Black Carbon and Global Warming: Impacts of Common Fuels

A Scientific Review

Atlantic Consulting

About the authors
Atlantic Consulting, an independent, privately-owned firm based in Zürich and London, specialises in the assessment of environmental impacts. Founded in 1994, the company has conducted hundreds of analyses for governments, NGOs and companies. Managing Director Eric Johnson is also editor of Environmental Impact Assessment Review, a Director of Green Cross, an advisor to the Global Pollution Remediation Fund and a nominated IPCC inventory assessor. Principal Derek Smith focuses on policy advice. Previously he was a senior environmental advisor to Ernst & Young and to BP.

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Atlantic Consulting
Obstgartenstrasse 14
8136 Gattikon, Switzerland
Atlantic@ecosite.co.uk

Contents

1 Why this report?

As a result of high-profile policy discussions, media coverage, and public debate, global warming (GW) is becoming an increasingly prominent issue. Perhaps driven by a need to explain this complex phenomenon in simple, accessible terms, many commentators have adopted the habit of presenting carbon dioxide (CO_2) (often simply called "carbon") as the unique cause of the problem and - by extension - the sole key to the solution. While there is no doubt that CO_2 emissions are the largest contributor to global warming, the near-exclusive focus on them poses the danger of masking additional elements that need to be addressed.

This report examines the nature and role in global warming of another significant emission; Black Carbon (BC). Despite the fact that BC emissions remain unregulated under the Kyoto Protocol and other prominent regulations aimed at combating climate change, findings suggest that it is probably the second largest contributor to global warming. Moreover, as has already been consistently documented by experts from the World Health Organisation and national authorities, BC compromises both outdoor and indoor air quality. BC and other Particulate Matter (PM) can cause serious health problems and have been to shown to substantially reduce average lifespans.[A]

This report is one attempt towards raising recognition of BC among policy-makers. After an overview of what Black Carbon is, the report reviews the currently understood role of BC in global warming, and it demonstrates the carbon footprints of three common fuels in two common applications: automobile transport and residential heating, taking BC emissions into account.

Available research suggests that adapting future regulation and policy with a view to limiting BC emissions could significantly slow global warming. It would also yield benefits in terms of human health, reducing the social burden associated with illness and reduced life expectancy as well as the associated costs. However, policies for reducing BC are not necessarily the same as those for reducing CO_2. Indeed, such policies can conflict with each other in some cases. For optimum reductions in global warming emissions, policy-makers need to consider the trade-offs between CO_2 and BC, and other global warmers such as methane. The fundamental objective is not to reduce CO_2 emissions but to slow or reverse the process of global warming and its harmful impacts on humanity and the natural environment.

