TFTEI

Under the Convention on Long Range Transboundary Air Pollution

Task Force on Techno-Economic Issues

Review on Black Carbon (BC) and Polycyclic Aromatic Hydrocarbons (PAHs) emission reductions induced by PM emission abatement techniques

TFTEI technical secretariat
Nadine Allemand (Citepa)

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Context and aim of the work

A technical work carried out in 2020 in the scope of questions addressed by the **Gothenburg Protocol Review Group (GPG)** to TFTEI on BC and PAH emissions and better know what measures can be implemented to reduce them.

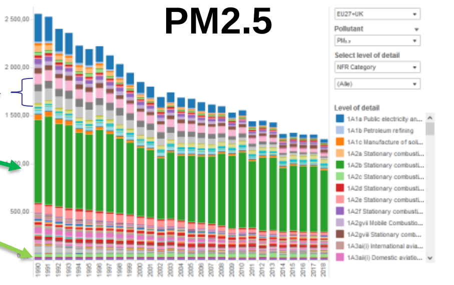
A review of latest scientific papers carried out (around 200 papers).

Sources examined: **small domestic combustion appliances, road transport and flares**

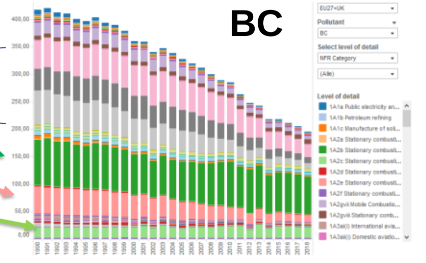
This technical work is complementary to the draft "**guidance document on prioritizing reductions of particulate matter** to also achieve reduction of black carbon"

Largest emitting sectors in the EU27+UK

- **2018, PM2.5**
  - Road traffic
  - **1A4bi Residential: Stationary**
  - 5C2 Open burning of waste
  - 1A1a Public electricity and heat production



- **2018, BC**
  - Road traffic
  - **1A4bi Residential: Stationary**
  - 1A4cii Agriculture/Forestry/Fishing: Off-road vehicles and other machinery
  - 5C2 Open burning of waste



https://www.ceip.at/data-viewer

Small combustion appliances in the residential sector

- **Residential wood burning** remains a major source of PM2,5 and BC
- BC, Condensable Organic Compounds (COC), VOC, CO are products of incomplete combustion
- Most BC emissions occur during the ignition stage
- Large range of BC emission factors

- From the EMEP/EEA guidebook:
  - PM2.5 : **740** g/GJ
  - PM10 : 760 g/GJ
  - TSP=800 g/GJ
  - BC as a fraction of PM2.5 (2-20% taken as 10%: **74** g/GJ)
- BC EF certainly underestimated according to a french study (CARABLACK, Raventos et al., 2018)

GAINS Emission factors ranges

Stoves	BC (g/GJ)	BC(%PM)
Traditionnal	32-100	4-22
Improved	30-95	25-55
New	9-30	18-30
Pellet	1.3-4.0	10-17

Klimont et al. (2017)

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Small combustion appliances in the residential sector

- In modern stoves, advanced methods limit the emission of PM, BC, PAH and improve the combustion efficiency such as: automatic fuel feeding, appropriate start-up, improvement of air staging combustion system, appropriate control systems to limit the impact of end-user…
- Wood pellet stoves have 2 to 3 times lower PM, BC and PAH emissions than wood logs in advanced wood stoves.
- Catalytic combustors are efficient on unburnt products, and limit the SOA formation later,
- Thermal Energy Storage helps to optimize the heating cycle from the start-up to the shutdown,
- ESP (electrostatic precipitator) can help to reduce emissions from existing appliances
    - Efficient for the solid fraction of PM (BC), less efficient on the condensable part,

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Small combustion appliances in the residential sector

- Correct installation and use of appliances, as well as maintenance and service/inspection of appliances and flue gas pipes are essential to reduce emissions.
- The quality and the type of wood is important to reduce emissions: Dry wood better, Coniferous type woods emit more PAH and BC…
- The Code of good practices for wood burning and small combustion installations developed by TFTEI is an excellent source of information.

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Small combustion appliances in the residential sector

- Start-up is a critical phase with high emissions of pollutants. Currently, test procedures for delivering labels are not able to characterise real conditions of use of domestic appliances.

  → New normalised test procedures should be developed and set-up, to better account for real uses of small-scale combustion appliances (start up and shut down phases, condensables).

