthesis in the temperature interval between 180 ^{o}C and 400 ^{o}C [44].

PCDD/PCDF emissions can be significantly influenced by the common practice to use paper, paper board or small wood pieces in varying amounts, even wood shavings and plastic.

Some households will certainly burn household wastes on their domestic fires either to reduce fuel costs or to avoid disposal fees.

The single more important source of chlorine in municipal solid waste (MSW) is PVC[45] which provides approximately 50% of the chlorine content. This means half the hydrogen chloride in the combustion gases from MSW incinerators is likely to be PVC derived but the contribution to domestic sources is far more uncertain.

There are very few studies investigating emissions in these circumstances but BiPRO in their review for the European Commission relied on work by Hedman to conclude that the whilst co-combustion of paper with wood fuels does not seem to change the emissions the addition of plastics raises the emissions by a factor of ten. They commented that the same conclusions result from a number of further studies (e.g. Enviros 2006) that do not provide specific measurement results but only mean or min.-max values. If contaminated wood is burned, emissions are reported to range from 785 – 28,570 µg TEQ/TJ (11-400 µg/t).

Hübner[46] reported that they found the highest emissions from domestic heating appliances using solid fuels when “relevant amounts” of other combustible material such as household wastes were co-fired or used to facilitate lightning the fires. In general they found that it is “a common practice to use paper, paper board or small wood pieces in varying amounts, even wood shavings and plastic, to speed up the incineration”. They also noted that the combustion of waste materials on previous days or weeks might have had an effect on the PCDD/F concentrations in samples taken later as contaminated soot can be expelled days after its formation. It is well established that this “memory effect” can have significant

[44] Karasek, F. W., & Dickson, L. C. (1987). Model studies of polychlorinated dibenzo-p-dioxin formation during municipal refuse incineration. *Science*, *237*(4816), 754-756. doi:10.1126/science.361660

[45] *The production of PVC may exceed 30 million tonnes by 2010. The main applications of PVC in Europe are the building sector, which accounts for 57% of all uses. In addition, PVC is used in many applications like household appliances (18%), packaging (9%), electric and electronic equipment (7%), automotive equipment (7%), furniture (1%) and other applications (1%). Consequently, to these statistics, the PVC waste amount will increase significantly, and the disposal of these wastes which include municipal and industrial waste is now recognised to be a major environmental problem*

Quoted in Saeed, L., Tohka, A., Haapala, M., & Zevenhoven, R. (2004). Pyrolysis and combustion of PVC, pvc-wood and pvc-coal mixtures in a two-stage fluidized bed process. Fuel Processing Technology, 85(14), 1565-1583

[46] Hübner, C., Boos, R., & Prey, T. (2005). In-field measurements of PCDD/F emissions from domestic heating appliances for solid fuels. *Chemosphere*, *58*(3), 367-372. doi:doi: 10.1016/S0045-6535(03)00702-1

implications for increased emissions in combustion equipment.

Chlorine-containing plastic waste gave rise to relatively high emissions of approximately 310 ng(WHO-TEQ)/ kg over the whole combustion cycle [47].

Wevers[48] reported mean air emission factors of 24.4 ng TEQ/kg and 350 ng TEQ/kg when burning the combustible portion of household waste with untreated and treated wood respectively in wood stoves for household heating.

Syc[49] recently reported the first data set of emission factors of selected pollutants from combustion of five fuel types (lignite, bituminous coal, spruce, beech, and maize) in six different domestic heating appliances of various combustion designs.

The researchers studies the effect of fuel as well as the effect of boiler type in a total of 46 combustion runs. during which numerous EFs were measured, including the EFs of particulate matter (PM), carbon monoxide, polyaromatic hydrocarbons (PAH), hexachlorobenzene (HxCBz), polychlorinated dibenzo-p-dioxins and furans (PCDD/F), etc.

The highest EFs of non-chlorinated pollutants were measured for old-type boilers with over-fire and under-fire designs and with manual stoking and natural draft. Emissions of these pollutants from modern-type boilers (automatic, downdraft) were a factor of 10 or more lower.

The authors concluded that the decisive factor for emission rate of non-chlorinated pollutants was the type of appliance; the type of fuel plays only a minor role. Emissions of chlorinated pollutants were proportional mainly to the chlorine content in fuel, but the type of appliance also influenced the rate of emissions significantly. Surprisingly, higher EFs of PCDD/F from combustion of chlorinated bituminous coal were observed for modern-type boilers (downdraft, automatic) than for old-type ones. On the other hand, when bituminous coal was burned, higher emissions of HxCBz were found for old-type boilers than for modern-type ones.

Gullet established emission factors for three fuels in San Francisco – although the authors did not specifically address the concerns associated with the burning of plastics they did test 'artificial logs'. The artificial logs were from a single manufacturer and were made of "wax and sawdust". These logs had notably elevated chlorine concentration compared with oak and pine although the authors note that "considerable variation in composition is expected across manufacturers, as this is a formulated product with different constituents and regional sources of materials":

Fuel properties	Oak	Pine	Artificial logs
Ultimate Analysis (Moisture Free)			
Carbon (%)	48.09	49.73	70.37

[47] Hedman, B., Näslund, M., & Marklund, S. (2006). Emission of PCDD/F, PCB, and HCB from combustion of firewood and pellets in residential stoves and boilers. *Environ Sci Technol*, *40*(16), 4968-4975. doi:10.1021/es052418

[48] Wevers, M., De Fre, R., Vanermen, G., 2003. PCDD/F and PAH emissions from domestic heating appliances with solid fuel. Organohalogen Cpds. 63: 21-24. See also Launhardt, T. & Thoma, H. (2000). Investigation on organic pollutants from a domestic heating system using various solid biofuels. *Chemosphere*, *40*(9–11), 1149-1157

[49] Šyc, M., Horák, J., Hopan, F., Krpec, K., Tomšej, T., Ocelka, T., et al. (2011). Effect of fuels and domestic heating appliance types on emission factors of selected organic pollutants. *Environmental Science & Technology*, *45*(21), 9427-9434

Hydrogen (%)	6.16	6.39	X.88
Nitrogen (%)	<0.5	<0.5	0.55
Sulfur (%)	<0.05	<.05	0.13
Chlorine (ppm)	<50	<50	437
Ash (%)	0.66	0.27	0.44
Oxygen (%, by differ.)	45.09	43.61	17.63
Heat of combustion (MJ/kg)	19.0	19.7	34.0
Proximate Analysis (Moisture Free) (%)			
Volatile matter	84.36	90.7	92.44
Ash (%)	0.66	0.27	0.44
Fixed carbon (by difference)	14.98	9.03	7.XII
Average Moisture Content (%)			
Oven drying method	16.2	8.7	1.0
Moisture meter	17.3	8.8	1.0

Average PCDD/F emissions factors ranged from 0.25 to 1.4 ng toxic equivalency (TEQ)/ kg of wood burned for natural wood fuels and 2.4 ng TEQ/ kg for artificial logs.

Mixed Plastic- Is it better to Recyle or Incinerate?

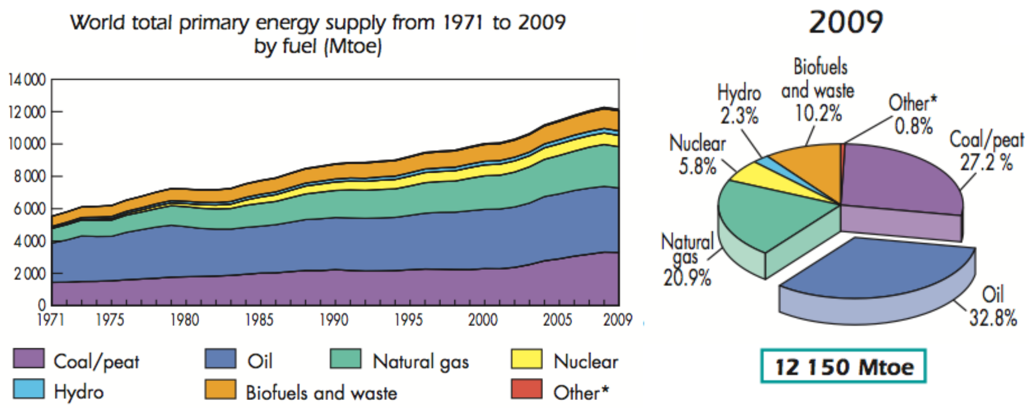
The question of whether it is better to recycle or burn plastic waste from an overall life cycle perspective is an important one. Kukačka[50] claimed in a research report that "incineration and gasification seem to be the most advantageous procedures for mixed plastic waste energy recovery" and "in view of high costs connected with plastic waste transport" recommended a network of large and small incinerators and gasification plants across the Czech Republic. This claims need careful scrutiny as they are inconsistent with the results of meta-reviews of life cycle assessments for plastics recovery. An important example relates to the work of the UK Waste Resources Action Programme (WRAP). This is a governmental research organisaton which undertook a specialist review of international studies titled "*Environmental Benefits of Recycling*"[51]. The review shows how increased recycling is helping to tackle climate change and emphasises the importance of recycling over incineration and landfill as the appropriate way forward. Of particular relevance here is that the evidence from WRAP concludes "*In the vast majority of cases, the recycling of materials has greater environmental benefits than incineration or landfill".* A more detailed review of this research is included in Annex 2.

50 Kukačka, J., Raschman, R. 2010: Possibilities of municipal plastic waste energy recovery Odpadové fórum (Waste Management Forum) 10/2010; 14 – 16.

51 WRAP (2006). Environmental Benefits of Recycling - An international review of life cycle comparisons for key materials in the UK Recycling Sector Sep 2006. Banbury, Waste Resources Action Programme,.

Coal Combustion

Coal consumption currently contributes approximately 27% of the world's total primary energy supply (OECD/IEA, 2011)[52] but in some countries where the percentage contribution from coal is much higher - notably China where about 69–76% of the primary energy requirements in China (NBSC, 2009 - quoted by Shen 2010[53]). The unusually heavy reliance on coal in China, both for commercial and domestic use, helps to explains why so much of the current research on the combustion of coal in domestic uses comes from China:



Although lower than China domestic use of coal is still relatively high in many parts of Eastern Europe – particularly in Poland which is the world's 9th largest coal producer.

Stage 1 of the European Emissions Inventory (Quass, Fermann & Bröker, 1997)[54] said that whilst it is "quite obvious" that domestic wood combustion is of significant relevance for the total emission of PCDD/F in Europe that coal and lignite combustion in residential plants "contribute only to a minor degree".

