Who's in the Dark: Satellite Based Estimates of Electrification Rates

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Abstract

A technique has been developed to estimate the percent population having electric power access based on the presence of satellite detected nighttime lighting. A global survey was conducted for the year 2006 using nighttime lights collected by the U.S. Air Force Defense Meteorological Satellite Program (DMSP) in combination with the U.S. Department of Energy Landscan population dataset. The survey includes results for 229 countries and more than 2000 subnational units. The results are compared to reported electrification rates for 87 countries compiled from a variety of sources by the International Energy Agency. The DMSP derived estimate of number of people worldwide who lack access to electricity is 1.62 billion, only slightly larger than the 1.58 billion estimated by the International Energy Agency.

Keywords: Electrification rates, nighttime lights, population grid.

Introduction

The wide distribution of 6+ billion people across more than 200 countries has made it difficult to collect and synthesize consistent data on the human condition at anything more that broad national and sub-national units. The primary reporting is for population and economic variables such as Gross Domestic Product (GDP). There is a paucity of data on quality-of-life variables and where such data are collected variations in the methods, survey questions used and timetables make the reports difficult to assimilate into a global assessment. Satellite sensors provide one of the few globally consistent and repeatable sources of observations. Clearly it would be useful to have one or more satellite derived indices that could used to estimate socioeconomic parameters, such as the distribution of economic activity, population, and living conditions. Historically, earth observing systems that aim for global coverage have been designed to observe environment and weather, not human activities. It would be sheer luck to find data from one of these global earth observing systems that also made a direct observation of a human activity. But there are several examples that can be pointed to. Satellite sensors such as NOAA's AVHRR and NASA's MODIS detect fires, many of which are anthropogenic in origin, using a combination of thermal bands. These same sensors detect urban heat islands and paucity of green vegetation in heavily built up urban cores. But the most remarkable example of a global earth observing satellite sensor detection of human activity are the nighttime lights collected by the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS).

Human beings around the world use lights at night to enable the extension of activity past sundown. The brightness of lights is affected by multiple factors, such as population density, economic activity, infrastructure investment, lighting type, lighting fixtures, and even cultural preferences in lighting. Despite these complexities, a number of studies have used nighttime lights to map phenomena which would be cost prohibitive to map based on ground surveys. This includes the distribution of economic activity (Doll *et al.* 2000, Ebener *et al.* 2005, Ghosh *et al.* 2009), the density of constructed surfaces (Elvidge *et al*. 2007a), poverty levels (Elvidge *et al*. 2009a), and resource consumption (Sutton et al. 2009).

By overlaying lights and population (Figure 1) it is possible to observe clear differences in the quantity of lighting per person around the world. Populations in the developed world generally have a surplus of lighting, yielding the blue-green and white areas on Figure 1. Areas with high population count and modest lighting levels show up as pink. (in portions of India and China). The red colors on Figure 1 indicate populations where no lighting was detected by the DMSP sensor.

In this study we develop a new application for the nightime lights, the estimation of electrification rates. For year 2005 the International Energy Agency (IEA) World Energy Outlook (IEA 2006) estimated the global electrification rate at 75.6% with 1.58 billion people living without electricity. Lack of electric power is a poverty indicator with links to conditions that are detrimental to health and well being such as lack of refrigeration for food, poor water quality, lack of sanitary facilities, and limited access to health care services. We map the spatial extent of electrification in 2006 based on the presence of DMSP detected lighting. Combining the spatial extent of lighting with population count we estimate electrification rates. We compare the DMSP estimates of electrification rates with reported rates for 87 countries published for year 2005 by the International Energy Agency (IEA 2006). Finally we discuss possible sources of error and ideas for improvements.

Insert Figure 1 about here.

Methods

Data Sources

The two primary data sources for this study are DMSP nighttime lights and gridded population count. Both the nighttime lights and population grid were from year 2006. National level reference data on the extent of electrification were drawn from the International Energy Agency's World Energy Outlook (WEO) 2006.

The DMSP-OLS visible band was designed to enable the detection of moonlit clouds at night in the visible band. A photomultiplier tube is used to intensify the visible band signal by about a million fold. This enables the detection of moonlit clouds and lighting present at the Earth's surface. NGDC has developed a capability to make cloud-free composites of the nighttime visible band OLS data (Elvidge *et al.* 2001). Additional procedures are used to remove ephemeral lights (mostly fires) and background noise to produce gridded stable lights products.

There are several gridded population products available. We have found the U.S. Department of Energy Landscan data (Dobson *et al.* 2001 and Bhaduri *et al.* 2002) to be the most compatible with the DMSP nightime lights. Both are produced in a geographic projection with the same 30 arc second grid resolution. Also, the recent Landscan products have not used nighttime lights as an input, thus there is not circularity in using the two data sets. The Landscan data are spatial allocations of census reported population numbers based on models developed using three satellite derived data sources: 1) NASA MODIS land cover, 2) the topographic data from the Shuttle Radar Topography Mission (SRTM), and 3) high resolution outlines of human settlements derived from the Controlled Image Base (CIB) from the U.S. National Geospatial Intelligence Agency (NGA). Landscan data are referred to as population count instead of population density, which is based on residence. On a population density grid commercial centers and airports have very low numbers, despite the fact that there are substantial numbers of people present during certain hours. Landscan attempts to represent the spatial distribution of population based on person hours. Thus population is distributed across residential, commercial, industrial and public areas such as airports and schools.

The IEA has been compiling and reporting on electrification rates since 2002 in a publication series titled “World Energy Outlook”. They admit there is no internationally accepted definition for electric power access and no standard method for collecting such data. Their objective has been to report the percentage of the population has access to electricity in their home. Data are collected from various sources, ranging from government agencies, international development programs and energy research organizations. Where the country reported data appeared contradictory, out of date, or unreliable the IEA reports estimates based on consideration of data from similar countries, earlier surveys, data from the international organizations, and journal articles.

