ECONOMICS OF LIGHT POLLUTION

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ABSTRACT Little attention has been directed toward the environmental and economic costs of light pollution. We estimate that 2.5 percent of the total United States electricity production is expended on nighttime outdoor lighting. About 30 percent of all outdoor nighttime lighting ends up in the night sky. This is equivalent to 17.4 billion kilowatt-hours of electricity, more than the individual electrical production of many countries, including Chile, Cuba, Hungary, Ireland, Indonesia, Israel, Libya, Peru, Syria, or Vietnam. About one half of light pollution arises from direct upward lighting and one half from reflections off the ground and buildings. Light pollution directly costs the country at least a *billion dollars* a year in unnecessary electricity charges, in addition to the associated environmental harm from the mining and burning of fossil fuels to generate this wasted electricity. The equivalent of 8.2 million tons of coal (or 30 million barrels of oil) are burned annually in the United States *simply to light up the night sky.* The proper use of full cut-off shielding, timers, and appropriate light levels, if widely instituted, could reduce the overall urban sky glow by at least a factor of four in the next few decades.

INTRODUCTION

Light pollution is a significant problem for professional and amateur astronomers, but the general public and many others in the scientific community are not aware of the problem (1-5). Environmental groups surprisingly have failed to understand that light pollution is quite harmful but relatively easy to reverse. Its solution immediately saves considerable money and environmental damage. A large body of literature (1-8) details the adverse effects of urban sky glow on professional and amateur astronomy, but there has been little research on the associated economic and environmental costs of wasteful lighting practices (9-12). In this paper, we attempt to put a price on the direct monetary

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and energy costs of light pollution. Our figures are only "best guesses," but they do give a good approximation for the magnitude of the problem.

CALCULATIONS

Table I lists some essential electricity facts (9-12). To calculate the percent of the total United States electricity sales that goes for outdoor nighttime lighting, we note the following:

1) Dr. Roy Garstang (13-15) estimates that in large cities overall nighttime illumination is equivalent to 1000 lumens per person. By assuming an average lighting efficiency of 25 lumens per watt, we estimate 40 watts is the approximate per capita amount of power devoted to outdoor lighting. By further assuming that outdoor lighting is turned on for an average of ten hours per night, then 40 watts x 10 hours x 365 days = 146 kilowatt-hours (KWH) per capita annual electricity use for outdoor lighting. This amount is approximately 1.2 percent of the United States annual per capita electricity usage.

2) In a study by Walker (2-3), 39 percent of the total urban sky glow was estimated to come from street lights. By extrapolating this ratio to the entire country, we find that (100/39) x 0.6% [0.6% is the total United States electricity consumption devoted to street and highway lighting] yields a figure of 1.6 percent of all United States electricity use for urban outdoor lighting.

3) All types of lighting use is estimated to be 20-30 percent of the total United States electricity consumption (16), or about 463,000 to 578,000 million KWH per year. Outdoor lighting accounts for at least 15 percent of all lighting energy use (16); therefore, approximately 69,450 to 86,820 million KWH of electricity is devoted to outdoor nighttime lighting. This amount is about 3.1 to 3.8 percent of the total United States electrical usage.

4) A survey of southwest cities (17) found the energy costs of municipal lighting for those cities with utility dominated lighting systems was about $9 per year per person, in 1980. Assuming a national average cost of $9 per year per person for municipal lighting and using the 1985 figures of 9,697 KWH of electricity sales per capita and a total ultimate customer cost of 6.47 cent/KWH (11), then municipal lighting accounts for 1.4 percent of all United States electricity costs. Further assuming that municipal lighting accounts for approximate 40 percent of the total outdoor nighttime lighting cost, then all outdoor nighttime lighting accounts for about 3.6 percent of our national electricity costs.

5) A further way to look at the problem is to "guess" from discussions with power company officials as to how much outdoor nighttime lighting contributes to the total United States energy consumption. Most power company officials we informally surveyed felt that nighttime lighting consists of far more than one percent of total power consumption but considerably less than five percent (18).

For the purposes of this paper, we will assume an intermediate, probably conservative, figure of 2.5 percent as the proportion of electricity use in the United States devoted to nighttime outdoor lighting. This number fits in well with the published figures for street and highway lighting (11-16).

To look at the national impact of light pollution from an economic viewpoint (Table II), we assume that 15 percent of all nighttime light is emitted

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above the horizontal plane of the light fixtures and goes directly into the sky (13-15). We also will assume that the light going down to the ground meets an average ground reflectivity of 15 percent (13-15). Therefore, about 30 percent of all outdoor lighting shines directly or indirectly into the sky.