This may be considered a little surprising given the levels of chlorine that are found in some coals compared with domestic wood. Tillman, for example, demonstrates that with whilst chlorine concentrations are significantly higher in plant materials than in various deposits of coal the exceptions include wood fuels and a number of other biomass materials,[55].

country	coal	chlorine concentration in coal (ppm)	chlorine concentration in coal ash (ppm)
Bulgaria	Maritza West	150	290
	Sofia	80	290
	Elhovo	90	210
	Maritza East	200	500

[52] OECD/IEA, 2011, *Key World Energy Statistics 2011,* Organisation for Economic Co-operation and Development,

[53] Shen, G., Wang, W., Yang, Y., Zhu, C., Min, Y., Xue, M., Ding, J., Li, W., Wang, B., Shen, H., Wang, R., Wang, X. & Tao, S., 2010, Emission factors and particulate matter size distribution of polycyclic aromatic hydrocarbons from residential coal combustions in rural Northern China, *Atmospheric Environment*, 44(39), pp. 5237-43

[54] Quass, U., Fermann, M., & Bröker, G. (1997). *The European dioxin emission inventory stage I volumes 1 - 2*. prepared by the North Rhine Westphalia State Environment Agency on behalf of the European Commission, Directorate General for Environment (DG ENV) Contract No.: 96/771/3040/DEB/E1

[55] Tillman, D. A., Duong, D., & Miller, B. (2009). Chlorine in solid fuels fired in pulverized fuel boilers — sources, forms, reactions, and consequences: A literature review. *Energy & Fuels*, *23*(7), 3379-3391

	Bobov Dol	360	1150
	Balkan	150	390
Australia	Ebenezer	370	2910
	Wambo	360	2950
	Blair Athol	440	3930
	Lithgow	480	2250
	Moura	710	6890
USA	Usibelli (Alaska)	90	970
	Black Thunder	200	3190
	Illinois	750	6470
Japan	Taiheyo	1090	4700
	Akabira	110	220
	Sunagawa	200	660
	Takashima	230	2800
Canada	Coal Valley	140	1370
	Fording River	280	2720
South Africa	Ermelo	260	2430
China	Datong	210	1590
Ukraine	Donbass	500	3420

biomass	**Cl concentration (% in dry fuel)**
alfalfa stems	0.50
wheat straw	0.23
rice hulls	0.12
rice straw	0.58
switchgrass	0.19
switchgrass (2) - WI	0.03
bagasse	0.03
willow wood	0.01
hybrid poplar	0.01
softwood sawdust	0.052
right of way trimmings	0.01
short rotation poplar	0.01
almond shells	0.01
almond hulls	0.02
olive pits	0.04
demolition wood	0.05
urban wood waste	0.06
corn stover (1)	0.22
corn stover (2)	0.72
corn stover (3)	0.23

There is good evidence, however, that the emissions from domestic coal uses are significantly more hazardous to the users than wood and this is reflected in much higher levels of lung cancer reported by Hosgood[56]:

56 Hosgood, H. D. ,. I., Boffetta, P., Greenland, S., Lee,
Y. -C. A., McLaughlin, J., Seow, A., et al. (2010). In-Home coal and Wood

Lignite combustion may be a specific problem in Germany (the largest producer in the EU mainly from the former area of East Germany) and Poland (the third largest) but the use of lignite shows a falling trend and the EU dioxin Inventory commented that "*it is likely to decrease to a level as in the western part of Germany within a few years with the rise of living standards in the former East- Germany*".

Use and Lung Cancer Risk: A pooled analysis of the International Lung Cancer Consortium. Environ Health Perspect, 118(12).

Emissions and Emission Factors

One of the most striking features of the data relating to emissions from domestic combustion is the enormous range even from a single source. Bignal, for example, reported gaseous and particulate phase measurements for 16 PAHs in the stack of a woodchip-fired 50 kW boiler used for domestic heating[57]. The concentrations of PAHs in both gas and particle phases varied from 1.3 to 1631.7 µg/m^3. The mean CO and NO concentrations varied from 96 to 6002 ppm and from 28 to 359 ppm. A large number of studies have been performed on wood and coal burning and the majority demonstrate similar variations and thus a very broad range of emission factors could be calculated depending on the fuel and stove types together with their operating conditions. A summary of the data collated by BiPRO (BiPRO, 2009) on these studies is included in Annex 3.

Kubica[58] says that emissions of both PAHs and VOCs depend on the volatile matter of fuels that are combusted in the same devices (stove, boilers, etc. particularly when fuelled by hand. The exchange of coal by coke or smokeless solid fuels decreased PAH emission by about 99%.

In general emissions caused by incomplete combustion are mainly a result of insufficient mixing of combustion air and fuel in the combustion chamber which is a fuel-rich combustion zone, an overall lack of oxygen, low temperatures, short residence times and in special cases such as the combustion of coke and the final stage of solid fuel combustion in fixed bed techniques low radical concentrations[59]. Obviously these circumstances and operating conditions can have significant effects on the co-combustion of household waste. As discussed above, however, there are too few studies of the emissions from burning waste, and too wide a combination of appliances operational conditions, to be able to derive robust emission factors for waste combustion.

The approach by UNEP has been to use emission factors similar to those for fuels with high chlorine concentrations.

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57 Bignal, K. L., Langridge, S., & Zhou, J. L. (2008). Release of polycyclic aromatic hydrocarbons, carbon monoxide and particulate matter from biomass combustion in a wood-fired boiler under varying boiler conditions. *Atmospheric Environment*, *42*(39), 8863-8871

58 Kubica, K., Paradiz, B., & Dilara, P. (2007). *Small combustion installations: Techniques, emissions and measures for emission reductions*. Joint Research Centre Scientific and Technical Reports, EUR

59 Kubica 2007 op cit.

Particulate Emissions

In recent years the evidence associating particulate emissions from combustion processes with health impacts has become much stronger and it is now generally accepted that there can be serious chronic impacts associated with even small increases in ambient particulate levels. The evidence is particularly compelling in relation to the effects of the smallest particulates[60]. This is of direct relevance to residential combustion as most of the probable human carcinogenic PAHs are reported to be associated with particulate matter and especially in fine mode particles in ambient air[61]. The fine particles may thus act as a carrier of carcinogenic material into the alveolar region of the human lung and thus provide a direct pathway into the blood stream.

Fine particulate matter is more harmful as it can penetrate deeper into the lungs. A number of studies have shown that the emissions from modern residential biomass combustion technologies are dominated by submicron particles (< 1 µm). The mass concentration of particles larger than 10 µm is normally < 10 % for small combustion installations [62,63,64].

A few studies have examined the difference in the emission factors and composition profiles between field emissions and laboratory chamber combustion[65,66,67, 68,69]. It has been reported that that both PM and CO emissions from actual cooking practice seem to be significantly higher than those measured in laboratory simulated combustion[70].

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[60] For a detailed review see: Cormier, S. A., Lomnicki, S., Backes, W., & Dellinger, B. (2006). Origin and health impacts of emissions of toxic by-products and fine particles from combustion and thermal treatment of hazardous wastes and materials. *Environmental Health Perspectives*, *114*(6), 810-7 < http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1480527/pdf/ehp0114-000810.pdf> and a report by Professor Vyvyan Howard presented as evidence to a public inquiry in Eire: Howard, C. V. (2009). *Statement of evidence to an bord pleanála on particulate emissions and health, proposed Ringaskiddy waste-to-energy facility < http://www.dpea.scotland.gov.uk/Documents/qJ13291/J169937.pdf>*

[61] Ravindra, K., Sokhi, R., & Van Grieken, R. (2008). Atmospheric polycyclic aromatic hydrocarbons: Source attribution, emission factors and regulation. *Atmospheric Environment*, *42*(13), 2895-2921

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[65] Dhammapala, R., Claiborn, C., Simpson, C., Jimenez, J., 2007. Emission factor from wheat and Kentucky bluegrass stubble burning: comparison of field and simulated burn experiments. *Atmospheric Environment* 41, 1512-1520

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[69] Shen, G., Wang, W., Yang, Y., Zhu, C., Min, Y., Xue, M., et al. (2010). Emission factors and particulate matter size distribution of polycyclic aromatic hydrocarbons from residential coal combustions in rural northern China. *Atmospheric Environment*, *44*(39), 5237-5243

[70] Roden, C. A., Bond, T. C., Conway, S., Osorto Pinel, A. B., MacCarty, N., & Still, D. (2009). Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves. *Atmospheric Environment*, *43*(6), 1170-1181.

PAH Emissions

Over the past two decades there has been growing interest in the polluting effects of Polycyclic Aromatic Hydrocarbons (PAHs). The main concern is the carcinogenic effects of some PAHs - indeed some of them are among the strongest known carcinogens[71]. There is also increasingly strong evidence associating PAH and associated particulate exposure with adverse impacts on pregnancy outcomes with sufficient evidence to infer a causal link between air pollution and infant death, mainly related to particulates, with PAHs being more likley responsible for intrauterine growth retardation [72]. These concerns have been reflected by PAHs gaining a higher profile in international environmental agreements and legislation such as the UNECE POPs Protocol where, unlike under the Stockholm Convention, they are defined as POPs. The consequence is that they are treated in a similar way to Stockholm POPs under the EU POPs legislation (Regulation 850/2004, as amended).

It is well known that relatively low combustion temperature combined with limited oxygen supply often yield higher PAHs emissions in residential combustion[73]. Smouldering combustion emit 4–5 times more PAHs than flaming combustion and PAH emission factors for all fuels increase with decreasing combustion efficiency [74]. The emissions are therefore very sensitive to the skill and care with which stoves and fires are operated and there are consequently high uncertainties in the estimation of total emission and the calculations of emission factors[75,76,77,78].
Notwithstanding the high level of uncertainty there is evidence that residential combustion is the major source of at least some of the important PAHs:

71 Ravindra, K., Sokhi, R., & Van Grieken, R. (2008). Atmospheric polycyclic aromatic hydrocarbons: Source attribution, emission factors and regulation. *Atmospheric Environment*, *42*(13), 2895-2921

72 Sram, R. J., Binkova, B., Dejmek, J., & Bobak, M. (2005). Ambient air pollution and pregnancy outcomes: A review of the literature. *Environ Health Perspect*, *113*(4), 375-82

73 Chen, Y., Sheng, G., Bi, X., Feng, Y., Mai, B., & Fu, J. (2005). Emission factors for carbonaceous particles and polycyclic aromatic hydrocarbons from residential coal combustion in China. *Environmental Science & Technology*, *39*(6), 1861-1867

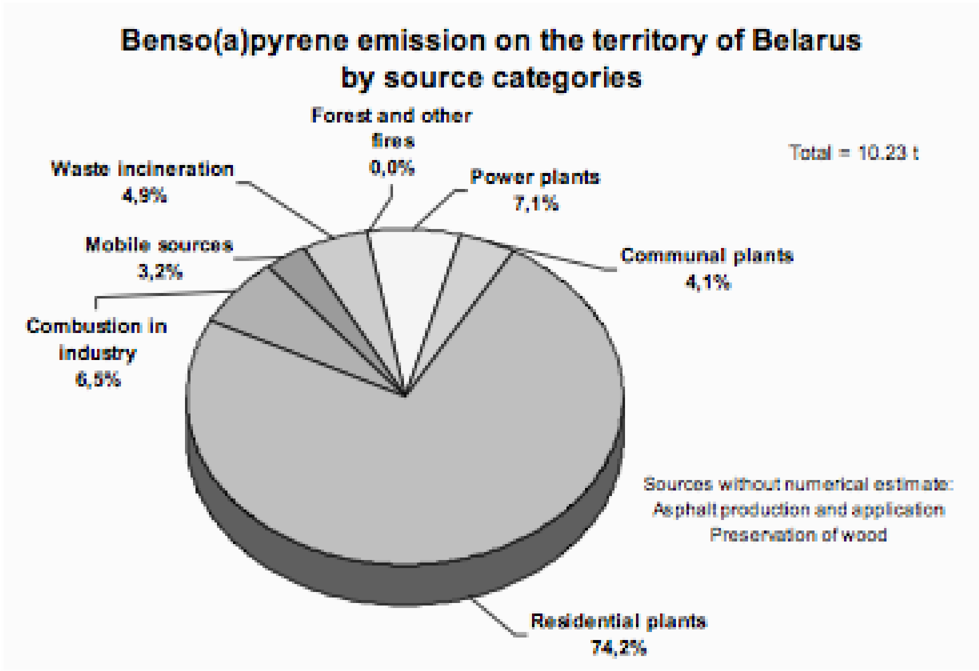
74 Jenkins, B.M., Jones, A.D., Turn, S.Q., Williams, R.B., 1996. Emission factors for polycyclic aromatic hydrocarbons from biomass burning. Environmental Science and Technology 30, 2462–2469.