Data Processing

While the fires and background noise were removed in the production of the stable lights for 2006 – the gas flares are still present. To avoid overestimating electrification rates in countries with substantial numbers of gas flares, areas lit by gas flares were masked out and not used in the analysis. The locations of gas flares in the DMSP nighttime lights had already been determined in consultation with high resolution imagery available in Google Earth (Elvidge et al., 2009b). The remaining lights are all deemed to be from electric lighting. A binary mask was generated for the areas lit by the presence of gas flares. The gas flare mask was applied to the Landscan grid to zero out the population count in areas lit by gas flares. A second mask was produced for the remaining lights. This mask was used to divide the gas flare free population grid into two segments A) population with lighting detected (Figure 3), and B) population with no lighting detected (Figure 4). The percent electrification rate is then calculated as:

$$\frac{\text{Population with DMSP lighting (A)}}{\text{Total Population (A+B)}} \times 100.$$

The analysis was conducted at both a national and subnational level.

Insert Figure 2 about here.

Insert Figure 3 about here.

Insert Figure 4 about here.

Results

Using the data shown in Figures 2-4 we estimated the electrification rates for 229 countries – listed in descending population order in Table 1. The national level DMSP estimates are represented in map form in Figure 5. The total number of people found to be without electricity is 1.62 billion, only 2.5% larger than the 1.58 billion estimated by the IEA. The IEA estimates are listed in the third data column in Table 1 and are shown in map form in Figure 6. Because the Landscan data are disaggregated it is possible to estimate electrification rates at the subnational level (Figure 7) or at user defined spatial aggregations.

Insert Figure 5 about here.

Insert Figure 6 about here.

Insert Figure 7 about here.

Insert Figure 8 about here.

Discussion

Figure 8 compares the DMSP estimated and IEA reported electrification rates. Overall, there is general agreement between the DMSP and IEA electrification rate estimates. Developed countries with near 100% electrification rates yielded DMSP electrification rates ranging from 98 to 100% (Table 2). The countries having DMSP estimated electrification rates less than 20% (Table 3) are countries long recognized among the poorest on Earth.

However, it is possible to identify cases where the two estimates differ substantially. Table 4 lists the top ten countries where the IEA reported electrification rate is higher than the DMSP estimate. Leading here are Thailand, China and Cuba, each with more than a twenty percent difference between the two numbers. Countries having ten to twenty percent higher electrification rates reported by the IEA include Brazil, Philippines, Paraguay, Mongolia, Chile, Cameroon and Algeria. We do not know the source of the discrepancies.

The IEA estimates China has a 99.4% electrification rate, citing the Chinese Ministry of Science and Technology and the U.S. Department of Energy National Renewable Energy Laboratory. In contrast, the DMSP estimated electrification rate is 75.6%. Thus, the DMSP estimate identified 320 million more people without electricity in China than the IEA had reported. That is more than the entire population of the USA! A large portion of the Chinese population identified to be without electricity are in Sichuan Province and surrounding provinces in the interior south-central China, known to be amongst the poorest regions of China. It is possible that the IEA reported electrification rate for China is valid in the wealthy coastal areas and underestimates the lack of electric power access in less wealthy the interior regions. Or it may be that the definition being used to define "access to electricity" is so broad that it encompasses 99.4% of the Chinese population. Another possibility is that the electrification rate is indeed high, but use of outdoor lighting is so sparse in some regions that the DMSP sensor is unable to detect the lighting. Similar possibilities exist for the other countries listed on Table 4.

Table 5 lists the top eleven countries where the DMSP estimates exceed the IEA reported electrification rates. Leading the list is Iraq, for which the IEA estimated an electrification rate of 15% and the DMSP estimate was 88.1%. In WEO 2004 (IEA, 2004) the electrification rate for Iraq was reported as 94.5%.for the year 2002. The number was revised down for 2005 based on a Iraq government report (COSIT, 2005), which includes results of a household survey regarding the stability of electric power service in the months following the U.S. invasion in 2003. The IEA summarized the COSIT surveys, concluding that only 15% of Iraqi households had reliable access to electricity. The disparity between the two electrification rate estimates for Iraq can be attributed to the DMSP's ability to detect intermittent lighting over the course of a year.

Other countries where the DMSP estimated electrification rate exceeded the IEA reported value include Congo, Pakistan, Sri Lanka, Qatar, Indonesia, Lesotho, Bangladesh, Afghanistan, Gabon, and India. The Indian estimate from DMSP is 75.5% nearly matches the DMSP estimate for China (75.6%). As with China, the core of the DMSP identified population with no lighting detected are located in a heavily populated zone known as the poorest region of the nation, in this case the Ganges River Plain stretching from Delhi to Calcutta.

There are several possible sources of error in the DMSP estimates. There may be errors of omission, or undercounting of the population with access to electricity in rural areas where the outdoor lighting is not bright enough for DMSP detection. This is the major source of error in developed countries such as the USA, France and New Zealand, which are believed to have near 100% electrification but fall 1-2% short of this in the DMSP estimates (Table 2). This style of error may be larger in the developing countries that have lower electric power consumption levels, such as China and India. There may errors of commission, or overcounting of the population with access to electricity in areas that have street lighting and commercial lighting, yet no electric power access in a portion of the homes in the same pixel. Another source of discrepancy arises from homes with intermittent or sporadic electric power service. In the case of Iraq the IEA only tallied population with reliable electric power service in the estimation of the electrification rate. The DMSP data were processed to detect intermittent lighting, yielding a substantially higher estimate of the electrification rate. Finally, it should be noted that the DMSP electrification rate estimates were derived from areas that are devoid of lighting from gas flares. That is to say, in areas with onshore gas flares, the electrification rate has been estimated outside of the area lit by the gas flares. This includes portions of countries listed by Elvidge et al. (2009 b), including Russia, Nigeria, Iran, Iraq, Algeria, Libya and others.