- Harmonized methods to determine the emission factors of PM and BC would be necessary. For PM, methods accounting for condensables like dilution tunnels are recommended.
- Important to better emphasize synergies between CC and AQ policies by better knowledge of emissions BC, BrC, OC…

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Road traffic

- PM produced by combustion emitted at the exhaust pipe are mostly fine particles below 2.5 µm and are mainly composed of carbonaceous species <u>with BC as main compound.</u>
- PM, BC, Particle number (PN), and PAH emissions are effectively reduced using tailpipe aftertreatment systems such as Diesel Particulate Filter (DPF) or Gasoline Particulate Filter (GPF). Decreases from 90 to 100% are commonly observed.
- Diesel particulate filters (DPFs) have been widely used in the motor vehicle industry and are found to be cost-effective. As example, $PM_{2.5}$ emission factors from Conventional to Euro VI for Heavy Duty Vehicles (HDV) decreased from 333-491 to 0.5-1.3 mg km^{-1}.
- The fraction of BC in PM ranges from 10 to 20% in Euro VI HDV vehicles as example.

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Road traffic

- Currently emissions from brake, tire and road wear become predominant.
  - The PM emissions per km are larger than current Euro VI emissions and a similar fraction of BC is observed either in exhaust and no-exhaust PM emissions.
  - Brakes also produce ultrafine particles, metals and PAHs, the temperature greatly affects the dust PM emissions. BC emissions from brakes are very correlated to PM1 emissions.
- No widely used after-treatment system to control brake, tire and road wear emissions.
  - The type of materials, and the behaviour of the driver is often cited as a key to reduce emissions.
  - Some companies develop brake particles collection systems that would reduce by 80% to 90 % respectively the brake mass and number emissions

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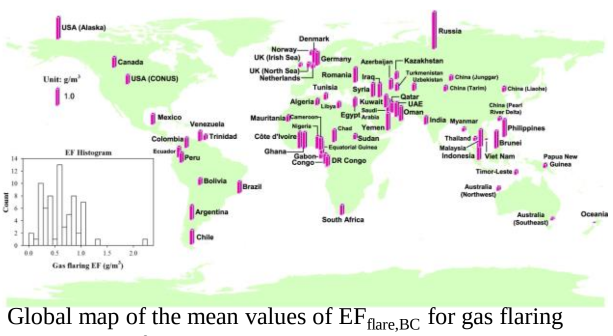
Gas Flaring



Global map of the mean values of $EF_{flare,BC}$ for gas flaring regions identified by the NOAA DMSP nighttime light products (Huang and Fu, 2016)

- Important source of BC emissions:
  - At least 90% of particulate carbonaceous species in the gas flare flue gas made of BC.
  - Routine flaring from a lack of gas uses is the most important and largest source of BC emissions.
  - Intermittent flaring and continuous flaring for operational reasons can also be significant sources.
  - Real emissions not well represented in emission inventories due to too large operating conditions and large range of emissions. Gap assessed by Satellite observations

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Gas Flaring

- Emission reduction solutions are available:
  - Avoiding flaring though use of gases for specific applications.
  - Steam-assist flares the most efficient in terms of soot emission reductions.
  - High pressure-assisted flares also an efficient technique if water is not available on site.

- Emission reductions also through better flare operation systems:
  - New flare models based on neural networks (advanced statistical methods) could help to better assist the flaring operations and better control soot formation.
  - The optimization of flare design and combustion conditions is an option thanks to the use of Computational Fluid Dynamic (CFD) models. Models and control systems can be used to monitor the flue gas characteristics and control the input data.

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Thank you very much for your attention! Questions?

TFTEI Technical Secretariat

https://unece.org/environment/documents/2020/12/informal-documents/Review on BC and PAH emission reductions

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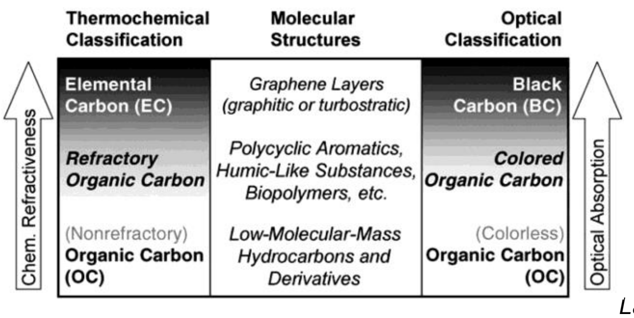
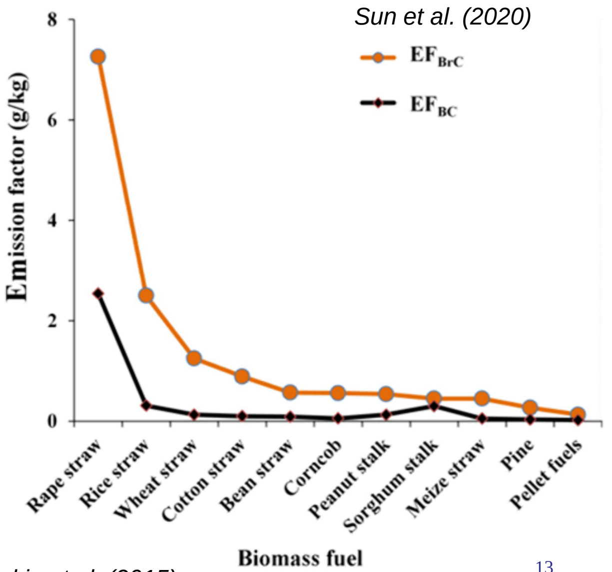
Black/Elemental/Brown Carbon