2 What is Black Carbon?

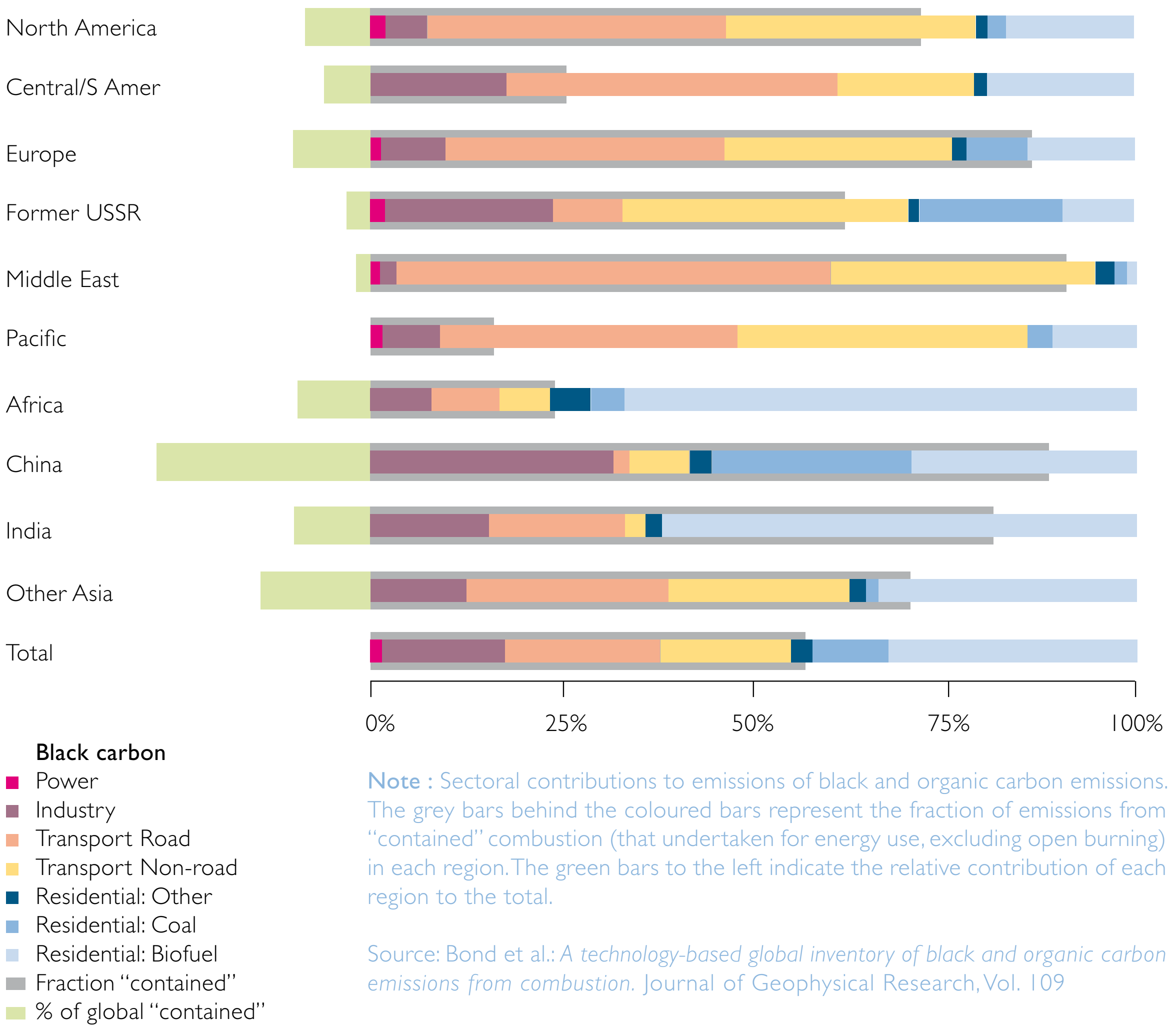
Picture a fireplace, a burnt field or forest, or the dark residue in a boiler's firing chamber – this is how many laypeople encounter BC. Commonly referred to as soot, this residue is actually a mixture of BC[B], another type of carbon called Organic Carbon (OC) and inorganic ash and salts.

BC is emitted primarily as a result of combustion (burning); more specifically from incomplete and/or inefficient combustion. Due to a lack of oxygen or a low temperature, some of the carbon in the fuel converts to BC rather than to CO_2. BC is almost always emitted together with other substances, in particles of varying sizes. There are many types of particles in the air, emitted by a variety of sources, containing varying amounts of BC.

Specific emissions of BC are not usually monitored directly, but are instead estimated from PM and BC factors. Nearly all global BC emissions come from combustion, the bulk of which is man-made. According to research led by University of Illinois' Bond (2004), the sources of BC emissions vary considerably by region (Figure 1), with residential emissions dominating in developing countries and transport/industry emissions dominating in the developed world.

[A] According to the World Health Organization (WHO): "air pollution with PM claims an average of 8.6 months from the life of every person in the EU." http://www.euro.who.int/mediacentre/PR/2005/20050414_1
[B] Often also referred to as elemental carbon (EC).

Figure 1: **Overview of global BC emissions, by region and by sector**



Note : Sectoral contributions to emissions of black and organic carbon emissions. The grey bars behind the coloured bars represent the fraction of emissions from "contained" combustion (that undertaken for energy use, excluding open burning) in each region. The green bars to the left indicate the relative contribution of each region to the total.