Using our estimate of 2.5 percent of the United States electricity production being devoted to outdoor nighttime lighting, we calculate that a total of 58 billion KWH of electricity is used annually for night lighting. Because 15 percent of this lighting is for light that is going directly up into the sky, 8.7 billion KWH of electricity, or the equivalent of 8.2 billion pounds of coal, are consumed annually solely to brighten the night sky. This DIRECTLY costs the country (using an average price of 7.40 cents/KWH) $644,000,000 per year. We also spend another $644,000,000 annually on lighting that is reflected into the sky. The actual total money spent is probably higher because street and highway lighting by themselves have an average cost of 10.21 cents/KWH rather than the residential cost average of 7.40 cent/KWH that we used in these calculations (See Table I). Moreover, large cities, the major source of light pollution, have higher average electricity cost per KWH than the national average and have more lights and lumens per capita as well.

DISCUSSION

Light pollution is costing the country a lot of money and is wasting a lot of natural resources. There is a lack of public awareness of the problem rather than a resistance to cures (3). The public needs to know that this kind of pollution is expensive and harmful, and they need to know that it is controllable with modest effort and cost. Cures will save money, even in the short haul.

Light pollution is the one form of pollution whose solution can produce immediate economic, esthetic, utilitarian, and environmental benefits. Nighttime outdoor lighting is a small consumer of electricity compared with other residential and industrial uses, but it is not trivial. The 58 billion KWH of electricity devoted to our nighttime lighting equals or exceeds the electricity production for many nations (See Table III). Light thrown directly up into the sky alone uses enough electricity (8.7 billion KWH) to supply the annual needs of countries such as Algeria, Burma, Ecuador, Libya, Morocco, Nigeria, Syria, Tunisia, Vietnam, or Zaire (9).

Light pollution harms the environment in four ways: 1) Urban sky glow hinders professional and amateur astronomy and deprives the public of its view of the night sky. 2) Coal, oil, and nuclear fuels are mined and consumed in large amounts merely to light the night sky. 3) The monies spent on unproductive lighting of the night sky are not available for more worthwhile uses. 4) The fossil fuels burned to produce harmful lighting also contribute to air and water pollution. Over 50 percent of the United States electricity production is derived from the burning of coal (Table I), much of which is obtained by strip mining. Coal burning in itself is no small contributor to air pollution and acid rain. Thus, it seems rather short-sighted for the country to allow its dark skies to be senselessly degraded by the consumption of non-renewable resources whose gathering and burning contribute nothing to the public good but further stress the environment.

It speaks for the minimal appreciation of the subject by environmental

groups that there has been no significant protest of this poor management of our country's resources. Even astronomers have been noticeably lax at understanding the rarity and fragility of the world's prime observing sites, all of which are variously threatened with degradation by light pollution (13).

Urban sky glow resulting from fixtures emitting light directly upward should no longer be tolerated. Efficient full cut-off shielded fixtures are now available for most night lighting applications. Urban sky glow resulting from light reflected off the ground and buildings, as opposed to light shining directly upward in the sky, is more difficult to assess and control. Some of it results from legitimate lighting necessary for nighttime recreation, security, and safety; even the most avid dark sky advocate wants properly lit major streets, highways, and parking lots. Effective security lighting is also necessary in built-up urban areas. Nevertheless, much can be done to control upward reflected light by judiciously reducing the average lumen emission of most fixtures. Billboard lighting and business signs should not be on all night. Unnecessary lights ought to be turned off, and security lighting should be kept to the level needed for the job, while street lights, parking lot lights, and security lights ought to use low pressure sodium lamps (LPS). This light source offers the best economy of any light source and is the by far the least harmful to astronomy (3).

Many lighting designs use the overkill method of throwing as many watts at a subject as possible, rather than designing the lighting level for the lighting task at hand. The lowest usable wattage necessary should be determined for a given application and then applied appropriately. The best lighting designs consider all relevant factors, such as glare control, energy efficiency, and the need for dark skies. Such designs do not compromise nighttime safety, security, and utility, but reduce energy waste, giving far less light pollution and light trespass, and far darker skies. Efficient, full cut-off shielded fixtures give more light on the ground, and they require less wattage.

