Global Lighting Energy Savings Potential

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Abstract

The global cost of lighting energy is approximately $230 billion per year, of which $100 to $135 billion can be saved with present-day technologies. Approximately 70% of these savings are to be found in electric lighting, with the remaining 30% in kerosene-based lighting in the developing world. The electricity savings are equivalent to the output of 240 to 385 power plants, and the kerosene savings are equivalent to 1.7 million barrels/day of oil production. The single-greatest way to reduce the greenhouse-gas emissions associated with lighting energy use is to replace kerosene lamps with white-LED electric lighting systems in developing countries; this can be accomplished even while dramatically increasing currently deficient lighting service levels.

Limitations of Past Work

We identified 13 studies estimating national or regional lighting savings potential (Table 1). Among these, most focused either on a specific technology (e.g. compact fluorescent lamps) and/or on a specific policy option (e.g. ballast standards). The studies also differ in whether they provide a technical potential (with no moderating assumptions for partial penetration or cost-effectiveness) versus a potential bounded by application-specific, market, or economic constraints.

Only three studies—covering Sweden and the United States—employed a detailed "supply-curve" style analysis for costing and ranking specific technology options and

(Atkinson et al. 1992, Swisher et al. 1994, and Vorsatz et al 1997). A study of ballast standards for the European Union employed a simple payback analysis (Webber and Slater ND), while most other studies offer no economic analysis whatsoever.

Only one study dealt in any quantitative detail with the question of the net indirect effects of lighting on heating and cooling energy (Sezgen et al 1994), although Nutek (1995) also made an attempt to account for this. We found only three studies (Atkinson et al. 1992; Granda 1997; Palmer et al. 1998) that computed lighting-related greenhouse-gas emissions and savings.

Importantly, most studies are unclear as to the reference case from which their "efficient" scenarios are developed. One study was very explicit in this for the U.S. (Atkinson et al. 1992) and three did so for Sweden (Bodlund et al. 1989; Swisher et al. 1994; Nutek 1995). The savings estimates offered by most studies are poorly documented.

Global Lighting Energy Use and Savings Potential

Based on previous work (Mills 2002), we have estimated global lighting electricity supply at 2016 TWh as of the mid-1990s. This analysis is based on a set of sectoral regression models constructed from country-specific data for 41 countries representing 63% of the world's population in 1997. In addition to this, approximately 3600 PJ is used for household kerosene lighting among the 2 billion people lacking electricity as of the mid-1990s. The corresponding lighting-related greenhouse-gas emissions represent about 15% of the global total. Note that we have not estimated the potential kerosene use outside of the household sector, which is likely significant given the longer hours of use and greater intensity (and rate of fuel consumption) of lanterns used there.

Based on Table 1 and our review of the literature, we determined a savings potential of 8800 to 12300 Petajoules for electricity and kerosene (Table 2). Note that these rough estimates are "overnight" savings, i.e., based on today's consumption levels. Re-computed for a future date based on a growing 'business-as-usual' reference case, the

absolute value of the savings would of course be greater. Kerosene use for lighting is growing particularly quickly, given the relative population and electrification rates in some regions.

Electricity Savings

Our electricity savings estimates represent a hypothetical policy pathway that assumes a combination of modest standards and aggressive voluntary programs promoting cost-effective lighting efficiency improvements using today's technologies. In practice savings will vary by country, depending on existing baseline conditions, etc.

Several conservatisms should be noted. Illuminance-level recommendations vary widely among IEA countries (Mills and Borg 1999). While rarely addressed by lighting energy policy analysts, these variations have significant energy implications, potentially leading to reduced lighting energy demand if standardized at a moderate level. Daylighting savings are not included here due to a lack of data on which to base national savings potentials. Note that these savings estimates also do not include the net indirect effects on space heating and air-conditioning in buildings. As an illustration of the greater potential that may be achieved by considering the above-mentioned factors, Nutek (1995) developed a 64% high-efficiency lighting savings potential for the service sector.

Another way to consider the savings potential is to compare lighting energy intensities across countries. As seen in Figure 1, for a given level of gross national product, we can readily observe a factor of two (or more) variability in per-capita lighting energy intensities, even among wealthier countries. Note that while it may be tempting to ascribe these differences to differences in daylight availability in southern versus northern regions, this correlation is not visible in the data.

The electricity savings shown in Table 2 correspond to approximately 550 to 890 TWh, or the electrical output of 240 to 385 400-megawatt power plants.

Fuel-Based Lighting Savings

Developing a savings potential for fuel-based lighting is conceptually more difficult than in the case of electric lighting, given the extremely low service levels provided today and a wider spectrum of potential technology choices. Per-lamp illuminance is typically 100-times lower than that for modern electric lamps. For fuel-based lighting, savings are generally high when assuming substitution of electricity and no increase in energy services (light levels).