75 Roden, C. A., Bond, T. C., Conway, S., & Pinel, A. B. O. (2006). Emission factors and real-time optical properties of particles emitted from traditional wood burning cookstoves. *Environmental Science & Technology*, *40*(21), 6750-6757

76 Gullett, B. K., Touati, A., & Hays, M. D. (2003). PCDD/F, PCB, hxcbz, PAH, and PM emission factors for fireplace and woodstove combustion in the San Francisco bay region. *Environ Sci Technol*, *37*(9), 1758-65.

77 Xu, S.S., Liu, W.X., Tao, S., 2006. Emission of polycyclic aromatic hydrocarbons in China. *Environmental Science & Technology 40*, 702-708

78 Oanh, N.T.K., Albina, D.O., Ping, L., Wang, X., 2005. Emission of particulate matter and polycyclic aromatic hydrocarbons from select cookstove-fuel systems in Asia. *Biomass & Bioenergy* 28, 579-590.



From Kakareka[79]

Other work by Kakareka detected the highest PAH emissions in Belarus from domestic waste and wood waste combustion. Lowest levels of PAH emission are from peat briquette combustion[80]. They found a wide variation in the PAH concentration of off-gases from the burning of firewood with different types of wood. Birch firewood was reported to give the largest PAH emissions with pine giving lower emission levels[81].

There is far from universal agreement on the contribution of residential combustion to total PAH emissions – although there is stronger consensus in relation to certain PAHs such as BaP . In the UK, for example, Lee reports that the National Atmospheric Emission Inventory estimates suggest emissions of 2,700 t/a for the 16 US-EPA PAHs and that the Inventory data shows residential combustion accounts for approximately 20% (ca. 500 t/a). This is close to the 17% contribution estimated by Lee. Various PAHs may make different contributions, for BaP the NAEI estimates annual emissions of 13 t, of which approximately 30% were due to residential combustion whilst Lee estimated 36% making this source the biggest single emitter of BaP. In each case the major contribution came from coal burning[82].

Attempts have recently been made to validate the source contribution in the Czech Republic[83] but the main PAH source categories examined (road traffic, residential wood combustion, residential and industrial

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[79] Kakareka, S. (n.d.). Test study of polycyclic aromatic hydrocarbons emission sources . Minsk, Belarus: Institute for Problems of Natural Resources Use & Ecology. Retrieved April 30, 2012, from the UNEP database, http://www.chem.unep.ch/pops/pcdd_activities/projects/cat3_energyconv/Annex%20XII_Kakareka%20Belarus%20Furnace.pd

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[81] Kakareka, S. V., Kukharchyk, T. I., & Khomich, V. S. (2005). Study of PAH emission from the solid fuels combustion in residential furnaces. *Environmental Pollution*, *133*(2), 383-387.

[82] Applying the EFs determined in the Lee study puts the total emission from the domestic burning of coal and wood in the UK at ca. 7 g TEQ/a, or just 2% of total emissions. This is very different from the claims made in the Czech Republic discussed earlier.

[83] Dvorská, A., Komprdová, K., Lammel, G., Klánová, J., & Plachá, H. (2012). Polycyclic aromatic hydrocarbons in background air in central Europe – seasonal levels and limitations for source apportionment. *Atmospheric Environment*, *46*, 147-154

coal combustion) could not be validated due to the similarity of the reference PAH profiles between from source together with the variability of ambient reference PAH profiles. It was suggested that the commonly studied set of EPA PAHs is not source category specific and thus not suitable for source apportionment. Until more work is done on this issue then the high proportion of emissions attributed to domestic emissions should be considered as an unvalidated hypothesis rather than as fact.

PAH emission factors have been established for coal combustion in the past and there is now more interest in establishing good data for residential coal stove emissions – particularly in China where domestic consumption of coal is particularly high[84,85,86],[87]. A number of studies have investigated PAH emissions from different combinations of fuel/coal and stoves[88,89,90]. Most of the work, however, has been carried out in laboratories rather than under real household combustion conditions.

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84 Chen, Y.J., Bi, X.H., Mai, B.X., Sheng, G.Y., Fu, J.M., 2004. Emission characterization of particulate/gaseous phases and size association for polycyclic aromatic hydrocarbons from residential coal combustion. *Fuel* 83, 781-790.

85 Chen, Y., Sheng, G., Bi, X., Feng, Y., Mai, B., Fu, J., 2005. Emission factors for carbonaceous particles and polycyclic aromatic hydrocarbons from residential coal combustion in China. Environmental Science & Technology 39, 1861-1867.

86 Liu, W.X., Dou, H., Wei, Z.C., Chang, B., Qiu, W.X., Liu, Y., Tao, S., 2009. Emission characteristics of polycyclic aromatic hydrocarbons from combustion of different residential coals in North China. *Science of the Total Environment* 407, 1436-1446.

87 Shen, G., Wang, W., Yang, Y., Zhu, C., Min, Y., Xue, M., et al. (2010). Emission factors and particulate matter size distribution of polycyclic aromatic hydrocarbons from residential coal combustions in rural northern China. *Atmospheric Environment*, *44*(39), 5237-5243

88 Chen, Y.J., Bi, X.H., Mai, B.X., Sheng, G.Y., Fu, J.M., 2004. Emission characterization of particulate/gaseous phases and size association for polycyclic aromatic hydrocarbons from residential coal combustion. *Fuel* 83, 781-790.

89 Chen, Y., Sheng, G., Bi, X., Feng, Y., Mai, B., Fu, J., 2005. Emission factors for carbonaceous particles and polycyclic aromatic hydrocarbons from residential coal combustion in China. Environmental Science & Technology 39, 1861-1867.

90 Liu, W.X., Dou, H., Wei, Z.C., Chang, B., Qiu, W.X., Liu, Y., Tao, S., 2009. Emission characteristics of polycyclic aromatic hydrocarbons from combustion of different residential coals in North China. *Science of the Total Environment* 407, 1436-1446.

Ash Disposal

The BAT/BEP guidelines advise that the primary emission of chemicals listed in Annex C from residential combustion is to air. They add "Ash and soot are also released and, when arising from clean wood or biomass combustion, typically contain only small quantities of chemicals listed in Annex C. Minor amounts of ash may be safely used for fertilizer (sic) as long as it is not spread in the same place on a regular basis. Larger quantities should be disposed of in a sanitary landfill".

Whether this is prudent or not depends largely upon the combustion of co-contaminants, including heavy metals such as lead from painted wood. All these contaminants could render the ash completely unsuitable - and even hazardous -for use as fertiliser. The possibility of high levels of dioxin contamination cannot be discounted. T draft UNEP dioxin toolkit gives reasonably high emission factors for household heating and cooking using biomass contaminated with, for example, waste wood (1 µg TEQ/kg ash[91]) and, although no source reference is given, much higher levels of contamination from high chlorine coal fired stoves (30 µg TEQ/kg ash) and even for coal fired stoves (5 µg TEQ/kg ash).

The levels of dioxin in ashes from high chlorine coal fired stoves would thus be twice the (high) provisional low POPs level and, if correct, then special precautions would need to be taken to avoid contamination of food and associated risks to human health. The spreading of ash in areas where hens have access must be anticipated as particular risk[92].

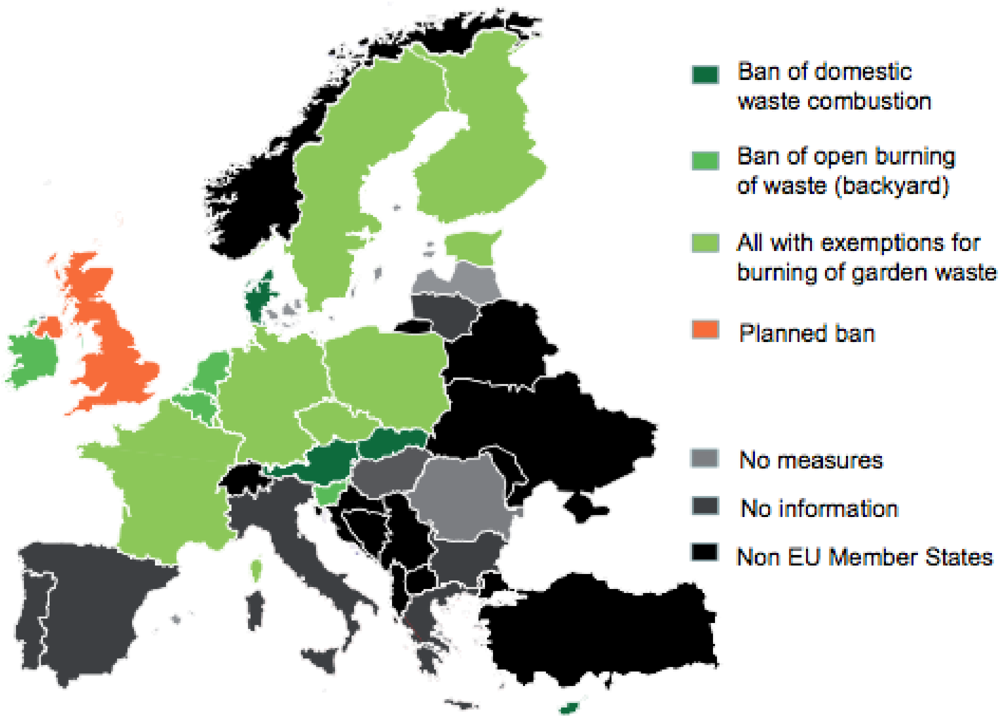
91 Based on Wunderli, S., Zennegg, M., Dolezal, I. S., Noger, D., & Hasler, P. (1996). Levels and congener pattern of PCDD/PCDF in fly and bottom ash from waste wood and natural wood burned in small to medium sized wood firing facilities in switzerland. *Organohalogen Compounds*, *27*, 231-36.

92 Petrlik, J. & DiGangi, J. (2005, April). *The egg report - contamination of chicken eggs from 17 countries by dioxins, PCBs and hexachlorobenzene* . Dioxin, PCBs and Waste Working Group of the International POPs Elimination Network (IPEN)

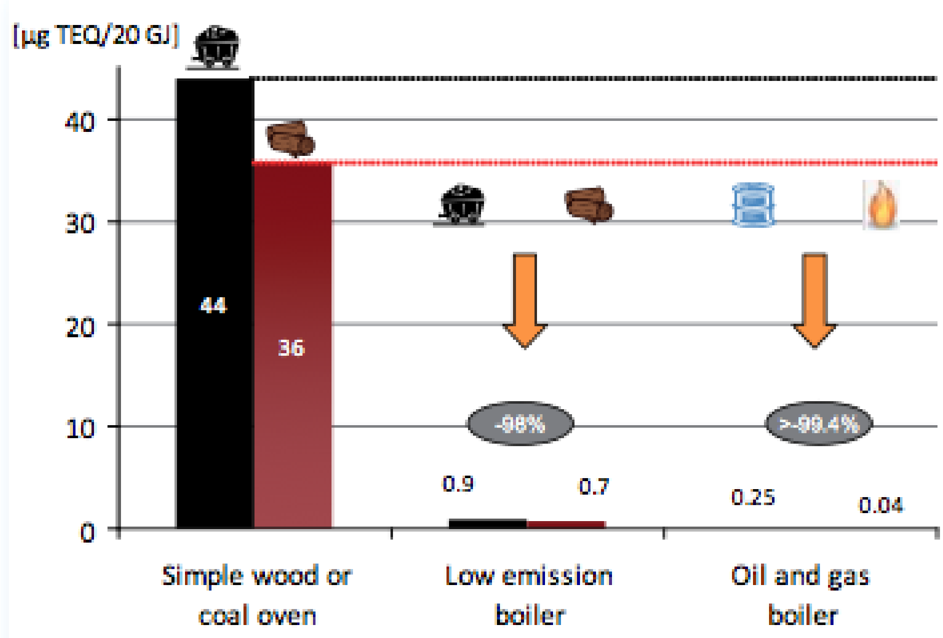
Bans on Waste Burning, New Equipment, Good Combustion Control and Minimising Emissions

Bans and restrictions on burning of waste

The most obvious approach to reducing emissions associated with the burning of wastes and plastics is to introduce legislation to outlaw the practice. This is now widespread in the EU where many member states have already taken measures to restrict the burning of waste by introducing legal bans as can be seen in the figure below:



The emissions of PCDD/PCDFs and other emissions can be significantly reduced by the replacement of old and existing combustion equipment and the introduction of advanced combustion techniques for solid fuels and the European Commission/BiPRO (BiPRO, 2009) indicate that the replacement of a simple wood or coal oven with an advanced boiler fired with the same (solid) fuel results in a reduction of dioxin emissions of more than 95%:



Dioxin emissions and reduction potential as a function of appliance type and fuel (per average household) (BiPRO, 2009)

The Stockholm Convention's BAT/BEP guidelines include useful information on reducing emissions from household stoves and boilers and emphasise that the complete combustion of fuel is important for ensuring low emissions and efficient operation of the appliance.