- Black or Brown Carbon?
- BC carbon c/should include BrC and then a part of Organic Matter
  - Possible double counting
  - EC is relevant for health issues
  - BC more relevant for climate impacts





Laskin et al. (2015)

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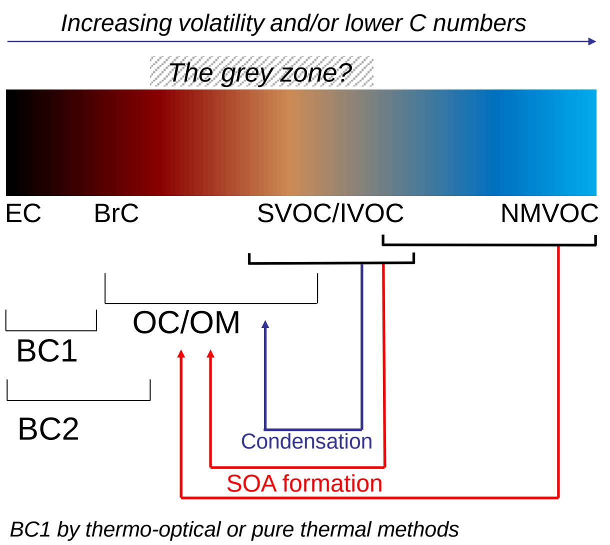
BrC/BC

- **The main critical issue: How to manage BrC in Emission Inventories??**
  - BrC as primary or secondary organic condensable fraction
  - Not included in BC if EF based on thermo-optical methods
  - Partly included in OC or OM
- **Include BrC in BC is relevant for CC policies and would show more co-benefits between AQ and CC policies**
- **The ratio BrC/BC is relevant to know for a good assessment of emission reduction strategies on CC and AQ**
  - Impact of PM abattement technologies on SOA formation and SVOC/IVOCs
  - A crucial point for residential wood burning
  - Implication for CC and AQ mitigation strategies
- **Is BrC a species to be considered at the emission or is it a modelling issue?**
  - The characteristic time of formation is certainly the key to attribute the species to « Emissions » or « AQ model outputs »



BC1 by thermo-optical or pure thermal methods
BC2 by pure optical methods

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PM concentrations in flue gas from two Belgian modern wood stoves

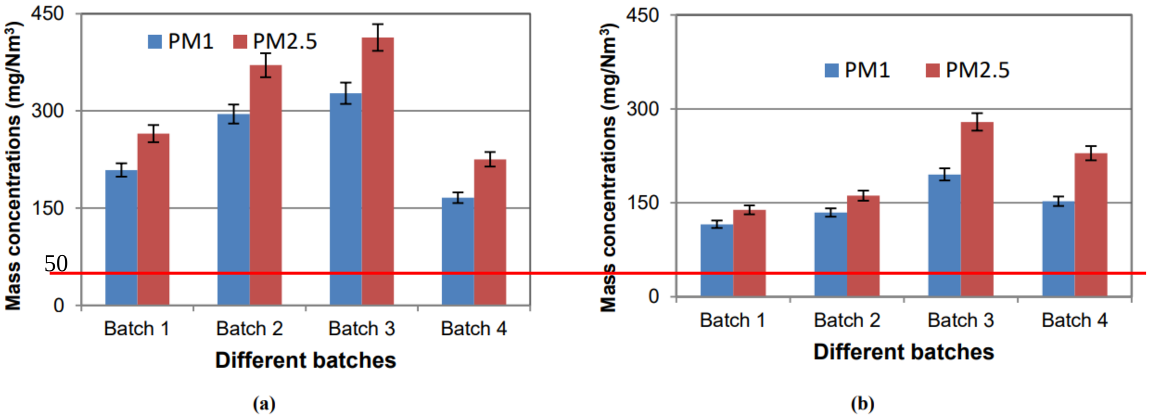

Fig. 4. PM_1 and $PM_{2.5}$ emissions from different batches, (a) for the 10 kW stove, (b) for the 20 kW stove

Obaidullah et al. (2019)

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Effect of catalytic combustor

