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Black Carbon and Kerosene Lighting: An Opportunity for Rapid Action on Climate Change and Clean Energy for Development

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Summary

Replacing inefficient kerosene lighting with electric lighting or other clean alternatives can rapidly achieve development and energy access goals, save money and reduce climate warming. Many of the 250 million households that lack reliable access to electricity rely on inefficient and dangerous simple wick lamps and other kerosene-fueled light sources, using 4 to 25 billion liters of kerosene annually to meet basic lighting needs (Lam et al., 2012a; UNEP, 2013). Kerosene costs can be a significant household expense and subsidies are expensive. New information on kerosene lamp emissions reveals that their climate impacts are substantial. Eliminating current annual black carbon emissions would provide a climate benefit equivalent to 5 gigatons of carbon dioxide reductions over the next 20 years.[1] Robust and low-cost technologies for supplanting simple wick and other kerosene-fueled lamps exist and are easily distributed and scalable. Improving household lighting offers a low-cost opportunity to improve development, cool the climate and reduce costs.

Kerosene Lighting Climate Change Impact Has Been Substantially Underestimated

About 250 million households comprising 1.3 billion people lacked reliable access to electricity to meet basic lighting needs in 2010 (IEA, 2012). As a result, kerosene-fueled simple wick lamps and other kerosene-

Figure 1. Simple kerosene wick lamps

Photo credits: Ajay Pillarisetti (left) and Evan Mills (right) fueled lamps are often the sole source of illumination for studying or income-generating work after sundown (Figure 1). To fuel these lighting sources, households consume an estimated 4 to 25 billion liters of kerosene per year (Lam et al., 2012a; UNEP, 2013). In South Asian and African countries, lighting demands account for 25 to 30 percent of kerosene consumed in the residential sector (Lam et al., 2012a).

The development benefits of improved lighting for people without grid-electrification are well known (UNEP, 2013; IIASA, 2012) and new research indicates that such improvements may also provide substantially higher environmental benefits. Simple kerosene lamps, used in regions with limited or no access to electricity, are now understood to be a significant global source of atmospheric black carbon (BC), a strong climate warmer (see box: What is Black Carbon?). Almost one-tenth of the fuel burned in these kerosene lamps is converted to BC particles (Lam, et al., 2012a). By comparison, a diesel engine emits only about one-thousandth of the original fuel as particles. While many other sources of BC also emit light colored particles that have an off-setting cooling effect, the emissions from kerosene lamps are almost entirely BC and carbon dioxide (CO_2), both of which warm the climate.

Black carbon is so efficient at absorbing sunlight, and the emissions from kerosene lamps are so high, that the BC particles emitted by basic kerosene wick lamps warm the climate 20 times more during the few days after emission than the CO_2 emitted by the same lamp does during 100 years. The total climate impact

What is Black Carbon?