This can be achieved by ensuring the following:

- Sufficient firing temperature;
- Sufficient airflow to provide enough oxygen for combustion;
- Avoidance of fuel overloading (more than the fire can burn efficiently);
- Sufficient mixing of air and the hot gases given off by the fire.

Specific measures to achieve these desired outcomes are:

- Good-quality, dry fuel;
- Collecting and seasoning wood to ensure it is dry when burnt;
- Ensuring adequate airflow (for example, preventing incoming air from being blocked by pieces of wood;
- Enough space in the firebox for optimal airflow.

There is some evidence that processing fuel into forms which encourage more homogeneous combustion can also be effective at reducing pollution.

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ANNEX 1

Definitions:

Fireplaces: Simple radiation device used as supplemental heating appliance primarily for aesthetic reasons. Can be subdivided into solid or gas fuelled, open, partly closed and closed; constructed as brick/cut stone or cast iron/steel. Open fireplaces usually have a very low efficiency and significant emissions, partly closed fireplaces are retrofitted with doors and other devices to increase their efficiency. Closed fireplaces have doors, systems for air distribution and discharge of exhaust gases. Efficiency is >50% with similar emissions to stoves, so that they can be rated in the same category.

Stoves: Stoves are mainly simple combustion devices (radiation or heat storing) used for heating and cooking purposes Conventional up-draught stoves, using only primary supply air from below corresponding to over-fire boilers have an efficiency of 40-50%. This technology is used in the majority of older appliances and is associated with higher emissions. Classic energy efficient stove have an efficiency of 55-70% and lower emissions due to secondary air supply (down-draught combustion technology corresponding to under-fire boiler). Advanced stoves are characterised by multiple air inlets and pre-heating of secondary air and achieve 70% efficiency at full load and lower emissions. Pellet stoves are equipped with a fan and air supply control system to improve combustion conditions, resulting in high efficiency 80-90% and low emissions. Heat storing stoves achieve efficiency of 60-80%.

Boilers: Boilers have a nominal capacity of 12-50 kW and are widespread in temperate regions. According to the combustion process applied boilers can be differentiated into over-fire boilers (cheap simple) and under-fire and inverse-fire boilers (advanced boilers) with increasing combustion efficiency. The simplest boilers are over-fire boilers for wood logs. The principle is that combustion takes place in the whole fuel batch as in wood-stoves with only primary air supply. Combustion in the cheap and simple over-fire boilers is not optimal and efficiency is similar to conventional stoves. In under-fire boilers the fuel is burning mainly from the bottom with also secondary air supply. The under-fire boiler can normally be switch between under-fire and over-fire by a flue gas valve. In advance under-fire coal boiler gasification and partial combustion takes place in the bottom of the fuel storage and the final, major combustion takes place in a separate combustion chamber. Inverse-fire or down-draught boilers have the primary combustion air supply above the fuel This group of boilers comprises downdraught wood boilers as state of the art for lump wood, stoker coal burners for coal with high efficiency over a wide load range and wood pellet boilers with high efficiency and emissions comparable to liquid fuel boilers. Combustion in under-fire and inverse fire boilers is more stable resulting in higher efficiency and lower emissions. Besides combustion technology, a differentiation can be made with respect to the feeding of boilers and stoves into overfed (the fuel is fed from above into the combustion chamber) and underfed (the fuel is fed from above into the combustion chamber). These differences in technology are especially important and used in modern automated biomass or coal (retort boilers) fired appliances.

ANNEX 2

Is it better to recycle or incinerate mixed Plastic Waste ?

Kukačka (Kukačka 2010)[93] claimed in a report for the Czech Government that "incineration and gasification seem to be the most advantageous procedures for mixed plastic waste energy recovery" and "in view of high costs connected with plastic waste transport" recommended a network of large and small incinerators and gasification plants across the Czech Republic. This claims need careful scrutiny as they are inconsistent with the results of meta-reviews of life cycle assessments for plastics recovery. An important example relates to the work of the UK Waste Resources Action Programme (WRAP). This is a governmental research organisaton which undertook a specialist review of international studies titled "*Environmental Benefits of Recycling*" (WRAP 2006)[94]. The review shows how increased recycling is helping to tackle climate change and emphasises the importance of recycling over incineration and landfill as the appropriate way forward. Of particular relevance here is that the evidence from WRAP concludes "*In the vast majority of cases, the recycling of materials has greater environmental benefits than incineration or landfill".* WRAP also concluded:

14. The message of this 2006 study is unequivocal. Recycling is good for the environment, saves energy, reduces raw material extraction and combats climate change. It has a vital role to play as waste and resource strategies are reviewed to meet the challenges posed by European Directives, as well as in moving the UK towards more sustainable patterns of consumption and production, and in combating climate change by reducing greenhouse gas emissions.

WRAP tabulated the results of their review showing the numbers of studies in each category:

Overall environmental preffrence of waste management options across all reviewed scenarios

	Recycling v Incineration			**Recycling v Landfill**		
Material	Recycling	Incineration	No preference	Recycling	Landfill	No preference
Paper	22	6	9	12	0	1
Glass	8	0	1	14	2	0
Plastics	32	8	2	15	0	0
Aluminium	10	1	0	7	0	0
Steel	8	1	0	11	0	0
Wood						
Aggregates				6	0	0
Totals	80	16	12	65	2	1

	Incineration v Landfill			**Recycling v Mixed**			**Grand Total**
Material	Recycling	Incineration	No preference	Recycling	Mixed	No preference	
Paper	1	0	0	12	0	0	63
Glass							25
Plastics	2	0	1				60
Aluminium	2	0	0				20
Steel							
Wood	7	0	0				7
Aggregates							6
Totals	12	0	1	12	0	0	201

93 Kukačka, J., Raschman, R. 2010: Possibilities of municipal plastic waste energy recovery Odpadové fórum (Waste Management Forum) 10/2010; 14 – 16.

94 WRAP (2006). Environmental Benefits of Recycling - An international review of life cycle comparisons for key materials in the UK Recycling Sector Sep 2006. Banbury, Waste Resources Action Programme,.

Out of 40 reviews only 20% supported incineration over recycling. This is remarkable considering that several of the original papers were supported by the waste disposal industry in an attempt to justify less recycling and more disposal. When the original papers are examined it is clear that these tended to make assumptions that are known to favour incineration such as the displacement of high carbon electricity generation. When future projected carbon intensities of displaced generation are substituted then few if any of the papers maintain the support for incineration over recycling.

In 2010 WRAP updated this 2006 review of waste management options (Michaud, Farrant et al. 2010)[95]. They assessed 55 'state of the art' LCAs on paper and cardboard, glass, plastics, aluminium, steel, wood and aggregates and the conclusion, they said again "*was clear – most studies show that recycling offers more environmental benefits and lower environmental impacts than the other waste management options*".

The results confirm that mechanical recycling is the best waste management option in respect of the change potential, depletion of natural resources and energy demand impacts. The analysis highlights again that these benefits of recycling are mainly achieved by avoiding production of virgin plastics.

The environmental benefits are maximised by collection of good quality material (to limit the rejected fraction) *and by replacement of virgin plastics on a high ratio (1 to 1).*

*Incineration with energy recovery performs poorly with respect to climate change imp*act, but pyrolysis appears to be an emerging option regarding all indicators assessed, though this was only analysed in two LCA studies.

WRAP concludes that:

"Looking to the future, as the UK moves to a lower carbon energy mix, collection quality improves and recycling technology develops, then recycling will become increasingly favoured over energy recovery for all impact categories".

It is not surprising, therefore, that climate change economist Nicholas Stern wrote (Stern 2009):

"*Recycling is already making a major contribution to keeping down emissions. Indeed, its scale is so little appreciated that it might be described as one of the 'best kept secrets' in energy and climate change....New technologies for separating out forms of waste could also have a great impact*."

A specific review for WRAP assessing the life cycle options for mixed plastics (Shonfield 2008)[96] rated incineration by far the worst option in terms of climate change impacts (see gaphs below) as well as being in the worst 25% for human toxicity potential, photochemical ozone creation potential, acidification potential and abiotic depletion:

[95] Michaud, J.-C., Bio Intelligence Service,, L. Farrant, et al. (2010). Environmental Benefits of Recycling - 2010 update An updated review of life cycle comparisons for key materials in the UK recycling sector SAP097 16 March 2010. Banbury WRAP Waste Resources Action Programme.

[96] Shonfield, P. (2008). *LCA of management options for mixed waste plastics.* Banbury: Waste Resources Action Programme WRAP