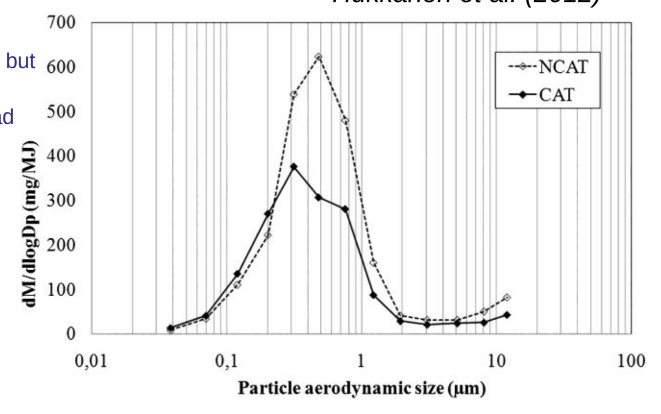
- Reduction of gaseous and particulate emissions from small-scale wood combustion with a catalytic combustor (Sauna stove in Finland)
- **PM1** (particle mass below aerodynamic size of 1 µm) was **reduced by 30%** during the whole combustion cycle.
- During gasification, a **44% reduction of PM1** was achieved but there was no reduction during burn out.
- The **organic and elemental carbon** analyzed from PM1 had reduced also only during gasification by **56% and 37%,** respectively.

However….

- The usage of catalytic converters in RWC is controversial.
- A catalytic converter reduced the adverse products of incomplete combustion such as CO, OGC and **PAHs** on average 26%, 24%, and **24%**, respectively.
- On the other hand, there is a clear **increase** in the concentrations of **PCDD/Fs** (8.7-fold) when the catalytic converter was used

(Kaivosoja et al., 2018)

Hukkanen et al. (2012)



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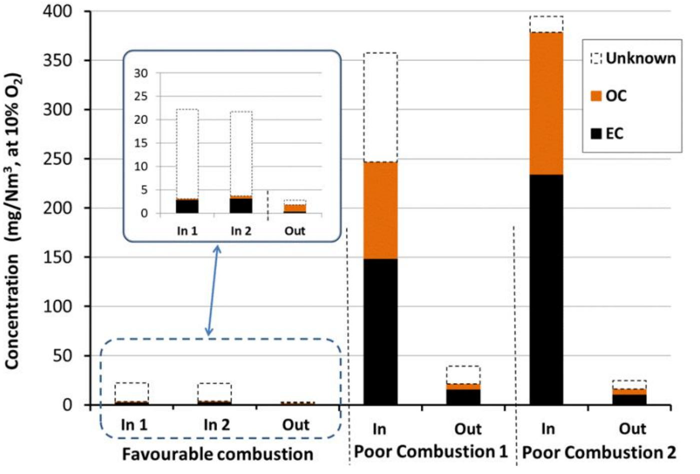
Impact of Electrostatic Precipitator on BC

Bäfver et al. (2012)

- Tests on wood Pellet Boiler under favorable and poor combustion
- Reduction efficiency > 90%
- Possible formation of condensable organic matter in the ESP in case of Temperature drop



Confirmed by industrial combustion processes (Mertens et al., 2020)

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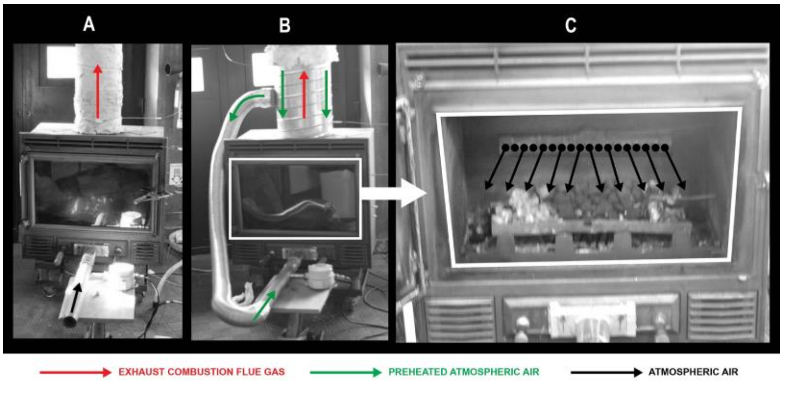
A low cost retrofit solution for conventional wood stoves

- PM EF decrease from 8.9 to 6.9 g/kg$_{fuel}$ but far from the reference limit
- Energy savings involved 30% in cost saving on annuities
- Expected similar performances on BC

Carvalho et al. (2018)



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Key messages

- BC/PAH emission reduced by modern devices
- Not clear for UFP
- A remaining issue on Organic Matter
  - – Possible formation of OM in the flue gas
  - – BrC-SVOC/IVOC need to be better estimated in emission inventory
    - Emission factor
    - Volatility split
  - – Important to better emphasize synergies between CC and AQ policies