Insert Figure 8 about here.

Conclusion

We derived the first systematic global assessment of electrification rates by combining DMSP nighttime lights with a population density grid. In this analysis, the electrification rate was estimated by tallying the population count in areas having DMSP lighting as compared to the total population. Using this technique we have a standardized product, with reporting for 229 countries and more than 2000 sub-national units. In contrast, the only other available reporting on international electrification rates comes from the International Energy Agency (IEA), which in 2006 reported electrification rates for 87 countries.

There are several potential areas for improvement in the estimation of electrification rates based on nighttime lights. The current method is flawed since it overestimates the population without access to electricity in sparsely populated rural areas in developed countries that have electricity, but do not produce enough light to be detected by the DMSP satellite. Conversely, the method over estimates the electrification rate in urban areas in developing countries where DMSP lighting detected from streetlights and other outdoor lighting types in areas where households have no electric power access or unreliable access. It may be possible to identify areas having intermittent access to electricity based on the percent frequency of light detection in the DMSP annual cloud-free composites. To address the problem with gas flares obscuring lights from small towns and villages the best solution would be to collect the nighttime lights data at higher spatial resolution (Elvidge et al. 2007b).

One of the applications for the full resolution grid of the population count in areas without DMSP detected lighting is to identify areas of the world that could benefit from installation of sustainable solar and wind energy systems. In many of these areas, people are burning kerosene to produce subsistence levels of heat and lighting that cannot be detected by DMSP. Mills et al (2007) have shown that liquid fuels are extremely inefficient and costly light sources. The only thing cheap about this approach to lighting is the cost of the lanterns. Given the emphasis being placed on reducing carbon emissions, Mills et al. (2007) have developed low cost photovoltaic panels and light emitting diode (LED) fixtures that enable families to produce light using locally generated electricity without the expense of extending the electric power grid. This approach has similarity to the rapid expansion of cell phone usage in places where the land line telephone system is antiquated and decrepit.

While there are some known sources of error in the current product, the method does provide electrification rates using a standardized definition and standardized data sources, with complete global coverage. We anticipate that there will be improvements to the nighttime lights approach to estimating electrification rates. We also anticipate that nighttime lights will be useful for detecting changes in electric power access. This could include both expansions and contractions in access to electric power.

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Table 1
Estimates of National Electrification Rates For 2006

China	1,308,905,728	76.8	99.4
India	1,104,764,800	75.7	55.5
United States	291,958,400	99.0	
Indonesia	223,445,600	78.9	54
Brazil	181,723,136	79.9	
Pakistan	165,333,376	91.4	54
Bangladesh	146,274,784	55.0	32
Russia	137,334,752	86.1	
Nigeria	131,131,568	40.7	46
Japan	121,929,464	99.5	
Mexico	106,107,432	93.7	
Philippines	84,165,344	64.9	80.5
Vietnam	82,873,472	80.6	84.2
Germany	82,284,928	98.8	
Egypt	78,002,176	99.9	98
Ethiopia	74,580,856	12.6	15
Turkey	68,341,640	83.1	
Iran	64,260,172	94.5	97.3
Thailand	64,074,048	72.3	99
Congo, DRC	62,137,408	23.5	5.8
France	59,562,360	98.0	
United Kingdom	59,185,168	99.1	
Italy	56,513,852	99.4	
South Korea	46,776,532	100.0	
Ukraine	46,517,576	85.0	
Myanmar	46,174,136	27.1	11.3
South Africa	45,957,312	74.0	70
Colombia	43,065,580	82.7	86.1
Sudan	41,005,056	33.5	30
Argentina	39,522,200	87.9	95.4
Spain	39,451,484	97.3	
Poland	38,388,900	96.9	
Tanzania	37,158,680	17.9	11
Kenya	35,813,744	29.3	14
Canada	32,498,608	97.3	
Algeria	32,268,142	88.0	98.1

Morocco	32,187,260	77.5	85.1
Afghanistan	31,032,188	29.6	7
Uganda	29,390,972	15.4	8.9
Nepal	28,748,452	32.7	33
Peru	28,113,022	69.0	72.3
Uzbekistan	27,253,948	94.4	
Iraq	26,810,654	88.1	15
Saudi Arabia	26,496,632	98.8	96.7
Venezuela	24,973,556	93.2	98.6
Malaysia	23,057,040	90.4	97.8
North Korea	22,510,660	37.6	22
Ghana	22,411,932	46.5	49.2
Romania	22,266,808	88.4	
Yemen	21,162,504	55.4	36.2
Mozambique	20,290,134	22.0	6.3
Sri Lanka	20,229,058	95.4	66
Australia	19,666,616	92.1	
Madagascar	18,730,568	14.8	15
Syria	18,670,416	95.1	90
Cameroon	17,516,510	36.4	47
Cote d'Ivory	17,016,192	53.7	50
Netherlands	16,320,233	100.0	
Chile	15,528,649	87.3	98.6
Kazakhstan	15,366,266	72.7	
Burkina Faso	13,915,535	15.5	7
Cambodia	13,900,239	15.6	20.1
Malawi	13,240,124	18.6	7
Ecuador	13,057,767	82.1	90.3
Niger	12,536,623	19.8	
Guatemala	12,447,853	78.1	78.6
Zimbabwe	12,220,747	34.1	34
Senegal	12,128,555	48.3	22
Angola	11,902,221	29.9	15
Mali	11,707,643	22.6	
Zambia	11,336,282	34.9	19
Cuba	11,227,785	74.9	95.8
Serbia & Montenegro	10,787,706	90.4	
Belgium	10,431,084	100.0	
Portugal	10,328,523	98.3	
Czech Republic	10,250,290	99.6	
Greece	10,137,542	97.2	
Chad	10,059,864	18.5	
Hungary	9,981,097	94.2	