Source: Bond et al.: *A technology-based global inventory of black and organic carbon emissions from combustion.* Journal of Geophysical Research, Vol. 109

BC emissions themselves are not usually monitored. Instead, they are generally estimated as a product of two factors:

- PM10 or PM2.5 emissions from a given fuel and/or a given application
- BC content of that PM emission

PM emission factors are published for a wide range of fuels and application. PM2.5 factors are published less frequently than PM10s because measurement of the former began later. Studies conducted in the past five years tend to include PM2.5; studies before that less so.

Carbon neutrality of wood fuel?

Most carbon footprints assume carbon neutrality of wood or other biomass used as fuel, i.e. biogenic CO_2 is assigned a GWP of zero. In recent years, however, this method has come into question. First came the issue of land-use change, which is no longer accepted as automatically carbon neutral. Significant losses of carbon stock due to land-use change (for instance, deforestation to create cropland) should now be included in most footprints.

More recently, researchers such as Rabl (2007), Johnson (2009) and Searchinger et al (2009) have proposed that carbon-stock changes in general should be tracked in biofuels accounting. As Searchinger et al (2009) put it: "Under any crediting system, credits must reflect net changes in carbon stocks, emissions of non-CO_2 greenhouse gases, and leakage emissions resulting from changes in land-use activities to replace crops of timber diverted to bioenergy."

3 Black Carbon and Global Warming

Through a variety of physical mechanisms, BC contributes to global warming. Over the past 10-15 years, the significance of its contribution has been increasingly recognised. Indeed its impact is now identified as being second only to that of CO_2, the world's primary warming emission.

Putting BC on a like-for-like footing with CO_2 and other conventional global warmers is complicated, because BC acts more locally than CO_2, has an atmospheric residence time of weeks - as opposed to years - and can be co-emitted with compounds that also cause cooling. Nonetheless, climate scientists agree that cutting BC emissions could substantially slow warming. This implies the need for a re-think of existing climate policy. When emission reduction efforts are revised to include BC, rather than being limited exclusively to conventional global warmers, new trade-offs and policy considerations come into play. For instance, biomass combustion – broadly encouraged under existing policy – appears much less attractive once BC emissions are taken into account. Decarbonization takes on a double meaning, referring not to just CO_2 but also to BC.

3.1 BC CONTRIBUTES SIGNIFICANTLY TO GLOBAL WARMING

According to estimates by Stanford University's Jacobson (2007), BC accounts for 16% of global warming, leaving it second only to CO_2. Estimates by the UN's Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (2007) appear to corroborate this assumption.

BC's temperature effects occur through several mechanisms, which can vary according to region. Primarily, BC absorbs sunlight and radiates it back to the atmosphere as heat. It also affects cloud formation and rainfall patterns. When BC settles back to the earth's surface, it can increase the melting rate of ice and snow, which makes it particularly significant in colder regions. For instance, experiments by Ramanathan (2009) of the Center for Clouds, Chemistry and Climate at the Scripps Institution of Oceanography suggest that BC and CO_2 play nearly equal roles in inducing springtime snow-cover loss in Eurasia. Similar work by NASA's Drew Shindell finds that half or more of the warming measured in the Arctic from 1976-2007 is due to soot, i.e. BC plus OC (Kintisch, 2009) most notably as a result of its effect on snow albedo.[C]

[C] Albedo is the term used to describe the extent to which an object or substance, snow in this case, diffusely reflects light from light sources such as the sun.

3.2 ALTHOUGH MECHANISMS DIFFER TO CONVENTIONAL GHGs, CUTTING BC DOES CURB WARMING

BC acts more locally than CO_2 because it is airborne for a shorter period of time. Also, it affects local climate due to its influence on cloud formation and rainfall. An additional difference is that BC's atmospheric residence time is measured in weeks, not years, meaning that the convention of using 100-year horizons for global warming analyses understates BC's impact in the short term, say in a 20-year horizon (Figure 2). For BC, data on 20 year GWP may therefore be the most relevant. In any case, findings suggest that the BC's relative warming potential is considerable.

