The Social Cost of Carbon: A White Paper on the NextGrid Illinois Study

Timothy R. Gerrity, Ph.D.

ACT-Chicago

Author Note

Timothy Gerrity, Ph.D. is the Principal of ACT-Chicago, a health technology consulting firm supporting the advancement of science and technology to further population health across public and private sectors. He is also a member of the Union of Concerned Scientists Science Network. Dr. Gerrity received his Ph.D. in Physics from the University of Illinois at Chicago and received postdoctoral training in pulmonary physiology and the pathogenesis of lung diseases at the UIC School of Medicine. Among his career accomplishments he led award winning research efforts on the health effects of criteria air pollutants at US EPA's Human Studies Facility in Chapel Hill, NC while he was also a Research Associate Professor in the School of Medicine at the University of North Carolina, Chapel Hill. His EPA team's peer-reviewed research contributed, and since his departure continues to contribute, to the scientific support of National Ambient Air Quality Standards for pollutants such as O_3, SO_2, NO_x, CO, and PM.

Address: 4727 N. Lawndale Ave, Chicago IL, 60625
Phone: 909-809-9359
e-mail: tgerrity@act-chicago.net or tim.gerrity2@gmail.com

Abstract

The stated purpose of the NextGrid Study is to address critical issues facing Illinois' electric utility industry in the coming decade and beyond by examining the use of new technologies to improve the state's electric grid while minimizing energy costs to consumers. Its efforts are focusing on innovation, technological advancements, economic development, environmental considerations, and education. This white paper is directed at that aspect of the NextGrid Study related to environmental considerations and most specifically to the human health costs of pollutants. The use of fossil fuels, in particular coal, for the production of energy is a principal contributor to anthropogenic climate change. In addition, and possibly of greater immediate importance to the citizens of Illinois, is the significant impact coal combustion has on the health of our citizens and the external costs created by those impacts. It is very encouraging to note that Working Group 6 is diligently working on the regulatory and environmental policy issues of NextGrid. It is hoped that this white paper will be a positive contribution to that group's efforts by helping to illuminate how and why the human health consequences of fossil fuel-based energy production need to be integrated into the overall design of the state's evolving electric grid.

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Background

Air pollution and the degradation of air quality are "negative externalities" whereby the market of products and services responsible for the externalities does not internalize the full opportunity cost of production borne by society as public goods because air quality and its degradation are imprecisely priced. Greenhouse gas (GHG) emissions globally, and non-GHG emissions nationally and regionally impose negative health and welfare costs on society that are not reflected in the market price electricity production. This has led to a decades long effort to take action to control the pollution generated through the production of electricity. The equilibrium market price of electricity may fail to incorporate the full opportunity cost to society of generating electricity. That constitutes a market failure that is not socially optimal if the marginal social cost of the last unit of electricity produced exceeds its marginal social benefit.

To its enormous credit Illinois has forthrightly stepped up into a necessary national leadership position to address this market failure and facilitate the internalization of the negative externality associated with CO2 emissions as they contribute to global climate change[1] and also to the direct adverse human health impacts from the other pollutants that are byproducts of electricity generation. The state's leadership is even more vital given the current abrogation of federal responsibility to help address this global problem facing all humans on earth.

The NextGrid Study is envisioning a modernized power grid for the state. To establish and then achieve measurable goals is complex due to a grid's complex interacting parts. Getting to a grid that is more efficient and economical, while minimizing environmental impacts can take

[1] It is taken as a scientific fact that the earth's climate has been changing for many years as a consequence of human activity, in particular the combustion of fossil fuels generating increasing atmospheric levels of the greenhouse gas CO_2. Mitigating adverse impacts from climate change depend on reducing to the greatest extent possible the introduction of all greenhouse gases into the atmosphere.

many paths. Each path will involve costs and benefits. The goal of this white paper is to present to the NextGrid Study participants a variety of documented facts and analyses that need to be at the forefront of grid plans especially in the context of weighing costs and benefits.