To identify the envelope of possibilities, we developed nine scenarios for fuel-based lighting, based on three types of electric lighting--incandescent, compact fluorescent, and white LED--and three tiers of numbers of light sources per households (Table 3). Given the extreme inefficiency of kerosene lamps, even the use of incandescent replacements generally results in a reduction in costs and greenhouse-gas emissions and a 100- to 300-fold increase in energy services (lumens produced).

The "thought experiment" of increasing the numbers of light sources to the point that carbon emissions begin to rise shows that two incandescent lamps for each existing kerosene lamp is the limit, versus 8.5 lamps for CFLs, and 128 lamps for LEDs. These three scenarios bear identical operating cost savings of approximately 50%, but yield 60-, 250-, and 128-\fold increases in service levels (light production), respectively.

Substantially increasing service levels is not possible with incandescent sources without elevating both carbon emissions and operating costs. For example, increasing from the existing baseline of three lamps per household to ten incandescents would result in a quadrupling of emissions and a 140% increase in operating cost. Similarly, ten CFLs would cause emissions to rise by 17%, although costs could still decline. The definition of "service levels" used here does not sufficiently reflect actual conditions. The LED yields far more focused light output and thus significantly greater utility for focused tasks such as reading.

A shift to white LEDs, however, yields very substantial cost and emissions savings, even for an increase from three to ten light sources per household. Further emissions reductions could be achieved with LEDs powered by local renewable energy supplies, based on highly successful demonstration projects that have been conducted by Irvine-Halliday (2002). The central conclusion of this exercise is that homes in the developing world could be lit to the same standards as those in industrialized countries, while reducing the cost burden and emissions released to the environment. At least in the case of lighting, attaining a higher standard of living does not require increased use of energy.

Conclusions

The potential for reducing lighting energy use, associated costs, and emissions is clearly substantial. The lower end of the electricity savings range presented here is greater than the total individual national electricity use of Canada, France, or Germany. Savings in kerosene lighting exceed the oil production of Algeria, Brazil, Indonesia, or Libya. The single-greatest way to reduce the greenhouse-gas emissions associated with lighting energy use is to replace kerosene lamps with white LED lighting systems in developing countries. Further work is clearly needed, however, to improve both the baseline energy use data and the appropriate savings factors.

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Figure 1. Total lighting electricity use for 33 countries versus gross national product (Mills 2002). The outlier at approximately 3500 kWh/capita is Norway.
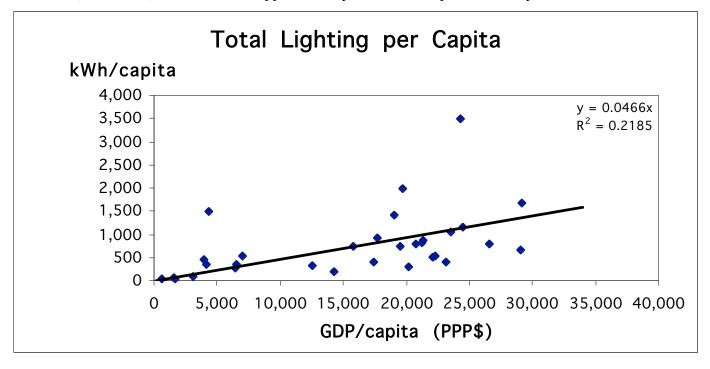

Total Lighting per Capita

kWh/capita

$y = 0.0466x$
$R^2 = 0.2185$

GDP/capita (PPP$)

Table 1. Studies of national or regional lighting energy savings potential.