Belarus	9,762,124	78.3	
Tunisia	9,752,671	91.6	98.9
Rwanda	9,629,262	13.6	
Guinea	9,362,449	21.0	
Dominican Republic	9,090,900	90.7	92.5
Bolivia	8,985,352	66.0	64.4
Somalia	8,729,994	24.7	
Sweden	8,441,214	98.0	
Burundi	8,245,397	7.7	
Austria	8,171,036	98.8	
Azerbaijan	8,046,536	82.1	
Benin	7,919,077	37.7	22
Haiti	7,808,419	29.3	36
Switzerland	7,629,250	99.6	
Bulgaria	7,319,524	92.1	
Honduras	7,182,415	72.6	61.9
Tajikistan	6,941,439	87.4	
El Salvador	6,778,252	93.6	79.5
Paraguay	6,507,533	70.5	85.8
Laos	6,389,236	22.0	
Israel	6,151,147	99.9	96.6
Sierra Leone	5,921,899	25.0	
Jordan	5,893,604	97.5	99.9
Libya	5,827,906	96.5	97
Nicaragua	5,527,336	60.6	69.3
Togo	5,522,532	33.3	17
Slovakia	5,459,714	95.1	
Papua New Guinea	5,210,907	17.6	
Denmark	5,157,683	96.6	
Kyrgyzstan	5,099,656	86.6	
Turkmenistan	5,090,828	85.9	
Finland	5,089,830	95.2	
Eritrea	4,723,351	27.0	20.2
Georgia	4,559,424	74.9	
Bosnia & Herzegovina	4,476,640	84.1	
Central African Republic	4,300,050	25.2	
Croatia	4,299,097	95.0	
Singapore	4,206,270	100.0	100
Moldova	4,176,313	85.5	
Norway	4,098,739	88.3	
Costa Rica	4,067,027	92.9	
Ireland	3,937,104	97.0	
Puerto Rico	3,824,000	100.0	

New Zealand	3,801,472	87.1	
Congo	3,752,949	60.5	19.5
Lithuania	3,603,037	78.5	
Albania	3,471,578	76.2	
Lebanon	3,458,243	99.6	99.9
Uruguay	3,424,161	90.1	95.4
Mauritania	3,197,154	36.2	
Panama	3,134,964	80.1	85.2
Armenia	2,985,608	87.9	
Oman	2,931,608	95.9	95.5
Liberia	2,923,682	30.0	
Mongolia	2,826,511	52.4	
Jamaica	2,631,911	99.8	87.3
West Bank	2,517,877	100.0	
United Arab Emirates	2,419,677	99.6	91.9
Bhutan	2,327,470	33.7	
Latvia	2,204,224	75.8	
Macedonia	2,059,063	91.9	
Kuwait	2,011,370	99.4	100
Namibia	1,984,458	43.0	34
Slovenia	1,984,024	95.8	
Lesotho	1,974,952	34.3	11
Botswana	1,640,102	53.8	38.5
The Gambia	1,599,751	45.0	
Guinea-Bissau	1,407,918	29.4	
Gabon	1,358,236	68.5	47.9
Gaza Strip	1,305,448	100.0	
Estonia	1,277,632	85.8	
Mauritius	1,219,407	100.0	93.6
Swaziland	1,123,708	49.1	
Timor Leste	1,027,709	9.5	
Trinidad & Tobago	929,390	99.7	99.1
Qatar	847,314	96.1	70.5
Fiji	786,719	56.1	
Reunion	754,849	99.8	
Cyprus	753,955	99.5	
Guyana	719,444	69.0	
Comoros	600,507	33.3	
Bahrain	581,127	100.0	99
Luxembourg	483,098	100.0	
Suriname	461,789	84.4	
Equatorial Guinea	435,168	18.1	
Martinique	426,392	100.0	

Guadeloupe	381,306	100.0	
Cape Verde	376,338	81.8	
Malta	368,860	100.0	
Western Sahara	331,567	92.1	
Brunei	303,062	96.9	99.2
Solomon Is.	293,641	0.5	
Belize	286,146	78.6	
The Bahamas	271,502	94.2	
Barbados	261,993	100.0	
Iceland	243,255	88.3	
Djibouti	203,931	59.4	
New Caledonia	199,394	67.6	
French Polynesia	182,166	96.6	
Sao Tome & Principe	179,070	61.7	
Netherlands Antilles	177,571	99.7	99.6
Mayotte	170,490	99.7	
St. Lucia	164,331	100.0	
Guam	158,857	100.0	
French Guiana	155,574	79.9	
Vanuatu	148,457	15.6	
Samoa	139,479	49.6	
Virgin Is.	98,686	100.0	
St. Vincent & Grenadines	92,502	99.3	
Jersey	88,366	100.0	
Grenada	75,259	100.0	
Northern Mariana Is.	73,153	99.9	
Aruba	71,740	100.0	
Andorra	71,447	98.8	
Isle of Man	68,639	97.9	
Seychelles	68,493	100.0	
Antigua & Barbuda	64,016	99.8	
Tonga	57,901	85.5	
Dominica	57,503	90.8	
Guernsey	56,408	100.0	
American Samoa	50,729	100.0	
Faroe Is.	37,755	73.7	
Monaco	37,046	100.0	
Micronesia	35,739	86.4	
Liechtenstein	34,768	100.0	
Greenland	33,363	76.1	
St. Kitts & Nevis	28,666	100.0	
San Marino	25,918	100.0	
Cayman Is.	25,902	100.0	