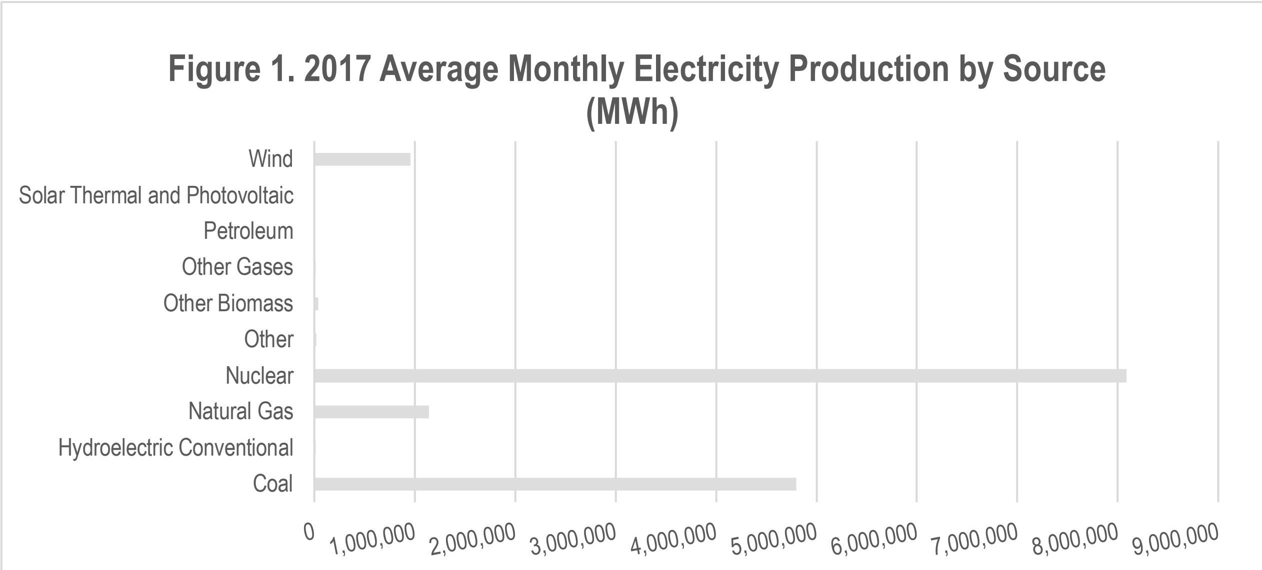
This white paper strives to establish for the record five interconnected information sets: 1) the current state of Illinois' energy resource portfolio; 2) the emissions associated with energy production; 3) the social costs of carbon in the context of GHG emissions; 4) the direct non-GHG-related human health impacts of emissions associated with fossil fuel (primarily coal) combustion; and 5) the social costs of these latter health impacts.

Although the information contained in this white paper is derived from publicly available sources, and is thus not advanced as being novel, it is the author's hops that by explicitly presenting this information, those involved with the design and implementation of Illinois' future grid will consciously and conscientiously incorporate this knowledge into their thought processes going forward.

The Illinois Energy Portfolio

As reported by the US Department of Energy, Energy Information Agency (EIA), Figure 1 below (extracted from the EIA website[2]) shows the average monthly electricity generation in Illinois by source for 2017.

[2] US Department of Energy, Energy Information Agency. https://www.eia.gov/state/?sid=IL



On average 54% of Illinois' 2017 monthly electricity came from its 6 nuclear power plants and 32% from its 15 coal fired generation plants. Approximately 7% came from nonhydroelectric renewables, such as wind and solar, and 8% came from natural gas-fired plants. Assuming constant electricity production over time, in order to achieve Illinois' goal of 25% power generation from nonhydroelectric renewals by 2025 means that it must triple its renewable energy production (with proportionate reductions from other sources) in 7 years – an ambitious and laudable goal. As this white paper intends to demonstrate, the state currently over-relies on fossil fuel-based electricity generation to detriment of its citizens. Cynics might say that in the context of GHG emissions, Illinois' contribution to this problem is miniscule on a global scale. But Illinois must join with other states to offset federal failures to join the world community in wrestling with the global threat of climate change. At the same time the state addresses GHG emissions it must also address health problems of regional importance from non-GHG emissions due to fossil fuel combustion.