Table 1: **Relative Global Warming Potential of a selection of key emisssions**

Emission	Global Warming Potential[D] Relative to CO_2	
	20 Year Period	100 Year Period
CO_2	1	1
Methane	72	25
Nitrous Oxide (NOx)	289	298
Black Carbon	2200	680

Ramanathan (2009) and others emphasise the potential for a reduction in BC emissions to cut warming in the short-term, i.e. 15-20 years. Jacobson (2007) has shown that over the coming two decades reducing emissions of BC would bring about temperature reductions more rapidly than equivalent reductions of methane or CO_2 emissions.

Global warming potential

Global warming potential (GWP) quantifies the global warming (radiative forcing) generated by a given mass of any substance over a given time. Given mass is typically specified in kilogrammes or tonnes, given time as 20, 100 and 500 years. The GWP of carbon dioxide, the primary global warming substance, is defined as 1, so GWPs of all other substances are defined relatively to CO_2, i.e. as CO_2 equivalents (CO_2e). GWPs can vary widely, depending primarly on: how much infrared radiation the substance absorbs; and how long the substance persists in the atmosphere.

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Carbon footprints are the product of:
substance mass (usually kilogrammes or tonnes) x GWP
so they are typically expressed in kg or t CO_2e over 20, 100 or 500 years.

Although GWP as a measurement is generally accepted, some researchers contend that other measures, such as Carbon dioxide Equivalency Factors (CEFs) or Global Temperature Potentials (GTPs), may in some cases be more suitable for guiding policy.

[D] Data for CO_2, methane and nitrous oxide are from 2007 IPCC Fourth Assessment Report (AR4) by Working Group 1 (WG1) and Chapter 2 of that report (Changes in Atmospheric Constituents and in Radiative Forcing) which contains GWP information. Data for BC are from Hill (2009).

4 Fuel Footprints: What if Black Carbon were included?

Most carbon footprints account only for so-called homogeneous greenhouse gases (GHGs) that are specified by the IPCC as global warmers: CO_2, CH_4, N_2O, and halocarbons. Footprints generally do not include gases or particles which are not regulated by the IPCC such as black carbon or other heterogeneous species such as carbon monoxide (CO), hydrogen (H_2), organic carbon (OC), ozone (O_3), nitrogen oxides (NOx) or sulphates (SOx).

The inclusion of these additional global warmers allows for a more complete assessment of the global warming footprints of different fuels in specific applications, often modifying relative warming impacts.

For example (Figures 4 and 5), Liquified Petroleum Gas (LPG) can be compared to diesel in an automotive application and to wood as a heating fuel:

Figure 2: **Carbon footprints of LPG and diesel as automotive fuels**

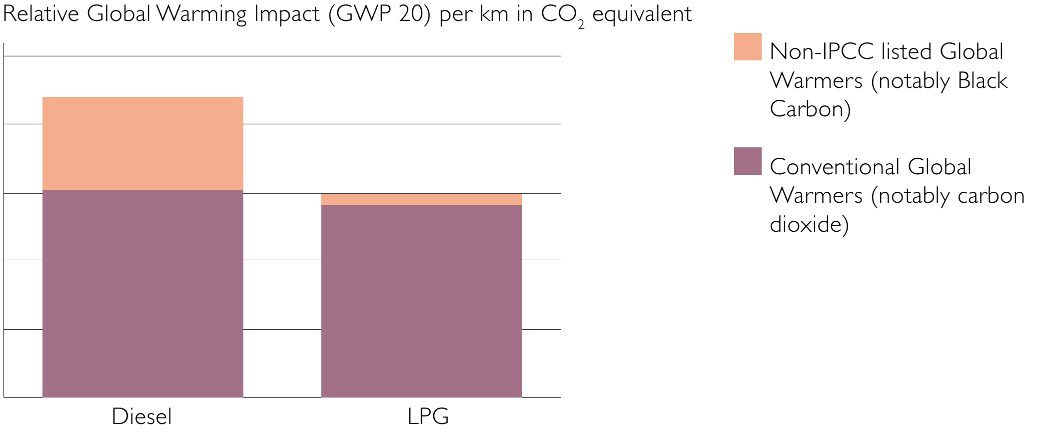
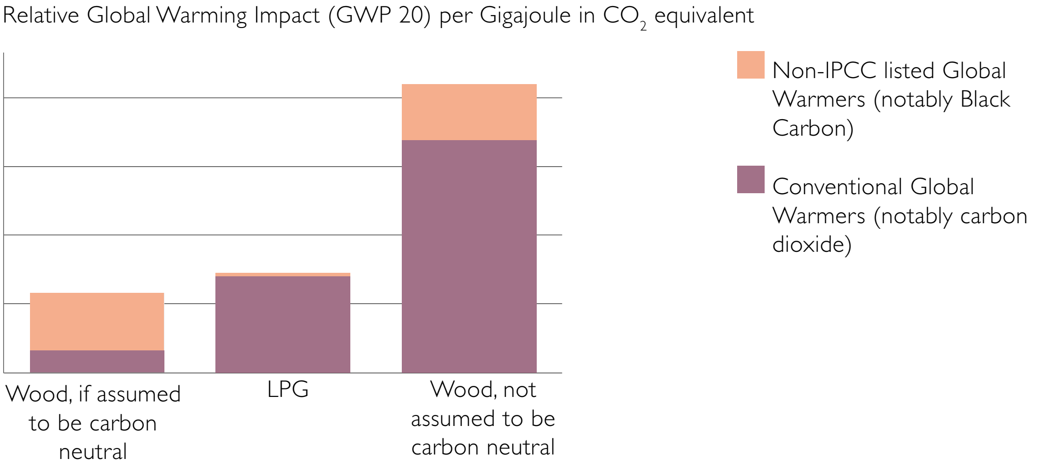


Figure 3: **Carbon footprints of LPG and wood as heating fuels**



Global warming – it's not just about CO_2

Because carbon dioxide is the primary anthropogenic global warmer, global warmer emissions are often referred to generically as 'carbon'. And some climate change regulations – for instance the European Union's Emissions Trading System – cover only emissions of carbon dioxide.

However, other anthropogenic emissions contribute significantly to global warming, including: methane, nitrous oxide, a wide variety of halocarbons, black carbon, carbon monoxide and nitrogen oxides.

5 Conclusion: More attention and action needed

While further research is needed in order to corroborate and to clarify existing data, it is increasingly clear that Black Carbon is a major contributor to global warming. The primarily anthropogenic origin of these emissions suggests that there may be scope for reducing them via policy measures designed to encourage citizens to (a) use energy more efficiently and (b) use energy resources whose combustion leads to relatively lower levels of BC emissions. One possible transition, applicable in both developed and developing regions, would be to reduce emissions associated with biomass and diesel. In the developing world, a shift from traditional to modern cooking stoves could deliver a two-for-one effect: less global warming and better human health.

The IPCC already recognises BC as a significant global warmer. The UN's Economic Commission for Europe finds that "urgent action to decrease (Black Carbon) concentrations in the atmosphere would provide opportunities, not only for significant air pollution benefits (e.g. health and crop-yield benefits), but also for rapid climate benefits, by helping to slow global warming and avoid crossing critical temperature and environmental thresholds."[E] In the US, two federal bills have been proposed, one in the House of Representatives and one in the Senate. The House bill[F] would authorise research to develop BC regulation and would require the US Environmental Protection Agency to propose specific regulations within a year of being enacted.

Preliminary evidence suggests that this may constitute a unique opportunity for Europe and indeed the world to achieve significant warming reductions within a 20 year window. This, combined with the more widely understood human health benefits associated with a reduction of PM concentrations in the ambient air, should combine to make BC emissions a subject of increasing importance and urgency in the coming years.

[E] From UNECE's Executive Body for the Convention on long-range transboundary air pollution, meeting in Geneva, 15-18 December 2008. Item 13 of provisional agenda. Air pollution and climate change: developing a framework for integrated co-benefits strategies.
[F] H.R. 1760, B lack Carbon Emissions Reduction Act of 2009, http://www.govtrack.us/congress/bill.xpd?bill=h111-1760&tab=summary

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