British Virgin Is.	19,578	100.0	
Wallis & Futuna	13,886	11.9	
Anguilla	13,201	100.0	
Palau	13,076	77.7	
Nauru	12,283	100.0	
Cook Is.	11,093	90.9	
Bermuda	9,391	100.0	
Turks & Caicos Is.	7,822	93.1	
Montserrat	7,638	73.8	64.6
St. Pierre & Miquelon	6,793	98.9	
St. Helena	6,006	69.0	
Falkland Is.	2,974	76.7	
Kiribati	2,462	2.6	
Gibraltar	2,195	100.0	
Niue	2,069	61.5	
Tuvalu	1,378	1.4	
Norfolk I.	1,170	95.6	
Maldives	405	53.6	
Christmas I.	359	100.0	
Vatican City	283	100.0	
Cocos Is.	233	72.5	

Table 2
Countries Where Electrification Rates Are Expected To Be Near 100%

Country	DMSP Estimated (%)
Singapore	100.0
Netherlands	100.0
Belgium	100.0
South Korea	100.0
Switzerland	99.6
Czech Republic	99.6
United Arab Emirates	99.6
Japan	99.5
Italy	99.4
United Kingdom	99.1
United States	99.0
Austria	98.8
Germany	98.8
Saudi Arabia	98.8
Portugal	98.3
Sweden	98.0
France	98.0

Table 3
Countries With Populations Over A Million And
DMSP Estimated Electrification Rates Under 20%

Country	DMSP Estimated (%)	IEA Reported %
Niger	19.8	
Malawi	18.6	7
Chad	18.5	
Tanzania	17.9	11
Papua New Guinea	17.6	
Cambodia	15.6	20.1
Burkina Faso	15.5	7
Uganda	15.4	8.9
Madagascar	14.8	15
Rwanda	13.6	
Ethiopia	12.6	15
Timor Leste	9.5	
Burundi	7.7	

Table 4
Top Ten Countries Where the DMSP Estimated Electrification Rate
Is Lower Than The IEA Reported Rate

Country	DMSP Estimated (%)	IEA Reported (%)	Difference
Thailand	72.3	99.0	-26.7
China	75.6	99.4	-23.8
Cuba	74.9	95.8	-20.9
Brazil	78.4	96.5	-18.1
Philippines	64.9	80.5	-15.6
Paraguay	70.5	85.8	-15.3
Mongolia	52.4	64.6	-12.2
Chile	87.3	98.6	-11.3
Cameroon	36.1	47.0	-10.9
Algeria	88.1	98.1	-10.0

Table 5
Top Eleven Countries Where the DMSP Estimated Electrification Rate
Is Higher Than The IEA Reported Rate

Country	DMSP Estimated (%)	IEA Reported (%)	Difference
Iraq	88.1	15.0	73.1
Congo	60.5	19.5	41.0
Pakistan	91.2	54.0	37.2
Sri Lanka	95.4	66.0	29.4
Qatar	96.1	70.5	25.6
Indonesia	78.8	54.0	24.8
Lesotho	34.3	11.0	23.3
Bangladesh	55.0	32.0	23.0
Afghanistan	29.6	7.0	22.6
Gabon	68.5	47.9	20.6
India	75.5	55.5	20.0

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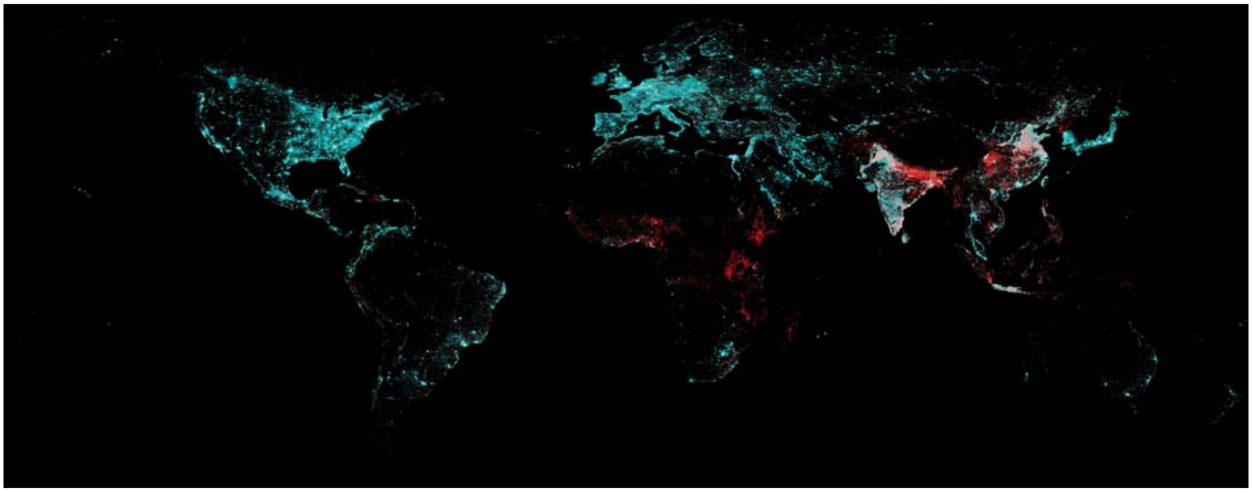

Figure 1.