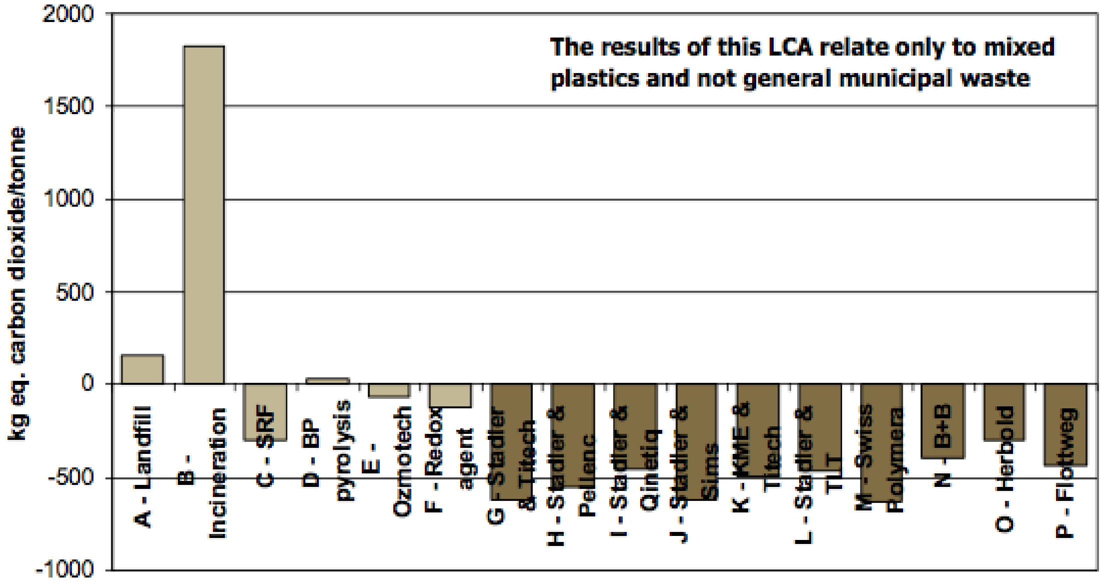
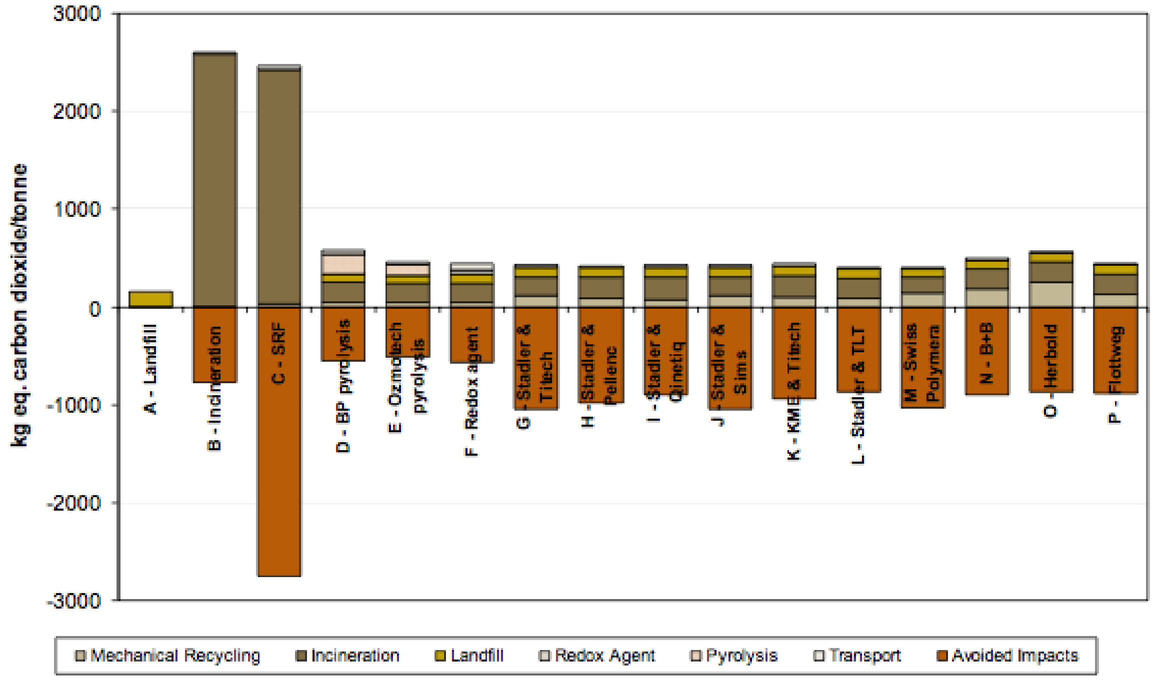


Chart 5.3.2 Contribution to global warming potential by process stage



Furthermore other research by consultants Oakdene Hollins for WRAP (WRAP 2008)[97] demonstrated that even exports of plastics over very long distances, such as to China, did not change the conclusions that recycling was a better from a carbon emissions perspective.

[97] WRAP (2008). *CO_2 impacts of transporting the UK's recovered paper and plastic bottles to China*. Banbury: Oakdene Hollins and critically reviewed by ERM for Waste Resources Action Programme

ANNEX 3

UNECE Default Emission Factors:

Hard Coal and Brown Coal:

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	1.A.4.b.i	Residential plants			
Fuel	Hard Coal and Brown Coal				
Not applicable	Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCP, SCCP				
Not estimated	Total 4 PAHs				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	110	g/GJ	36	200	Guidebook (2006) chapter B216
CO	4600	g/GJ	3000	7000	Guidebook (2006) chapter B216
NMVOC	484	g/GJ	250	840	Guidebook (2006) chapter B216
SOx	900	g/GJ	300	1000	Guidebook (2006) chapter B216
NH3	0.3	g/GJ	0.1	7	Guidebook (2006) chapter B216
TSP	444	g/GJ	80	600	Guidebook (2006) chapter B216
PM10	404	g/GJ	76	480	Guidebook (2006) chapter B216
PM2.5	398	g/GJ	72	480	Guidebook (2006) chapter B216
Pb	130	mg/GJ	100	200	Guidebook (2006) chapter B216
Cd	1.V	mg/GJ	0.5	3	Guidebook (2006) chapter B216
Hg	5.I	mg/GJ	3	6	Guidebook (2006) chapter B216
As	2.V	mg/GJ	1.V	5	Guidebook (2006) chapter B216
Cr	11.II	mg/GJ	10	15	Guidebook (2006) chapter B216
Cu	22.III	mg/GJ	20	30	Guidebook (2006) chapter B216
Ni	12.VII	mg/GJ	10	20	Guidebook (2006) chapter B216
Se	1	mg/GJ	1	2.IV	Expert judgement based on Guidebook (2006) chapter B216
Zn	220	mg/GJ	120	300	Guidebook (2006) chapter B216
PCB	170	μg/GJ	85	260	Kakareka et. al (2004)
PCDD/F	800	ng I-TEQ/GJ	300	1200	Guidebook (2006) chapter B216
Benzo(a)pyrene	230	mg/GJ	60	300	Guidebook (2006) chapter B216
Benzo(b)fluoranthene	330	mg/GJ	102	480	Guidebook (2006) chapter B216
Benzo(k)fluoranthene	130	mg/GJ	60	180	Guidebook (2006) chapter B216
Indeno(1,2,3-cd)pyrene	110	mg/GJ	48	144	Guidebook (2006) chapter B216
HCB	0.62	μg/GJ	0.31	1.II	Guidebook (2006) chapter B216

Note: 900 g/GJ of sulphur dioxine corresponds to 1.2% S of coal fuel or lower heating value on a dry basis 24 GJ/t and average sulphur retention in ash as value of 0.1

Biomass

Tier 1 default emission factors		
	Code	Name
NFR Source Category	1.A.4.b.i	Residential plants

Fuel	Biomass				
Not applicable	Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCP, SCCP				
Not estimated	Total 4 PAHs				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	74.5	g/GJ	30	150	EMEP/CORINAIR B216
CO	5300	g/GJ	4000	6500	EMEP/CORINAIR B216
NMVOC	925	g/GJ	400	1500	EMEP/CORINAIR B216
SOx	20	g/GJ	10	30	EMEP/CORINAIR B216
NH3	3.VIII	g/GJ	3.04	14	EMEP/CORINAIR B216
TSP	730	g/GJ	500	1260	EMEP/CORINAIR B216
PM10	695	g/GJ	475	1200	EMEP/CORINAIR B216
PM2.5	695	g/GJ	475	1190	EMEP/CORINAIR B216
Pb	40	mg/GJ	10	60	EMEP/CORINAIR B216
Cd	1,4	mg/GJ	0.1	2.5	EMEP/CORINAIR B216
Hg	0,5	mg/GJ	0.2	0.6	EMEP/CORINAIR B216
As	1	mg/GJ	0.3	2.5	EMEP/CORINAIR B216
Cr	2.9	mg/GJ	1	10	EMEP/CORINAIR B216
Cu	8.6	mg/GJ	0.5	11.2	EMEP/CORINAIR B216
Ni	4.4	mg/GJ	1	250	EMEP/CORINAIR B216
Se	0.5	mg/GJ	0.25	0.75	EMEP/CORINAIR B216
Zn	130	mg/GJ	60	250	EMEP/CORINAIR B216
PCB	0.06	mg/GJ	0.012	0.3	Kakareka et. al (2004)
PCDD/F	700	ng I-TEQ/GJ	500	1000	EMEP/CORINAIR B216
Benzo(a)pyrene	210	mg/GJ	130	300	EMEP/CORINAIR B216
Benzo(b)fluoranthene	220	mg/GJ	150	260	EMEP/CORINAIR B216
Benzo(k)fluoranthene	130	mg/GJ	60	180	EMEP/CORINAIR B216
Indeno(1,2,3-cd)pyrene	140	mg/GJ	80	200	EMEP/CORINAIR B216
HCB	6	µg/GJ	3	9	EMEP/CORINAIR B216

ANNEX 3

Compilation of emission factors from the literature (BiPRO, 2009)

Range of EF for coal combustion in different domesic appliances in the EU (цg TEQ/TJ)

Year	Short reference	MS	Domestic appliance (type)	Manufacture	Fuel	EF air цg TEQ/TJ
1999	Thanner & Moche 2002	AT	stovetyp 1 low priced multi-fuel stove	~1999	coal Poland	8,990 9,470 12,100 11,700
1999	Thanner & Moche 2002	AT	stovetyp 1 low priced multi-fuel stove	~1999	coke Czech Republic	1,500 1,980
1999	Thanner & Moche 2002	AT	stovetyp 2 cast iron stove for coke	~1979	coal Poland	4,190 3,640 8,620
1999	Thanner & Moche 2002	AT	stovetyp 2 cast iron stove for coke	~1979	coke Czech Republic	1,560 860
1999	Thanner & Moche 2002	AT	stovetyp 3 danish style cast iron wood stove	~1990	coal Poland	3,230
1999/2000	Boos et at. 2005 resp. Hübner et al. 2005	AT	Single stove (continuous burning)	~1960	wood, coal	29
1999/2000	Boos et at. 2005 resp. Hübner et al. 2005	AT	Single stove (continuous burning)	1990	wood, coal	27
1999/2000	Boos et at. 2005 resp. Hübner et al. 2005	AT	Stingle stove (kitchen)	~1970	wood, coal	130
1999/2000	Boos et at. 2005 resp. Hübner et al. 2005	AT	Stingle stove (kitchen)	~1970	wood, coal	48
1999/2000	Boos et at. 2005 resp. Hübner et al. 2005	AT	Stingle stove (kitchen)	1985	wood, coal	2,400
1999/2000	Boos et at. 2005 resp. Hübner et al. 2005	AT	Residential heating boiler for solid fuels	1981	coke	71
1999/2000	Boos et at. 2005 resp. Hübner et al. 2005	AT	Residential heating boiler for solid fuels	1999	coke	87
1999/2000	Boos et at. 2005 resp. Hübner et al. 2005	AT	Residential heating boiler for solid fuels	1978	coke	280
1999/2000	Boos et at. 2005 resp. Hübner et al. 2005	AT	Residential heating boiler for solid fuels	1987	coke	380
1994/1995	Erken et al. 1996	DE	fireplace	~1986	lignite briquette	61
1994/1995	Erken et al. 1996	DE	fireplace	~1986	lignite briquette	38
1994/1995	Erken et al. 1996	DE	fireplace	~1986	lignite briquette	11
1994/1995	Erken et al. 1996	DE	fireplace	~1986	lignite briquette	8
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette	37

1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette	62
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette	19
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette	16
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	lignite briquette	13
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	lignite briquette	19
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	lignite briquette	10
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	lignite briquette	11
1994/1995	Erken et al. 1996	DE	boiler 2	~1987-90	lignite briquette	20
1994/1995	Erken et al. 1996	DE	boiler 2	~1987-90	lignite briquette	49
1994/1995	Erken et al. 1996	DE	boiler 2	~1987-90	lignite briquette	21
1994/1995	Erken et al. 1996	DE	boiler 2	~1987-90	lignite briquette	35
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette	32
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette 2	31
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette 2	20
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette 2	17
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	lignite briquette 2	33
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	lignite briquette 2	14
1994/1995	Erken et al. 1996	DE	boiler 2	~1987-90	lignite briquette 2	19
1994/1995	Erken et al. 1996	DE	boiler 2	~1987-90	lignite briquette 2	32
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette 3	54
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette 3	25
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette 3	15
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	lignite briquette 3	12
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	lignite briquette 3	27
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	lignite briquette 3	12
1994/1995	Erken et al. 1996	DE	boiler 2	~1987-90	lignite briquette 3	17
1994/1995	Erken et al. 1996	DE	boiler 2	~1987-90	lignite briquette 3	30
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	Anthracite 1	24
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	Anthracite 1	31
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	Anthracite 1	21
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	Anthracite 1	20