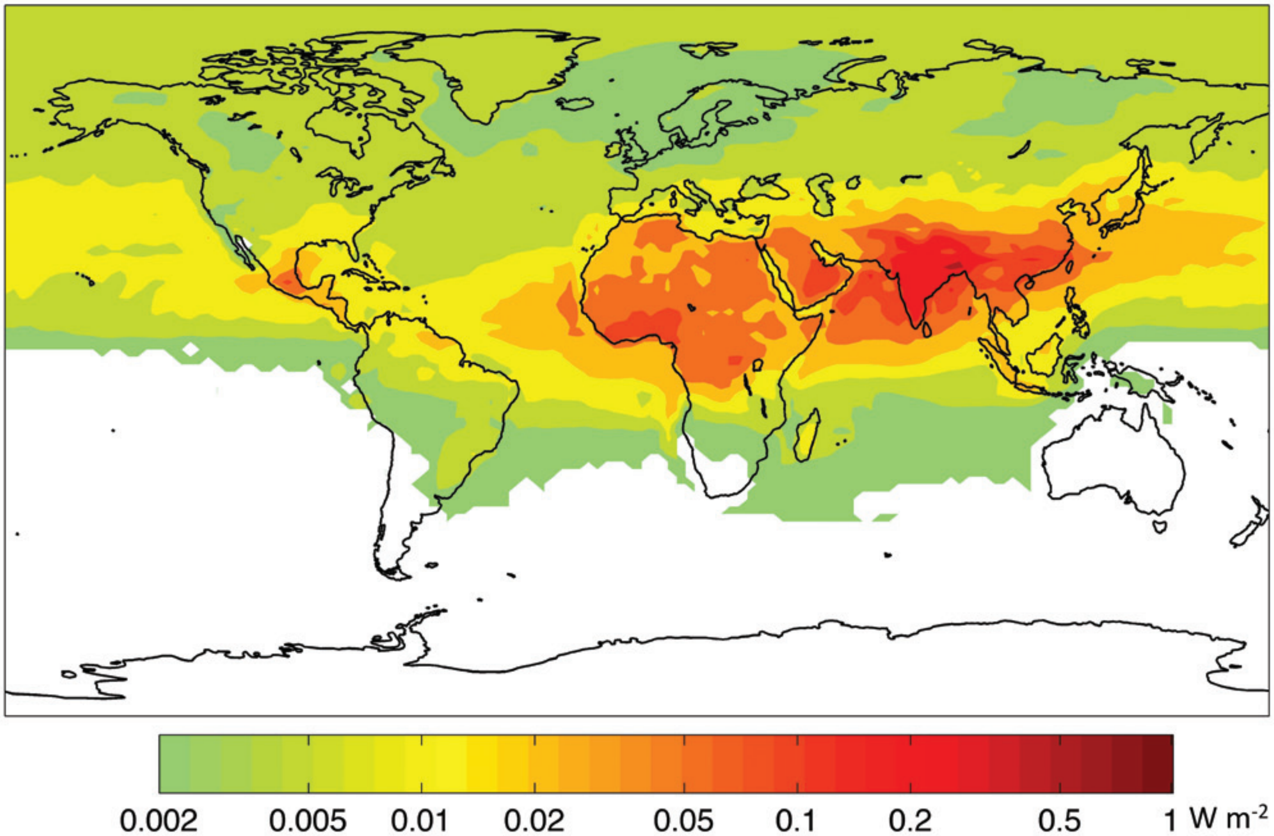
Black carbon (BC) is a powerful absorber of sunlight. A particle rather than a greenhouse gas, it is the second largest climate warmer in today's atmosphere, following carbon dioxide (CO_2). One gram of BC dispersed in the atmosphere absorbs about as much light as 10 black umbrellas. Although black carbon remains in the atmosphere for only a few days, one gram of black carbon warms the atmosphere several hundred times more during its short lifetime than one gram of carbon dioxide does during 100 years.

Black carbon comes from incomplete combustion. The largest sources are open burning of forests and savannas, diesel engines, household burning of solid fuels and some kinds of industry. The type of combustion greatly affects black carbon emission rates, and poor combustion emits more black carbon than good combustion for the same type of fuel. For example, although burning coal in power plants produces some air pollutants, modern combustion produces much less black carbon than burning the same quantity of coal in heating stoves.

Sources of black carbon also emit other particles and gases that may either warm or cool the climate. Turning off sources that emit a mix of black and non-black particles could cause either warming or cooling. However, if a source emits only black carbon and carbon dioxide, it is unequivocally a warming source, and turning it off produces cooling.

Because atmospheric concentrations vanish almost as soon as emissions stop, reducing black carbon emissions may be a quick way to slow climate warming. The United Nations Environment Program has recommended some actions, like cleaning up diesel engines, which could assist in keeping global temperature increases within tolerable limits. Their analysis shows that addressing black carbon alone cannot solve the long-term climate problem, but it can be a part of the solution.