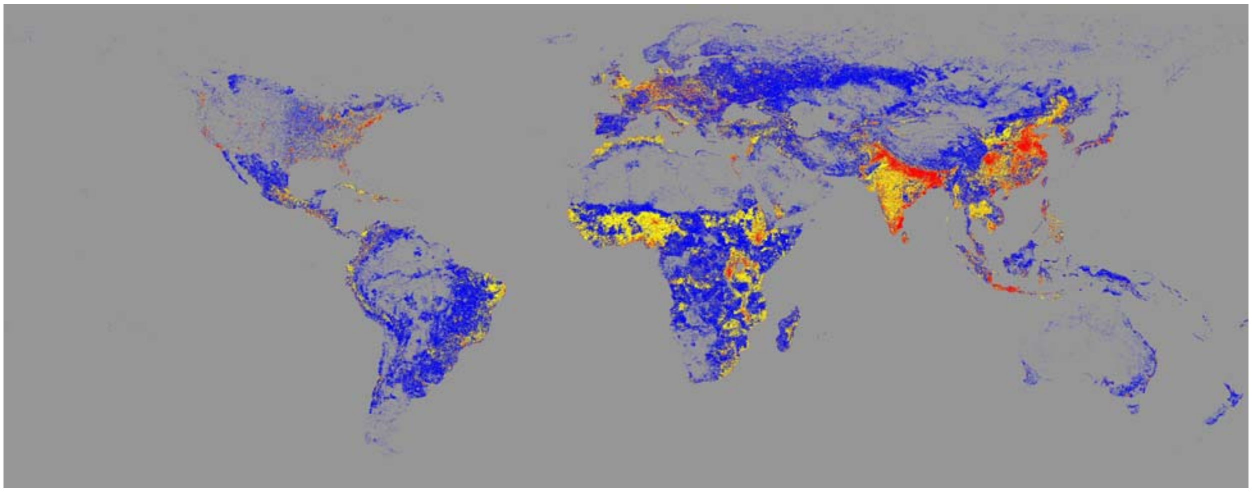

Figure 2. Landscan population count. Uninhabited areas with population counts of zero are gray. Rural areas having population counts ranging from 1-10 are blue. Suburban and densely populated rural areas with population counts ranging from 11 to 99 are yellow. Red areas have population counts of 100 or more per grid cell.

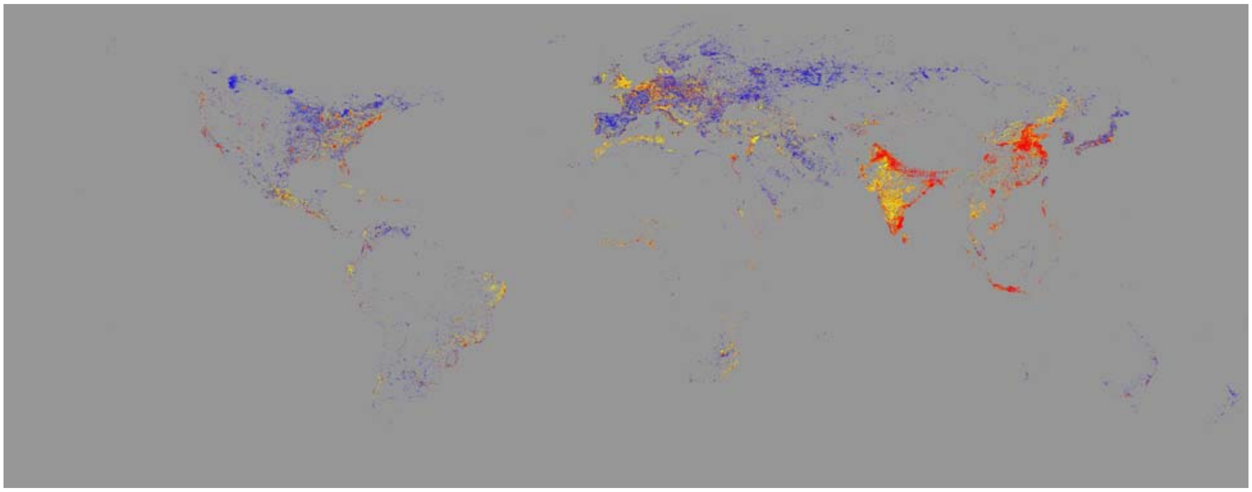

Figure 3. Landscan population count in areas with DMSP detected lighting. The color coding is the same as Figure 2.

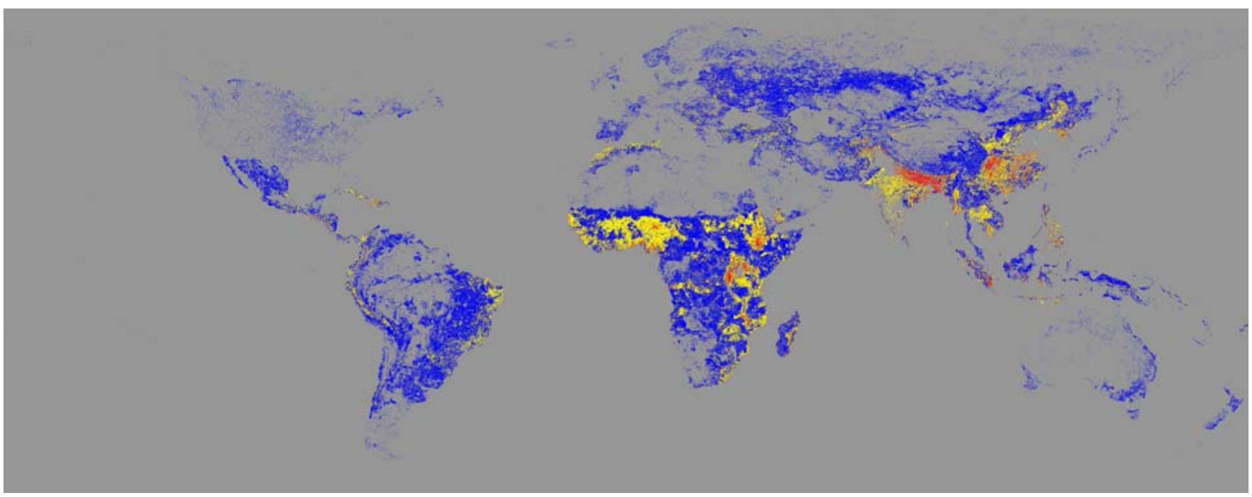

Figure 4. Landscan population count in areas with no DMSP detected lighting. The color coding is the same as Figure 2.