1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	Anthracite 1	10
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	Anthracite 1	13
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	Anthracite 1	6
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	Anthracite 1	10
1994/1995	Erken et al. 1996	DE	Boiler 1	~1986/87	Anthracite 1	14
1994/1995	Erken et al. 1996	DE	Boiler 1	~1986/87	Anthracite 1	13
1994/1995	Erken et al. 1996	DE	fireplace	~1987	hard coal briquettes	81
1994/1995	Erken et al. 1996	DE	fireplace	~1987	hard coal briquettes	68
1994/1995	Erken et al. 1996	DE	fireplace	~1987	hard coal briquettes	47
1994/1995	Erken et al. 1996	DE	fireplace	~1987	hard coal briquettes	31
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	hard coal briquettes	21
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	hard coal briquettes	19
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	hard coal briquettes	11
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	hard coal briquettes	23
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	hard coal briquettes	18
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	hard coal briquettes	17
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	hard coal briquettes	7
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	hard coal briquettes	10
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	hard coal coke	50
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	hard coal coke	69
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	hard coal coke	23
1994/1995	Erken et al. 1996	DE	Stove continuous burning	~1982	hard coal coke	36
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	hard coal coke	18
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	hard coal coke	49
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	hard coal coke	28
1994/1995	Erken et al. 1996	DE	Continuous heating device	~1985	hard coal coke	20
?	Hobson et al. 2003	UK	Domestic open fire <5 kW	?	Yorkshire housecoal	120.8[1)]
?	Davies et al. 1992	UK	Domestic open fire <5 kW	?	Smokeless coal, bituminous coal anthracite	87.5 - 238[1)]
?	Geueke et al. 2000	DE	Stoves	?	Lignite Germany	70; 58[1)]
				?	Lignite Czech Rep.	20; 21[1)]
				?	Anthracite	95,175[1)]

				?	Hard coal Poland	633; 1,430[1)]
?	Grochowalski 2002	PL	Stoves	?	Coal	6,000; 11,000[1)]
	Williams et al. 2001	PL	Household, advanced manual fuelled boiler, 30 kW	?	Coal J	285
					Coal W	804; 540.1
?	Quass et al. 2000	DE	Stove A, Simple design	?	Lignite Germany	117.6[1)]
				?	Lignite Czech Rep.	39.4[1)]
				?	Anthracite	145[1)]
				?	Hardcoal briq. Ger.	310.4[1)]
				?	Coke Germany	26.61)
				?	Hardcoal Poland	1,127[1)]
			Stove B, Modern design	?	Lignite Germany	192.9
				?	Lignite Czech Rep.	69.4[1)]
				?	Anthracite	364.3[1)]
				?	Hardcoal briq. Ger.	186.7[1)]
				?	Coke Germany	90.3[1)]
				?	Hardcoal Poland	3,687[1)]
?	Kakareka et al. 2003	BY	Small and medium boiler, non controlled combustion	?	Coal	104[2)]
			Small and medium boiler, party controlled combustion	?	Coal	42[2)]
?	Pfeiffer et al. 2000b	DE	Fireplaces, stoves and boilers (households)	?	High rank coal and products	27.4
				?	High rank coals	20.3
				?	Briquettes	37.3
				?	Coke from hight rank coals	39.4
				?	Brown coal briquettes	23.3

[1)] Original factors in g/kg of fuels, for recalculation H_U of 24 GJ/t (d.b.) for hard coal was, of 17 GJ/t (d.b.) for lignite and brown coal, of 30 GJ/t (d.b.) for anthracite, of 30 GJ/t (d.b.) for coke were assumed

[2)] Original factors in цg TEQ/Mg of fuels (default emission factors), recalculated

Range of dioxin emission factors from domestic coal combustion in the UK

Year	Short Reference	Type of appliances	Type of fuel	Specification (mean, median, min, max)	EF air цg TEQ/t
2006	Enviros 2006	Domestic heating	Smokeless coal/anthracite (SSF)	min	2
				max	50
			Bituminous coal	min	1.V
				max	100

Range of EF for coal combustion in different domesic appliances in the EU

Year	Short reference	MS	Domestic appliance (type)	Manufacture	Fuel	EF air mean цg TEQ/TJ
~2000	Quass et al. 2000	DE	Stove A through-burning, only primary air supply	1955-62	Lignite DE	2.00
~2000	Quass et al. 2000	DE			Lignite CZ	0.67
~2000	Quass et al. 2000	DE			Anthracite DE	4.35
~2000	Quass et al. 2000	DE			Hard coal briq. DE	7.46
~2000	Quass et al. 2000	DE			Coke DE	0.85
~2000	Quass et al. 2000	DE			Hard coal PL	27.05
~2000	Quass et al. 2000	DE	Stove B under-burning, thermostat, + secondary air supply	1983	Lignite DE	3.28
~2000	Quass et al. 2000	DE			Lignite CZ	1.18
~2000	Quass et al. 2000	DE			Anthracite DE	10.93
~2000	Quass et al. 2000	DE			Hard coal briq. DE	4.48
~2000	Quass et al. 2000	DE			Coke DE	2.89
~2000	Quass et al. 2000	DE			Hard coal PL	88.49
1999	Thanner & Moche 2002	AT	stovetyp 1 low priced multi-fuel stove	~1999	coal Poland	251.67 265.02 338.75 327.67
1999	Thanner & Moche 2002	AT			coke Czech Republic	42.66 56.41
1999	Thanner & Moche 2002	AT	stovetyp 2 cast iron stove for coke	~1979	coal Poland	117.21 101.84 241.32
1999	Thanner & Moche 2002	AT			coke Czech Republic	44.45 24.38
1999	Thanner & Moche 2002	AT	stovetyp 2 danish style cst iron wood stove	~1990	coal Poland	90.49
~2000	Kubica 2003	PL	Boiler		"Julian" coal (nut)	8.40
~2000	Kubica 2003	PL	Boiler		"Wujek" coal (nut)	26.30
~2000	Kubica 2003	PL	Boiler		"Wujek" coal (pae)	7.5
~2000	Kubica 2003	PL	Boiler		Briquettes of "Wujek" coal and Sawdust	9.90
~2000	Kubica 2003	PL	Boiler			7.6

~2000	Kubica 2003	PL	Boiler		"Wujek" coal and Sawdust	22.3
~2000	Kubica 2003	PL	Boiler		"Wujek" coal and Rape straw	23.4
~2000	Kubica 2003	PL	Retort boiler 25kW		"Julian" coal (pea)	1.70
2000	Lee et al. 2005	UK	Open fire		House coal	3
2000	Lohmat et al. 2006	Uk	modelling		coal	3
2002	Schleicher et al. 2002	Dk	Garden grill		Briquettes type A	11
2002	Schleicher et al. 2002	DK	Garden grill		Briquettes type B	6

Dioxin concentrations in exhaust gas from combustion of different types of coal briquettes

Year	Short reference	MS	Domestic appliance (type)	Manufacture	Fuel	Conc. air
						mean цg TEQ/TJ
~1994	Thuß et al. 1995 & 1997	DE	tiled stove with air circulation	?	"salt" coal briquettes (2,000 ppm w/w Cl)	0.087
~1994	Thuß et al. 1995 & 1997	DE	tiled stove with air circulation	?	"salt" coal briquettes (2,000 ppm w/w Cl)	0.134
~1994	Thuß et al. 1995 & 1997	DE	tiled stove with air circulation	?	"salt" coal briquettes (2,000 ppm w/w Cl)	0.106
~1994	Thuß et al. 1995 & 1997	DE	tiled stove with air circulation	?	"normal" coal briquettes (300 ppm w/w Cl)	0.013
~1994	Thuß et al. 1995 & 1997	DE	tiled stove with air circulation	?	"normal" coal briquettes (300 ppm w/w Cl)	0.021
~1994	Thuß et al. 1995 & 1997	DE	tiled stove with air circulation	?	"normal" coal briquettes (300 ppm w/w Cl)	0.01

Range of EF for wood combustion in different domesic appliances in the EU (цg TEQ/TJ)

Year	Short reference	MS	Domestic appliance (type)	Manufacture	Fuel	EF air
						цg TEQ/TJ
1999	Thanner & Moche 2002	AT	stovetyp 1 low priced multi-fuel stove	~1999	beech wood	70 20 690
			stovetyp 2 cast iron stove for coke	~1979	beech wood	70 260 630

			stovetyp 3 danish style cast iron wood stove	~1990	beech wood	550 270
1999/2000	Boos et al. 2005 resp. Hübner	AT		~1985	wood	2,300
1999/2000	Boos et al. 2005 resp. Hübner et al. 2005	AT	Single stove (continuous burning)	~1985	wood briquettes (oak)	27
				1990	wood (logs)	150
				~1985	beech wood (logs)	23
				~1960	beech wood, lignite briquettes	29
				1990	wood, lignite briquettes	27
			Single stove (kitchen)	~1970	spruce wood (small logs)	1,000
				1980	wood (small logs)	150
				1993	wood logs (beech oak)	73
				~1970	spruce wood, lignite briquettes	130
				~1970	wood, lignite briquettes	48
				1985	wood, coal	2,400
			Single stove (tiled stove)	1956	beech wood (logs)	4,500
				1990	beech wood (logs)	45
				1998	beech wood (logs)	120
1999/2000	Boos et al. 2005 resp. Hübner et al. 2005	AT	Residential heating boiler for solid fuels	1983	wood	30
				1988	wood	72
				1986	wood	82
				1983	wood	86
				1979	wood	2,600
			Residential heating boiler, fan-assistant	1990	wood	18
				1989	wood	21
			Automatic charged wood heating boiler	1999	pelleted wood	2
				1992	wood chips	3
				1982	wood chips	6
				1991	wood chips	2,000
1994/1995	Erken et al. 1996	DE	fireplace	~1987	birch wood	38
				~1987	birch wood	11
				~1987	birch wood	4
				~1987	birch wood	3
			stove continuously operating	~1982	birch wood	34
				~1982	birch wood	23
				~1982	birch wood	13
				~1982	birch wood	14
			continuous heating device	~1985	birch wood	10
				~1985	birch wood	28
				~1985	birch wood	10
				~1985	birch wood	9

			boiler 2	~1987-90	birch wood	16
				~1987-90	birch wood	18
				~1987-90	birch wood	11
				~1987-90	birch wood	12
	Pfeiffer et al. 2000b	DE	Fireplaces, stoves and boilers (households)	?	natural wood	29.5