Figure 2. Direct black carbon radiative forcing from residential kerosene lighting (W/m^2)



Reproduced from Lam, et al., 2012

of the lamps, and of residential lighting in developing countries, has been drastically underestimated by considering only CO_2. Lam et al. (2012a) estimated that 270,000 tonnes of BC were emitted to the atmosphere each year from kerosene lamps. The warming effect of these emissions is equivalent to about 240 million tonnes of CO_2—about 4.5 percent of the United States' CO_2 emissions and 12 percent of India's.[2]

Eliminating these emissions would be equivalent to a 5-gigaton CO_2 reduction over the next 20 years. Climate impact is highest around source regions and reaches 0.5 watts per square meter (Figure 2).

Kerosene lamps are not the largest emitters of BC. Residential burning of solid fuels like wood and coal for cooking, also an important component of the household energy challenge, emits about six times more BC than lamps do. Diesel engine emissions of BC are about five times higher than kerosene lighting. However, emissions from kerosene lamps are one of the few known BC sources for which reductions are inexpensive, technically feasible and promote increased energy access.

Figure 3. Solar charged LED lighting systems

Photo credit: Kellie Brown

There are Alternatives to Simple Wick Kerosene Lighting

Several measures can reduce black carbon emissions from kerosene lighting. These fall into two general categories: providing more efficient lamps that also use kerosene, or replacing fuel-burning lamps with electric lighting and a source of electricity. Improved kerosene lamps have better combustion efficiency and can reduce black carbon emissions. They also improve lighting somewhat, but they generally require more fuel, increasing household expenditures. Electric lighting improves lighting service, reduces fuel costs and improves health and safety while emitting no BC (Nieuwenhout, et al., 2000; Mills, 2005; Mills, 2012). Electric lighting can be delivered through a variety of technologies and approaches, and each has pros and cons.

Off-Grid LED Lighting

Perhaps the most cost-effective approach to displace kerosene lighting with electric lighting is with small off-grid lighting systems that use light emitting diodes (LEDs) and rechargeable batteries. Batteries may be charged with solar photovoltaic modules (Figure 3), Alternating Current (AC) electricity and mechanical dynamos. Good quality LEDs provide better lighting than fuel-based lamps. Many off-grid lighting systems include attractive features such as mobile phone charging and could provide power for the new wave of advanced cookstoves that use battery-powered fans to improve efficiency. Off-grid LED lighting product costs vary—from under $10 for a small solar powered desk lamp, to about $120 for multi-light mini-solar home systems—and economic payback from saved costs for kerosene and mobile phone charging is typically about six to 12 months. The total investment to replace the approximately 1 billion kerosene lamps in use globally with good quality solar charged LED lamps until 2030 is less than $200 billion. Replacements would quadruple the quality of lighting and save over $800 billion in avoided kerosene purchases and mobile phone charging fees.[3] These numbers are an upper bound because some users might continue to use kerosene even after adopting electric lighting (see box: Rural Energy Technology Transitions).

Although LED-based off-grid lighting is at an early stage of commercial development, sales have grown very rapidly over the past few years. Over 1.4 million quality-assured solar LED lights have been sold in Africa since 2009, where sales growth exceeds 100 percent annually (Lighting Africa, 2013). Sales and growth rates in Asia are of a similar magnitude, although less well documented. This rapid emergence has been enabled in part by falling prices and technology advances. The price of LEDs has dropped quickly and efficiency has more than tripled since 2009 (DOE, 2011) so that a smaller photovoltaic unit and battery can provide the same lighting. As these gains continue, solar powered off-grid lighting systems become even more viable.

Household Photovoltaic Systems

Several million household solar photovoltaic systems have been installed since the early 1980s, with greatest adoption in countries such as Bangladesh (over 1.5 million systems), India (over 0.7 million), and Kenya (over 0.3 million) (IDCOL, 2012; Palit and Sarangi, 2011; Ondraczek, 2012). Capital and installation costs range from $150 to $1000, but these systems power televisions, radios, fans and mobile phone chargers in addition to lighting (Jacobson, 2007; Siegel and Rahman, 2011).