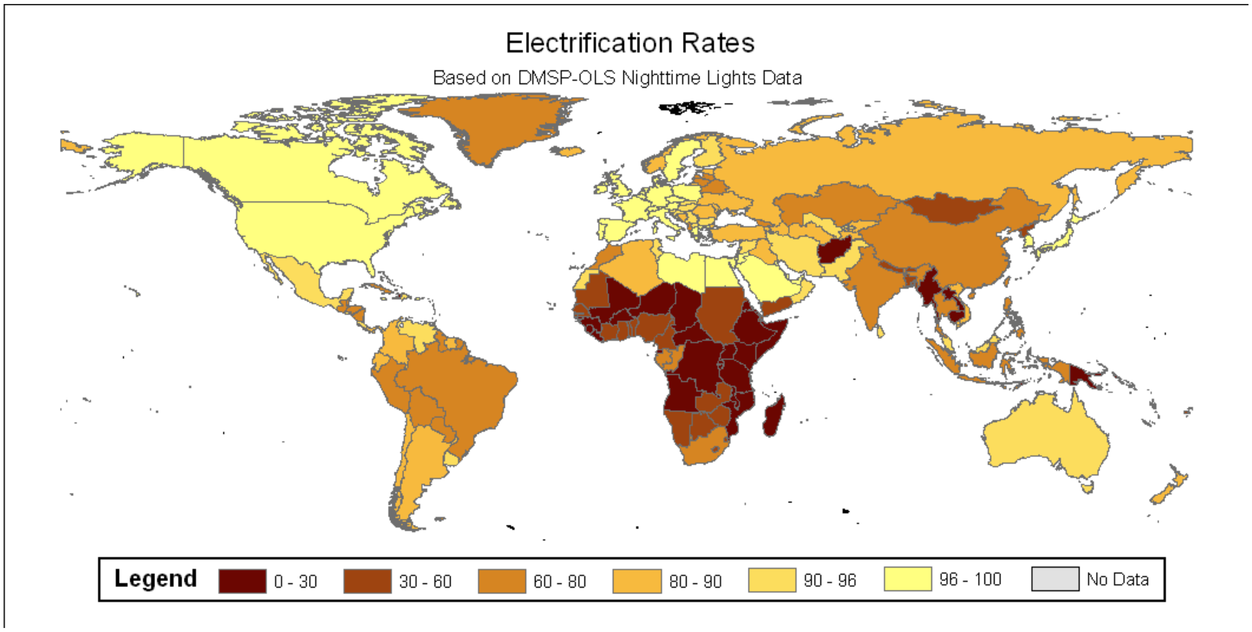

Figure 5. DMSP estimated electrification rates for the countries of the world for year 2006.

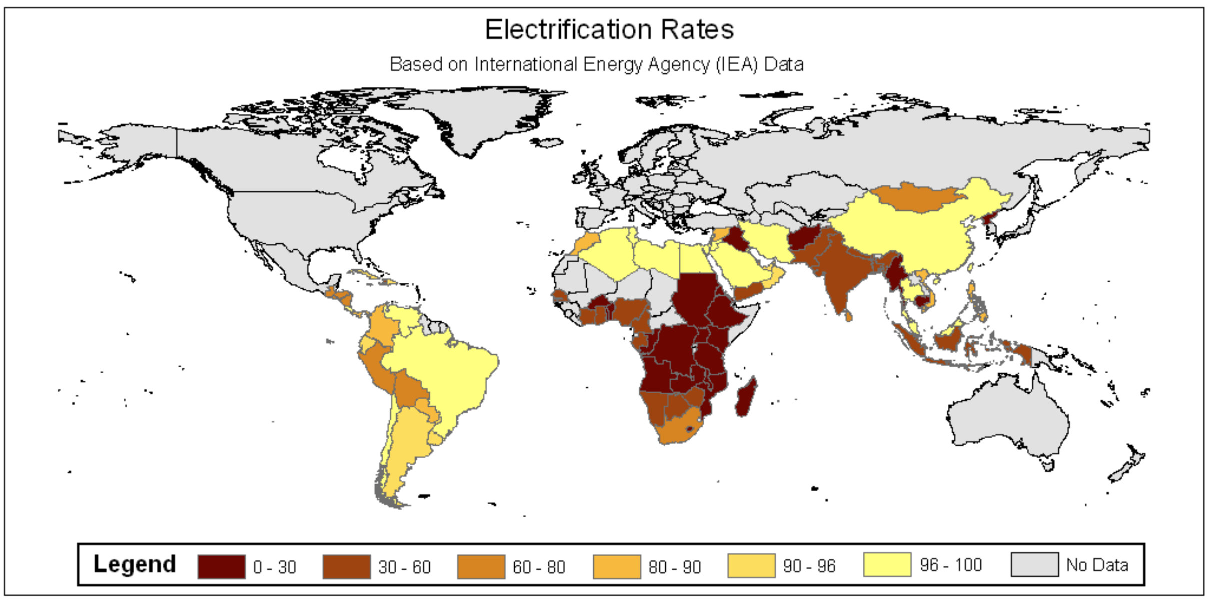

Figure 6. Electrification rates published by the IEA for year 2005.