Range of EF for wood combustion in different domesic appliances in the EU

Year	Short reference	MS	Domestic appliance (type)	Manufacture	Fuel	EF air
						mean цg TEQ/TJ
1999	Thanner & Moche 2002	AT	stovetyp 1 low priced multi-fuel stove	~1999	beech wood	1.03 (1.56) 0.24 10.68
1999	Thanner & Moche 2002	AT	stovetyp 2 cast iron stove for coke	~1979	beech wood	1.13 4.07 9.77
1999	Thanner & Moche 2002	AT	stovetyp 3 danish style cast iron wood stove	~1990	beech wood	8.49 4.17
~2000	Kubica 2003	PL	boiler 35kW	?	lump wood	33.20
~2000	Kubica 2003	PL	boiler 35kW	?	wooden briquettes (sawdust)	2.00
~2000	Kubica 2003	PL	65 kW low capacity boiler	?	rape straw	13.40
~2000	Kubica 2003	PL	65 kW low capacity boiler	?	wheat-rye strav	12.40
~1996	Pfeiffer et al. 2000a	DE	masonry heater open (prim. air) / open (sec. air)	1989	wood	0.63
~1996	Pfeiffer et al. 2000a	DE	tiled-stove heating insert open (prim. air) / open (sec. air)	1990	wood	0.76
~1996	Pfeiffer et al. 2000a	DE	tiled-stove heating insert medium (prim. air) / open (sec. air)	1990	wood	0.44
~1996	Pfeiffer et al. 2000a	DE	tiled-stove heating insert closed (prim. air) / open (sec. air)	1990	wood	0.14
~2005	Hedman et al. 2006	SE	boiler for pellet fuel or oil	?	wood pellets	11.0
~2005	Hedman et al. 2006	SE	boiler for pellet fuel or oil		wood pellets	2.0
~2005	Hedman et al. 2006	SE	boiler with two separate fireplaces, one for oil, one for solid fuels (wood or coke)		wood pellets	6.0

~2005	Hedman et al. 2006	SE	boiler with two separate fireplaces, one for oil, one for solid fuels (wood or coke)		birchwood	12.00
~2005	Hedman et al. 2006	SE	boiler with two separate fireplaces, one for oil, one for solid fuels (wood or coke)		coniferous wood	6.3
~2005	Hedman et al. 2006	SE	boiler with two separate fireplaces, one for oil, one for solid fuels (wood or coke)		birchwood + paper	5.0
~2005	Hedman et al. 2006	SE	boiler with two separate fireplaces, one for oil, one for solid fuels (wood or coke)		birchwood + paper + plastic	290
~2005	Hedman et al. 2006	SE	modern wood boiler	?	birchwood	2.8
~2005	Hedman et al. 2006	SE	modern wood boiler		birchwood	1.2
~2005	Hedman et al. 2006	SE	modern wood boiler		coniferous woos	1.2
~2005	Hedman et al. 2006	SE	modern wood stove	?	birchwood	3.5
~2005	Hedman et al. 2006	SE	modern wood stove		birchwood	5.9
1991/1993	Vikelsøe et al. 1994	DK	4 types of stove		wood	1.9
2000	Lee et al. 2005	UK	open fire		wood	0.6
2000	Lohman et al. 2005	UK	modelling		wood	0.2
~2004	Gönczi et al. 2005	SE	steel barrel		straw	4.4
2002	Schleicher et al. 2002	DK	wood stove		air dried birch firewood	5.1
2002	Schleicher et al. 2002	DK	wood stove		kiln dried beech wood, without bark	1.9
2002	Schleicher et al. 2002	DK	wood stove		air dried birch firewood	0.61
2002	Schleicher et al. 2002	DK	wood stove		kiln dried beech wood, without bark	0.64
2002	Schleicher et al. 2002	DK	19 kW stoker boiler		wood pellets	0.53
2002	Schleicher et al. 2002	DK	19 kW stoker boiler		wood pellets	0.21
2002	Schleicher et al. 2002	DK	19 kW stoker boiler		straw	5.3
2002	Schleicher et al. 2002	DK	19 kW stoker boiler		straw	9.2

Range of dioxin concentrations in exhaust gas and of EF for wood combustion in different domesic appliances

Year	Short reference	Type of appliances	Type of fuel		air (ng TEQ/m^3)	EF air (µg TEQ/t)
~1995	Collet 2000	3 MW industrial boiler + bag filter	bark & sawdust		0.019	0.32
~1995	Collet 2000	2.4 MW industrial boiler + bag filter	wood chips & sawdust		0.011	0.05

2001/2002	Gullet et al. 2003	woodstoves, fireplaces	oak, pine	min	0.0004	0.25
				max	0.0025	1.4
			artificial log	mean	0.0006	2.4
2005	Glasius et al. 2005	five wood stoves and one wood boiler	wood chips & sawdust	min (12 samples)		0.3
2005	Glasius et al. 2005	five wood stoves and one wood boiler	wood chips & sawdust	max		17.7
2007	Glasius et al. 2007	12 wood stoves and one wood boiler	wood	min (26 samples from 13 houses)		0.027
				max		140
				mean		19
				median		3
1997	Collet 2000	2 MW, with bag filter	wood, "non-doped" (0.6 ppm PCP)		1.28	11.5
		2 MW, with bag filter	wood, "doped" (20-36 ppm PCP)		2.33	21.0
		400 kW pilot installation, optimum conditions	wood pallets treated with PCP (0.1% PCP)	min	0.063	0.76
				max	0.186	2.23
~1994	Schatowitz et al. 1994	various furnaces (6 - 850 kW)	beech wood sticks, natural wood chips, uncoated chipboard chips	min	0.019	
				max	0.076	
			waste wood chips	min	2.7	
				max	14.42	
			charcoal	mean	0.028	
			household waste	mean	114	
2006	Enviros 2006	wood stove open fireplace	untreated wood	min		0.043
				max		11
2006	Enviros 2006	wood stove open fireplace	contaminated wood	min		11
				max		400
2003	Allemand 2003	open fireplaces	wood	mean***		1.8
2003	Allemand 2003	stoves	wood	mean***		1.8
2003	Allemand 2003	closed fireplaces	wood	mean***		1.8
2003	Allemand 2003	boilers (old)	wood	mean***		1.8
2003	Allemand 2003	boilers (class 1)	wood	mean***		1.8
2003	Allemand 2003	boilers (class 3)	wood	mean***		1.8
2003	Allemand 2003	<9MW industrial or collectvice heating installations	wood	mean***		0.72
2000	Baggio et al. 2001	30 kW gasifying boiler (reverse flame)	wood log (beech)	min		0.004
				max		0.01

Dioxin concentrations in exhaust gas from combustion of different types of wood and other biomass

Year	Short reference	MS	Domestic appliance (type)	Year of manufacture	Fuel	Conc. air mean ng TEQ/Nm^3
1992/1993	Kolenda et al. 1994	DE	hand fed chute incinerator	?	wood blocks, coated and uncoated plywood, wood residues	1.05
1992/1993	Kolenda et al. 1994	DE	hand fed chute incinerator	?	wood blocks, coated and uncoated plywood, wood residues	0.45
~1998	Launhardt & Thoma 2000	DE	multi-fuel furnace with an automtic charging and electronic control unit	~1997/1998	spruce wood - chipped	0.052
~1998	Launhardt & Thoma 2000	DE	multi-fuel furnace with an automtic charging and electronic control unit	~1997/1998	wheat straw - pelleted, chopped	0.656
~1998	Launhardt & Thoma 2000	DE	multi-fuel furnace with an automtic charging and electronic control unit	~1997/1998	hay (set aside land) - pellated, chopped	0.891
~1998	Launhardt & Thoma 2000	DE	multi-fuel furnace with an automtic charging and electronic control unit	~1997/1998	triticale (whole crop) - pelleted, chopped	0.052
~1997	Launhardt et al. 1998	DE	tied stove with "modern" combustion technology (design for wood combustion) upward burning	early nineties	birch	0.0043
~1997	Launhardt et al. 1998	DE	tied stove with "modern" combustion technology (design for wood combustion) upward burning	early nineties	conifer	0.006
~1997	Launhardt et al. 1998	DE	tied stove with "modern" combustion technology (design for wood combustion) upward burning	early nineties	spruce (humid)	0.011
~1997	Launhardt et al. 1998	DE	tied stove with "modern" combustion technology (design for wood combustion) upward burning	early nineties	conifers briquettes type A	0.015
~1997	Launhardt et al. 1998	DE	tied stove with "modern" combustion technology (design for wood combustion) upward burning	early nineties	conifers briquettes type B	0.022
~1997	Launhardt et al. 1998	DE	tied stove with "old" combustion technology (design for wood combustion) upward burning	70s to 80s	conifer	0.015
~1997	Launhardt et al. 1998	DE	tied stove with "old" combustion technology (design for wood combustion) upward burning	70s to 80s	conifer	0.007
~1997	Launhardt et al. 1998	DE	wood boiler (with flue blower and combustion control) downward burning	early nineties	birch	0.003

~1997	Launhardt et al. 1998	DE	wood boiler (with flue blower and combustion control) downward burning	early nineties	birch	0.003
~1997	Launhardt et al. 1998	DE	wood boiler (with flue blower and combustion control) downward burning	early nineties	birch	0.007
~1997	Launhardt et al. 1998	DE	wood boiler (with flue blower and combustion control) downward burning	early nineties	conifer	0.004
~1997	Launhardt et al. 1998	DE	wood boiler (with flue blower and combustion control) downward burning	early nineties	spruce	0.015
~1997	Launhardt et al. 1998	DE	wood boiler (with flue blower and combustion control) downward burning	early nineties	spruce chips	0.004
~1997	Launhardt et al. 1998	DE	wood-burning fireplace upward burning	early nineties	conifer	0.011
1991/1993	Vikelsøe et al. 1994	DK	4 types of stoves		wood	0.18
2000	Raventos et al. 2000	FR	NON-domestic boiler, equipped with multi-cyclone flue gas treatment	1996	wood fibre board, hard	≤0.016
				1998	wood particle board, melaminated	0.084
2000	Raventos et al. 2000	FR	NON-domestic boiler, equipped with multi-cyclone flue gas treatment	1998	wood particle board (non-chloride hardener)	≤0.014
					plywood (with non-chlorice phenolic resine)	0.016
2000	Raventos et al. 2000	FR	NON-domestic boiler, equipped with multi-cyclone flue gas treatment	1998	wood particle board (chloride based hardener)	0.016
1999	Deroubaix 1999	FR	NON-domestic boiler, collective heating installation, equipped with multi-cyclone flue gas treatment	1998	bark	0.07
					wooden pallets	0.13
1999	Deroubaix 1999	FR	NON-domestic boiler, collective heating installation, equipped with multi-cyclone flue gas treatment	1998	wooden pallets	0.02
					wooden pallets	0.05
2003	Allemand 2003	FR	industrial or collective heating boiler	?	natural wood and wood with a few additives	0.05
2003	Allemand 2003	FR	industrial or collective heating boiler		particular wood (containing PCP, with mixed painted wood…)	1.80

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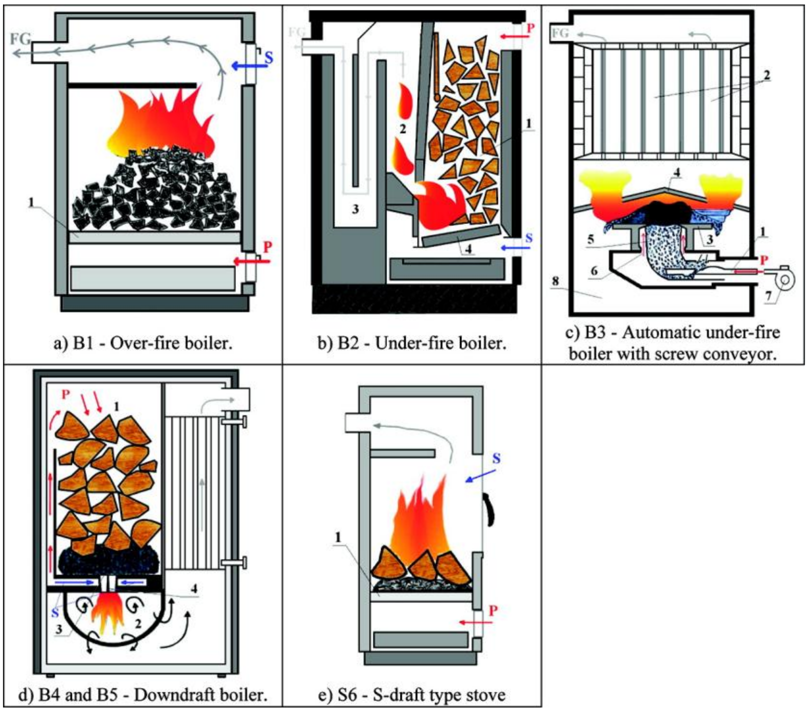
Annex 4: Different domestic heating appliences types

Picture and following graphs are From: Šyc, M., Horák, J., Hopan, F., Krpec, K., Tomšej, T., Ocelka, T., et al. (2011). Effect of fuels and domestic heating appliance types on emission factors of selected organic pollutants. *Environmental Science & Technology*, *45*(21), 9427-9434.



a) B1 - Over-fire boiler. b) B2 - Under-fire boiler. c) B3 - Automatic under-fire boiler with screw conveyor.
d) B4 and B5 - Downdraft boiler. e) S6 - S-draft type stove

Boiler 1 is a hot water over-fire boiler with manual stoking and natural draft (see Figure 1a). The whole fuel batch is combusted at one time, and the operation of the facility is periodical. Primary air (P) is blown under the water-cooled fixed grate (1) through an automatic draft-regulating damper in the ash pit door (see Figure 1a). A secondary air (S) inlet into the gas combustion zone is in the fuel feeding door and can be manually regulated with a damper. The recommended fuels are coke, bituminous coal, and wood logs; lignite is also possible.