All newly manufactured outdoor lighting fixtures ought to be well shielded, and there should be retrofitting of as many old, inefficient light fixtures as possible. If this were done, then over a period of years, there would be at least a two-fold reduction in the average urban sky glow. A several decade effort to reduce nighttime light output to reasonable and proper per capita levels could effect at least another two-fold reduction. Thus, in an ideal world (Why not? It is not beyond the realm of possibility.), at least a four-fold overall reduction in urban sky glow could be affected within the next generation. In addition, professional astronomy would also benefit greatly from especially rigid controls on growth and lighting near major observatories and prime observing sites. If these changes could be brought about, the public would see less money spent for wasteful, environmentally detrimental practices and would regain a view of the sky that has been lost for most people over the last few generations. Our children and grandchildren would be assured of their view of the wonders of the universe. We think these are noble, important, and achievable goals.

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TABLE I ESSENTIAL FACTS

A. United States Electricity Consumption (11):

1985 Energy Sales (Million KWHs):		
Residential:	797,010	34.4%
Commercial:	608,480	26.3%
Industrial:	821,990	35.5%
Street/Highway:	13,954	0.6%
Others:	73,572	3.2%
Total:	2,315,006	100.0%

B. Annual Per Capita Electricity Sales (KWH) (11):

1985	9,697
1965	4,927

C. Cost Considerations:

Average revenues/KWH sold, total Electric Utility Industry (11):

Residential:	7.40 cents
Commercial:	7.27
Industrial:	5.04
Street/Highway:	10.21
Total Ultimate Customers:	6.67

D. Sources of Electricity Production, 1985 (11):

Coal	56.8 %
Nuclear Power	15.5
Hydro	11.4
Gas	11.8
Oil	4.1
Other	0.4

E. Other Energy Considerations (9, 10, 12):

It takes 0.47 tons of coal (940 lbs) to produce 1000 KWH of electricity. Therefore: 1 KWH is the equivalent of 0.94 lbs of coal, or 1 lb of coal can produce 1.1 KWH of electricity.

It takes 1.8 barrels (76 gallons) of crude oil to produce 1000 KWH of electricity. Therefore: 1 KWH is the equivalent of 0.076 gallons of crude oil, or 1 gallon of crude oil can produce 13.2 KWH, or 1 barrel of crude oil can produce 556 KWH.

It takes 10,000 cubic feet of natural gas to produce 1000 KWH of electricity. Therefore: 1 KWH is the equivalent of 10 cubic feet of natural gas, or 1 cubic foot of natural gas can produce 0.1 KWH.

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TABLE II SOME ENERGY FACTS AND INFORMATION

Annual United States Energy Costs Associated with Nighttime Lighting and Light Pollution:

Annual total U.S.A. Electricity Consumption: 2,315,000 million KWH

Percent devoted to outdoor nighttime lighting: 2.5 percent

Annual nighttime lighting electricity consumption: 58 billion KWH

This is the equivalent of 55 billion lbs (27.5 million tons) of coal or 104 million barrels of crude oil.

Annual cost for outdoor nighttime lighting (at 7.40 cents per KWH): $4,290,000,000

Direct Costs of Light Pollution:

Percent of nighttime light emitted above the horizontal: 15%
Percent of nighttime light reflected off the ground: 15%

Cost of the direct light:	$644,000,000
Cost of the reflected light:	$644,000,000

Equivalent Energy Costs:

The energy lost due to this sky glow from light emitted above the horizontal or from the reflected light:

8.7 billion KWH of electricity, or
8.2 billion lbs (4.1 million tons) of coal, or
15 million barrels of oil.

Total amount wasted:

17.4 billion KWH of electricity, or
16.4 billion lbs of (8.2 million tons) of coal, or
30 million barrels of oil.

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Table III ELECTRIC ENERGY PRODUCTION OF REPRESENTATIVE NATIONS

(Units are Billion KWH)

	1983
Algeria	8.5
Argentina	43.0
Australia	106.3
Belgium	52.7
Burma	1.9
Canada	408.4
Chile	12.6
Cuba	11.6
Denmark	22.2
Ecuador	4.3
Ethiopia	0.8
Finland	40.2
France	283.4
Greece	22.3
Hungary	16.5
Ireland	11.2
India	148.0
Indonesia	15.3
Iraq	13.7
Israel	14.6
Japan	602.4
Libya	7.2
Malaysia	12.1
Mexico	82.3
Morocco	6.0
New Zealand	25.5
Nigeria	8.5
Peru	9.3
Portugal	18.2
Soviet Union	1408.1
Switzerland	51.8
Syria	6.2
Thailand	18.4
Tunisia	3.5
Vietnam	4.2
Zaire	4.2
Zambia	10.1

1985

United States

Total Electrical Consumption: 2315

Estimated consumption for outdoor nighttime lighting: 58

Estimated cost of light pollution from direct upward light: 9

Estimated cost of light pollution from ground reflected light: 9

Total Estimated Cost of Light Pollution: 17

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