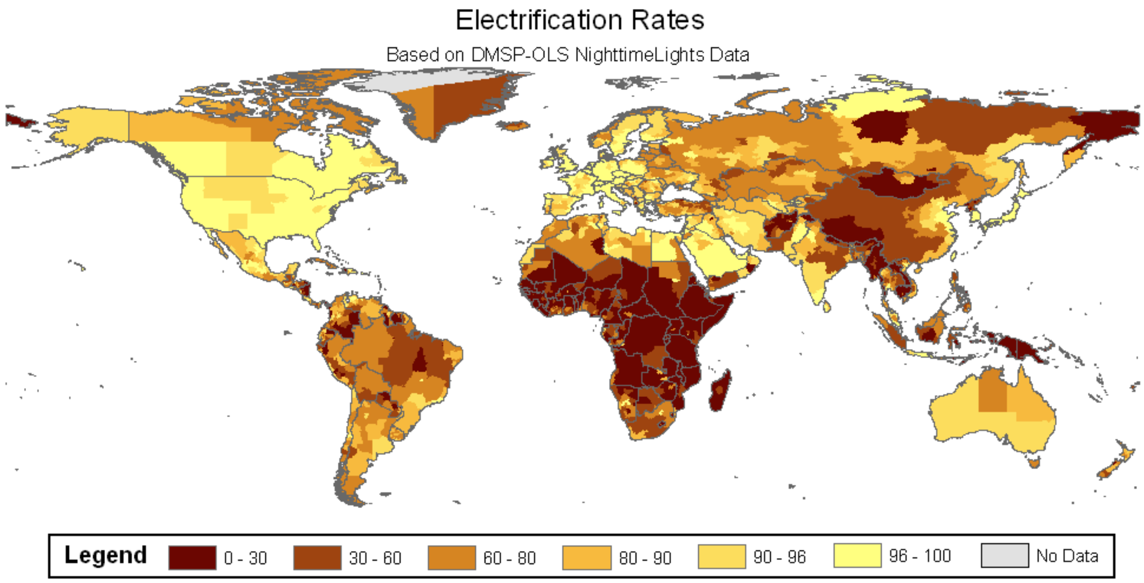

Figure 7. DMSP estimated electrification rates for primary subnational units (states and provinces) for year 2006.

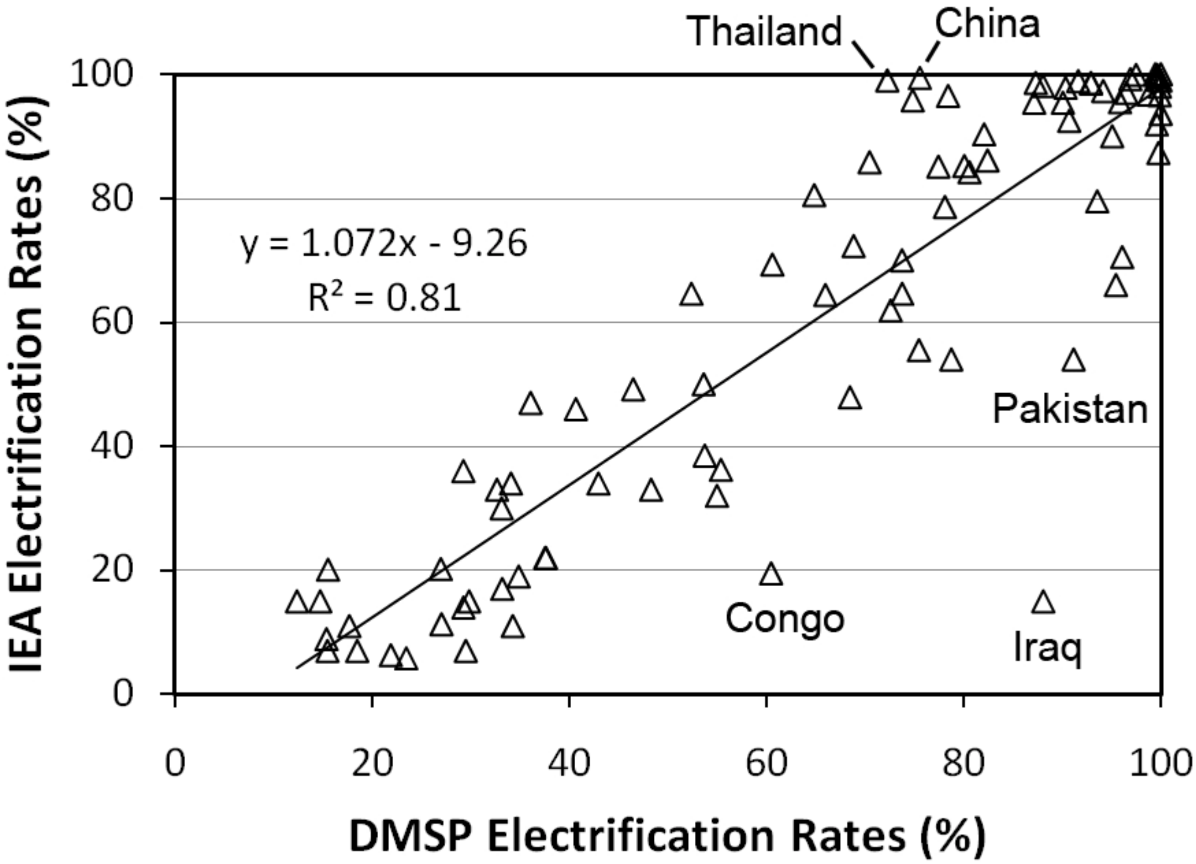

Figure 8. DMSP versus IEA estimates of national electrification rates. The outlier in the bottom right corner is Iraq, and the possible reasons for the discrepancy are discussed in the text.

Index Words

Electrification
Electrification rates
DMSP
Nighttime lights
Landscan
DOE – Department of Energy
IEA – International Energy Agency
WEO – World Energy Outlook
National
Subnational
Light emitting diode (LED)
China
India
Iraq
Russia
Nigeria
Iran
Algeria
Libya
Thailand
Cuba
Congo
Pakistan
Sri Lanka
Qatar
Indonesia
Lesotho
Bangladesh
Afghanistan
Gabon
Brazil
Philippines
Paraguay
Mongolia
Chile
Cameroon