Mini-Grids

Village-scale mini-grids provide electrical service to a cluster of households and businesses, relying on one or more generation sources that may include diesel generators, hydropower, solar photovoltaics and wind turbines. The cost of electricity from mini-grids varies widely depending on system size and technology (ARE, 2011), but capital and installation costs range from hundreds to thousands of dollars per customer. Mini-grid technology is well established, but commercial and institutional models for widespread deployment of renewable energy-powered mini-grids still require development.

Grid Electrification

Grid extension is a well-established approach to rural electrification. In addition to improved lighting and household services, grid power can support income generation through mechanical power, water pumping

Rural Energy Technology Transitions

Behavioral factors affect technology adoption and market transformation, and adoption of new technologies does not necessarily mean that the incumbent technology will be abandoned. For example, Masera et al. (2000) showed that households frequently use new cookstoves to supplement, rather than replace, old ones. Promotion of new technologies usually results in only partial substitution; for replacement of kerosene lighting by LED-based off-grid lamps, substitution rates vary from 50 percent to 100 percent (e.g. Tracy, et al., 2010; Mills and Jacobson, 2011). The factors that govern these dynamics are not yet fully understood. Lighting programs should include monitoring and evaluation to assess the usage and impacts of both the original and replacement technologies.

and cold storage. The number of people without a grid connection dropped from 2 billion in 1990 to 1.3 billion in 2010 despite population growth (IEA, 2002; IEA, 2012). This transition has been especially rapid in China, where over 900 million people received access to grid electricity over the past 50 years, bringing the electrification rate to over 99 percent by 2010 (Jiuhua, 2006; IEA, 2012). The rates of residential grid electrification in sub-Saharan Africa and South Asia remain considerably lower, at 43 percent and 70 percent, respectively (IEA, 2012). The cost per customer ranges from hundreds to thousands of dollars, depending on the distance and type of terrain. Additionally, grid electrification requires sufficient generation capacity to supply the new customers.

Policy Mechanisms Can Promote Better Lighting

National and international policies can facilitate a transition to the technologies listed above. For the off-grid interventions in particular, policies should focus on creating an enabling market environment. Experience with cookstove and lighting programs indicates that successful market-oriented policies include several complementary elements:

- **A Trusted Quality Assurance Program:** Buyers of emerging technologies often cannot discern which products will perform as advertised and meet their needs. Negative experiences with a few poorly manufactured items can create a broad negative perception of the entire product class. A quality assurance program can increase transparency and improve confidence.
- **Adequate Financing Availability Across the Supply Chain:** During early stages of market development, trade finance can provide suppliers and distributors with the working capital that they need to manage production and stock. Low-income households can benefit from microfinance programs that help overcome initial cost barriers. Innovative sales models, including microcredit loans and 'pay-as-you-go' arrangements that involve small daily or weekly payments through mobile phone transfers, can reduce initial cost barriers.
- **Effective Consumer Awareness Campaigns:** Educating consumers about the benefits of improved and quality-assured products promotes informed purchasing decisions. Education that informs purchasing agents in governments and donor organizations about product quality and performance can aid product selection.

In addition to market development, broad-based, high-level policy support can accelerate the transition toward cleaner lighting. Options for international collaborations include:

1. **Set ambitious but realistic goals for lighting services.** The Millennium Development Goals demonstrate the value of salient and measureable goals for development. Quantifiable goals to ensure that all households have access to basic energy services will emphasize the critical role of energy in enabling development, and a practical but ambitious timetable should be developed. Developing provisions for energy access within the 2015 Development Goals, including the Sustainable Development Goals, is one possible venue. The U.N. Sustainable Energy for All (SE4ALL) target of universal access to modern energy by 2030 would contribute to improved lighting service and reduced BC emissions.

2. **Conclude an international agreement on black carbon**. An international collaborative effort to reduce black carbon has been evolving over the past few years. In 2012, this effort accelerated substantially with the formation of the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants, which currently comprises 21 member states. Other international organizations working on short-lived climate pollutants include the Global Alliance for Clean Cookstoves, the Arctic Council and the Global Methane Initiative. The new evidence on BC from kerosene provides a concrete locus for agreement among stakeholder organizations.