Country or Region	Title	Pub. Date	Published by	Sector(s)	Baseline data	Baseline Scenarios	Efficient Scenarios	Savings Potential	Scope of Scenario	Enduse Detail	Market Data	CO2	Comments
Bulgaria	Possibilities for the Improvement of Energy Efficiency of Electric Lighting in Bulgaria	1997	Technical University, Sofia-lighting Lab	R, C, I, S, O	R, C, I, S, O	None	Overnight			By subsector	Middle	No	
China	Energy efficient lighting in China	1997	Lawrence Berkeley National Laboratory	National	National	Overnight	Overnight	41%-61%	Lamp efficiency improvements, national, by lamp type	By lamp type	Light source producution	No	Lower savings estimate is for bringing light sources up to western performance standards; Higher savings estimate is for substitution premium efficiency product
EU	Lighting and Energy in Buildings	1996	BRE									No	
EU	DELight	1998	Univeristy of Exford, Swedish national Energy Administration, Energiestiftung Schleswig-Holstein	R	R	2020	2020	43%	CFL Focus (?)		Extensive, mostly housing stock and consumer attitude surveys	Yes	Detailed estimates for Germany, Sweden, and UK extrapolated to all EU
Europe	Study on the Cost Benefit Analysis of the Impelemntaton of Minxxxx	ND	EC	R, C, I	R, C, I	2020 (C & I)	2020 (C & I)	Resid'l: 12%-20% Com'l: 10%-18% Ind'l: 10%-18%	Fluorescent ballasts only	Extensive for this e	Extensive	No	Scenarios and market data pertain only to lamp ballast
Europe	GreenLight	ND	European Commission Joint Research Centre	C	C	Overnight	Overnight	30-50%	Various			No	Based on case studies of GreenLight projects in Belgium, Norway, Italy, and Portugal.
India	Energy Efficient Lighitng in India - Potential and Strategies	1993	Ministry of Power; Energy Management Center	R, C, I	R, C, I	2005	2005	10-90%	By lamp type	By lamp type	by sector and by lamp type	No	
Lithuania	Assessing the Residential Lighting Efficiency...	1997	Lawrence Berkeley National Laboratory	R	R		Overnight	54%	Replace 2 incandescents per home with CFLs				
Poland	Case Study: The IFC/GEF Poland Efficient Lighting Project	1997	IAEEL	R	R	None	Overnight			Middle	Middle	Yes	Scenarios focus strictly on a CFL program
Sweden	Framtida Elvaendning--Effektiviseringspotentialer	1995	Swedish National Board for Industrial and Technical Development	R,C,I, S	R,C,I,S	2020	2020	Resid'l: 29%; Com'l: 64%; Ind'l: 69%; Streetlight: 55%	Comprehensive			No	
Sweden	Dynamics of energy efficient lighting	1994	UNEP, Lund University	C	R, C, I, Other	2010	2010	Res'l: 10-40% Com'l: 12-36% Ind'l: 25-41%	Various combinations of standards and DSM; based on supply curve analyses.	By subsector	Neg.	No	Savings measured vs. "constant efficiency" baselines.
USA	Residential Lighting: Use and Potential Savings	1996	US Department of Energy, Energy Information Administration	R	R	Overnight	Overnight	35%	Replace 4 incandescent lamps per home	Extensive survey		No	
USA	Lighting Market Sourcebook	1997	Lawrence Berkeley National Laboratory	R, C	R, C	2010	2010	67%, ~40%	Supply curve analyses	Very extensive		No	
USA	. "Analysis of Federal Policy Options for Improving U.S. Lighting Energy Efficiency: Commercial and Residential Buildings	1992	Lawrence Berkeley National Laboratory	R, C	R, C	2030	2030	21%-56%; 35%-64%	A: Minimum Life-cycle cost; B: Research & Development	Extensive	Extensive	Yes	Includes separate analysis of savings from standards, by technology type.

Table 2. Global lighting energy savings potential.

	Baseline Energy Use (PJ/year)	Savings Potential	Savings (low)	% of total savings	Savings (high)	% of total savings
Electric Lighting						
Residential	5,604	40-60%	2,242	25%	3,362	27%
Commercial	9,551	25-40%	2,388	27%	3,821	31%
Industrial	3,272	15-25%	491	6%	818	7%
Streetlighting & Other	1,507	25-50%	377	4%	753	6%
Fuel-based Lighting						
Residential	3,603	92-99%	3,300	38%	3,581	29%
Total	**23,536**	**37%-52%**	**8,797**	**100%**	**12,335**	**100%**

Note: Savings range for kerosene represents CFL - LED technology choice.

Table 3. Scenarios of energy and emissions reductions for fuel-based lighting in developing countries.

	Number of Light Sources	Annual GHG Emissions (MT CO_2)	Change	Annual Cost ($B)	Change	Service Level (lumens/house)	Service Index (Basecase=1)
Baseline - 3 Kerosene Lamps per Household		244	--	48	--	30	1
Baseline Number of Light Sources							
60W incandescents	3	115	-53%	11	-77%	2,700	90
15W CFLs	3	29	-88%	3	-94%	2,700	90
1W LEDs	3	2	-99.2%	0.2	-99.6%	90	3
More Light Sources							
60W incandescents	10	1,150	371%	115	140%	9,000	300
15W CFLs	10	287	17%	29	-40%	9,000	300
1W LEDs	10	19	-92%	2	-96%	300	10
Constant Carbon Emissions							
60W incandescents	2.1	244	0%	24	-50%	1,890	63
15W CFLs	8.5	244	0%	24	-50%	7,650	255
1W LEDs	128	244	0%	24	-50%	3,840	128

Notes: The above case for LEDs assumes an 8-LED fixture with a total wattage of 1W and light output of 30 lumens (Luxeon technology as of mid-2002). The definition of "service levels" used here does not sufficiently reflect actual conditions. wherein the LED yields far more focused light output and thus significantly greater utility for focused tasks such as reading. Carbon emissions factors assumed to equal those of India and China. Electricity prices: $0.1/kWh.