Emissions Produced from Illinois Electricity Generation

Table 1 below is an inventory published by EIA of electric power related emissions for Illinois[3] .

Table 1. Illinois electric power industry emissions estimates,for 2014

Emission type	2014	2014 Percent
Sulfur dioxide (short tons)		
Coal	187,419	99.9376%
Natural gas	14	0.0075%
Other	49	0.0261%
Petroleum	54	0.0288%
Total	187,536	100%
Nitrogen oxide (short tons)		
Coal	48,656	83.7799%
Natural gas	3,515	6.0524%
Other	5,753	9.9060%
Petroleum	152	0.2617%
Total	58,076	100.0000%
Carbon dioxide (thousand metric tons)		
Coal	93,282	96.5412%
Natural gas	3,260	3.3739%
Other	10	0.0103%
Petroleum	71	0.0735%
Total	96,624	100.0000%
Total emission rate (lbs/MWh)		
Sulfur dioxide	1.9	
Nitrogen oxide	0.6	
Carbon dioxide	1,052	

EIA does not provide data on PM emissions, but EPA's National Emissions Inventories (NEI)[4] do. According to NEI, in 2014 Illinois electricity generation resulted in 4,750 tons and

[3] US Department of Energy, Energy Information Agency. https://view.officeapps.live.com/op/view.aspx?src=https://www.eia.gov/electricity/state/illinois/xls/sept07IL.xls

[4] USEPA National Emissions Inventories https://www.epa.gov/air-emissions-inventories

5,840 tons of filterable and condensable PM_{10} and $PM_{2.5}$ and respectively. It must be noted that in comparison to the EIA data, EPA's NEI reports lower total emissions associated with electric power generation. However, the NEI does not break their data down by sector (i.e. coal, natural gas, etc.). If the NEI data are used and proportionately adjusted by sector using the EIA data, Illinois 2014 electric power generation from coal emitted 136,199 tons of SO2 and 39,745 tons of NO_x. In all future calculations, this white paper will use EPA's more conservative metrics.

As the EIA data demonstrate, nearly 100% of SO_2, 96.5% of CO2 emissions, and 84% of NO_x emissions associated with power generation in Illinois come from coal-fired plants. However, although natural gas combustion for power generation accounts for only 3.3% of CO_2 emission, methane (i.e., natural gas) is a much more potent GHG compared to CO_2 with a 30-fold greater Global Warming Potential.[5] Methane release into the atmosphere from its extraction and transportation significantly magnifies the global danger of its use as a source of electricity generation.

To put Illinois' emissions inventory into a national context, coal-fired power plants are concentrated in the eastern half of the United States. Consequently, atmospheric concentrations of the pollutants from coal-fired plants are also significantly higher in the east than elsewhere. The US map in Figure 2 shows modeling results for the annual ambient $PM_{2.5}$ concentrations across the US[6]. Because of atmospheric transport, Illinois emissions affect not only our own citizens, but citizens of neighboring states as well.

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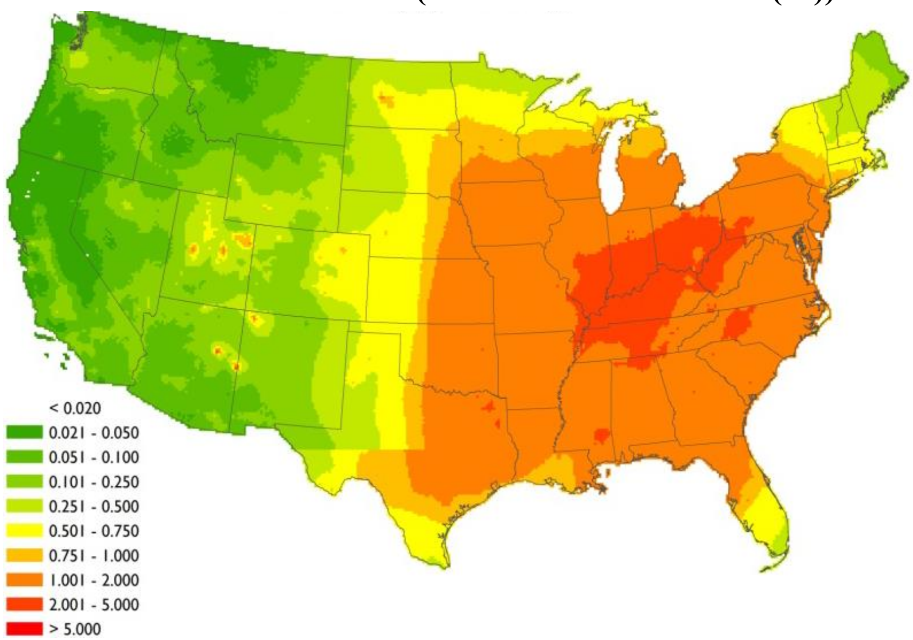
[5] U.S. Environmental Protection Agency https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