3. **Leverage existing international partnerships and cooperative efforts**. The SE4ALL initiative and the Clean Energy Ministerial (CEM) both set energy technology and development goals, and have the support of governments and other stakeholders. Key areas of focus of these groups include building technical capacity, sharing knowledge and peer marking. Examples of activities to develop kerosene lighting alternatives and promote grid-based rural electrification are the CEM-affiliated Global Lighting and Energy Access Partnership, the SE4All-affiliated U.N. Foundation-led Energy Access Practitioner Network and the Alliance for Rural Electrification. These or similar efforts should be expanded and strengthened, rather than inventing wholly new groups.

4. **Support commercial solutions and provide access to new finance**. Policies to overcome market barriers, including increased access to finance, can enable delivery of cost effective solutions. Finance can be made available through existing commercial channels with support from multilateral development bank programs or new funds such as the Green Climate Fund or Climate Investment Funds. Models for expanded market development activities include the joint International Finance Corporation-World Bank Lighting Africa program and the affiliated Lighting Asia program.

5. **Reduce and redirect kerosene subsidies toward clean alternatives**. Countries that subsidize kerosene fuel in order to ensure affordable energy access to low-income households can redirect those expenditures toward cleaner alternatives. International collaboration can help enable such transitions through policy analysis and technical support for the development and deployment of affordable clean energy alternatives.

6. **Align national efforts with international standards.** The International Electrotechnical Commission recently published standards for solar charged LED lighting systems that are aligned with the quality framework developed by the Lighting Africa program (IEC, 2013). Widespread adoption

would facilitate off-grid lighting product market development. International conversations on meeting the latest World Health Organization guidelines for ambient and indoor particulate matter concentrations are needed, perhaps at the Clean Energy Ministerial or similar fora. Lighting improvements would help achieve these targets and potentially reduce the risk from a growing list of adverse health outcomes associated with kerosene use in homes, including tuberculosis, low birth weight and still birth (Lam et al. 2012b, Mills 2012, Pohkrel et al. 2010, Epstein et al. 2013, Lakshmi et al. 2013).

Conclusion

Addressing the multiple challenges of development, energy security, energy access, fossil fuel subsidies and climate change is often fraught with conflicting interests and disagreements about priority and pacing. The case of kerosene lighting is an unusual opportunity in which priorities are aligned. Improved access to clean and reliable lighting benefits health, children's education and well-being. Climate warming by black carbon emissions would be rapidly reduced by kerosene lamp replacement. A broad-based and coordinated replacement strategy is feasible with the existence of simple, low-cost technical alternatives and tested policies on financing and market development. The relatively short lifetime and low capital investment in existing kerosene lamps means there are few barriers to replacement. In addition, there are few losers and many winners from replacing kerosene lighting sources on an accelerated timetable. A targeted and aggressive push toward a single, focused and technically simple policy target could provide immediate benefits and a high likelihood of success.

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Endnotes

1. All estimates of global warming potential in this article are made in reference to the warming potential of carbon dioxide over a 100-year time period.

2. Emission rate calculated by applying BC emission factors specific to lamp design and escape to outdoors (Lam et al. 2012a), with country-level estimates of kerosene consumption for lighting and lighting device stock estimates reported by UNEP (2013). Estimates of kerosene consumption for lighting by UNEP (2013) are higher than those used in Lam et al. (2012a) and yield a BC emission rate that is approximately twice as large: 580,000 tonnes of BC per year.

3. This analysis assumes a $35 retail price for a solar charged off-grid lamp that can deliver 120 lumens for six hours per day, charge a mobile phone three times per week and last three years. It also assumes kerosene prices of $1/liter and mobile phone charging at $0.15 per charge. In practice, the investment estimate is likely to be substantially lower than $200 billion because this value assumes that current price, performance and durability levels for LED lamps will remain constant. In fact, prices are likely to decrease and product performance and durability should increase because technological development is still in an early phase. Kerosene prices may also increase over time relative to current levels, which would increase the estimate of total potential savings. The calculations do not include discounting of future costs.