Boiler 2 is an under-fire boiler with natural draft and manual stoking (see Figure 1b). The boiler can be divided into three parts: a fuel storage (1), a combustion chamber (2), and a gas flow chamber (3). Devolatilization and partial combustion occurs in a small part of fuel in the bottom of the fuel storage, while main combustion takes place in the follow-up combustion chamber. Primary air (P) is supplied through a damper in the fuel feeding door. Secondary air (S) is led through a channel to the combustion chamber; tertiary air is supplied sidewards to the combustion chamber as well. Rotary grates (4) are placed below the fuel storage and the combustion chamber. The recommended fuel is lignite, but other solid fuels can be used as well.

Boiler 3 is a modern under-fire boiler (see Figure 1c) with forced draft and automatic stoking by a screw conveyor (1). The upper part of the boiler is a lamellate heat exchanger (2). The lower part is a combustion chamber formed by an iron grate (3), a ceramic heat reflector (4), a retort for fuel feeding (5), and an air mixing system (6). Primary air (P) is supplied by a fan (7) to the air mixing system. There is an ash chamber (8) situated under the combustion chamber. The recommended fuels are lignite and biomass pellets. Other solid fuels with required granulometry can be combusted as well.

Boiler 4 is a modern downdraft boiler with manual stoking and forced draft by a draw-off fan (see Figure 1d). The boiler consists of two chambers; the upper one is for fuel storage (1) and the lower one is a combustion chamber (2). The chambers are divided by a special rotating burner (4). Primary air (P) is supplied to the combustion chamber from above through the batch of fuel and a special cast-iron grate (3). Secondary air (S) is supplied to the grate. The recommended fuels are lignite, but wood logs and other solid fuels can be used as well.

Boiler 5 is a modern downdraft boiler with manual stoking and forced draft by a draw-off fan. It has a similar construction to boiler 4 with larger chambers. It is for wood combustion only and has a stationary fire-clay grate. The recommended fuel is wood logs.

Stove 6 is a modern S-draft stove with grate (1) and periodical combustion operation (see Figure 1e).

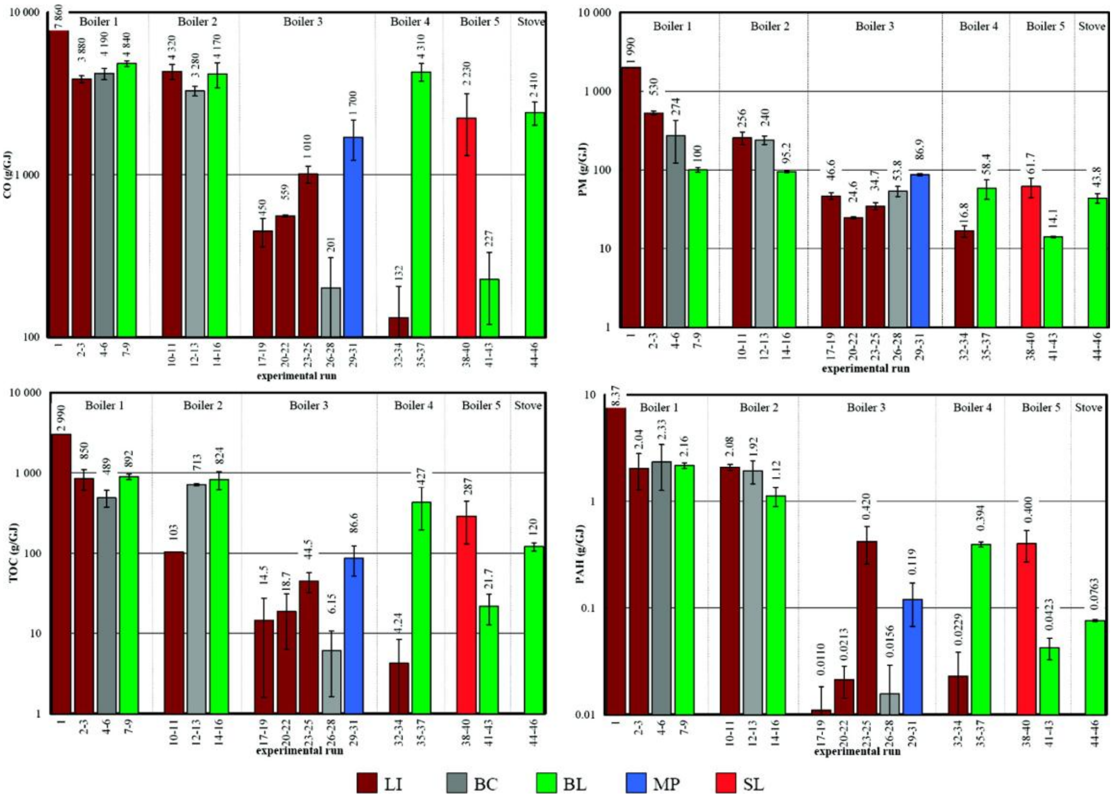
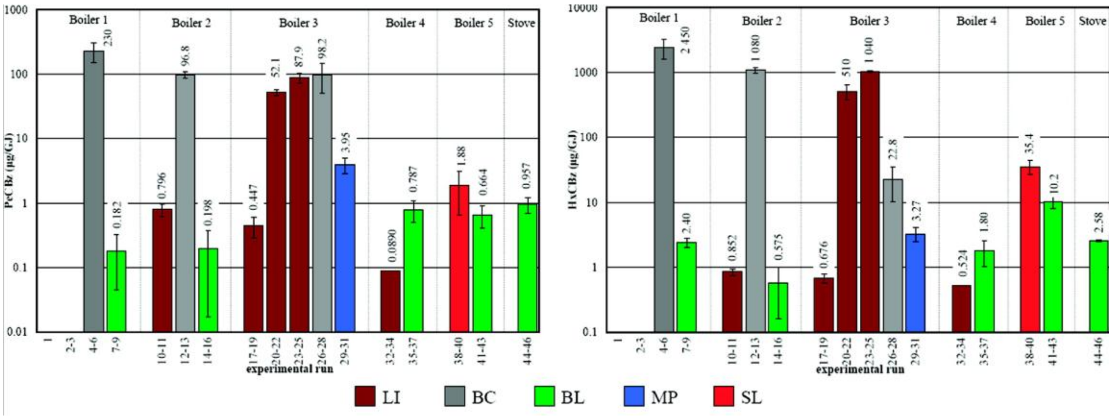


Figure 2. Mean values of emission factors of CO, PM, TOC, and PAH with standard deviations. PAH is the sum of 10 polyaromatic hydrocarbons: fluoranthene, pyrene, benzo[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, benzo[*g*,*h*,*i*]perylene, dibenzo[*a*,*h*]anthracene, and indeno[1,2,3-*cd*]pyrene.



Mean values of emission factors of PeCBz and HxCBz with standard deviations. Runs 1–3 of PCBz were not analysed due to matrix effects. Run 32–34 were based on only two values.

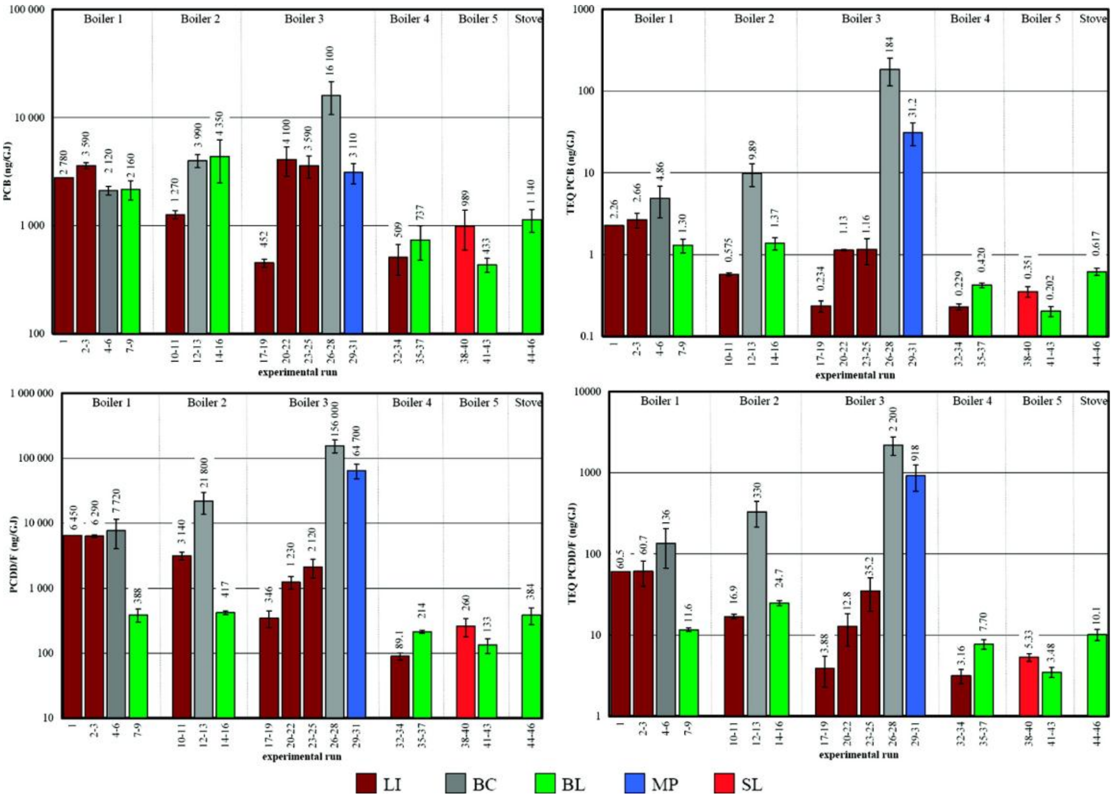


Figure 4. Emission factors of PCB and PCDD/F. PCB is the sum of PCBs 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, 170, 180, and 189. PCDD/F is the sum of tetra- to octa-CDD/F. TEQ values were determined according to EN 1948.