[6] Technical Support Document: Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors https://www.epa.gov/sites/production/files/2018-02/documents/sourceapportionmentbpttsd_2018.pdf Accessed June 4, 2018

Figure 2. Modeled Annual Mean $PM_{2.5}$ Levels Attributable to Electricity Generating Units in 2016 (extracted from reference (13))



Particulate matter attributable to electricity generation is concentrated in the Midwest and Eastern half of the United States, especially in the Ohio River Basin.

If Illinois can increase to 25% the share of renewables in its electric power generation mix - combined with an offsetting reduction of power production from coal-fired plants and assuming a constant electricity demand - coal fired electricity production would be reduced from approximately 4.8 GWh to 2.5 GWh. Based on the EIA data for CO_2 emissions from coal-fired plants, this could mean a reduction of approximately 45 million metric tons of CO_2 emissions per year. The current economics of coal as an energy source, would seem to drive such a shift.

The Social Cost of Carbon as a GHG

Notwithstanding attempts to reverse the EPA Clean Power Plan, the EPA is still mandated by law under CAA 1990 to regulate CO_2. Under Executive Order 12866[7] the Interagency Working Group (IWG) on the Social Cost of Carbon was formed to conduct a regulatory impact analysis estimating the social cost of carbon. IWG's first analysis was published in 2010[8], and then revised in 2016[9] based on a review of the first analysis by the National Academies of Science, Engineering and Medicine in 2015[10]. Executive Order 12866 requires federal agencies, "…to assess both the costs and the benefits of an intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." (i.e. regulation can correct a market failure).

The purpose of the "social cost of carbon" (SC- CO_2) estimates allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The work of the IWG was based on a large body of scientifically peer reviewed research conducted by academic, government, and industry researchers. The IWG acknowledges the many uncertainties associated with their estimates and shows a clear understanding that they

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7 https://www.reginfo.gov/public/jsp/Utilities/EO_12866.pdf
8 2010 Social Cost of Carbon Technical Support Document
9 2016 Social Cost of Carbon Technical Support Document (Revised)
10 NAS Review of 2010 Social Cost of Carbon (2015)

need to be updated and externally reviewed over time to reflect ever-increasing knowledge of the science and economics of climate change.

Quoting from the 2010 Social Cost of Carbon Technical Support Document, "The SC-CO_2 is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change." The SC-CO_2 estimate does not account for the cost due to emissions other than CO_2 from coal-fired power plants such as SO_2 and PM. These latter costs are addressed in the next section of this white paper.

To generate its cost estimates the IWG used three integrated assessment models[11] [12] calculating 150,000 separate cost estimates with various model inputs. For each set of model inputs, discounts of 5%, 3%, and 2.5% were applied in order to obtain a range of net present value cost estimates. Figure 3 (extracted from reference (9)) is a frequency distribution of estimates from a full set of 150,000 runs at each discount rate for the year 2020. The SC-CO_2 is expressed in units of 2007$/metric ton of CO_2. The frequency distribution is right-skewed as one might expect since the higher modeled cost projections are associated with more extreme impacts that have a lower likelihood of occurring. The "central estimate" yields an average cost with a 3% discount rate applied of $42/metric ton CO_2. The high impact cost (at the 95th percentile of the distribution) at a 2.5% discount is approximately triple the "central estimate."

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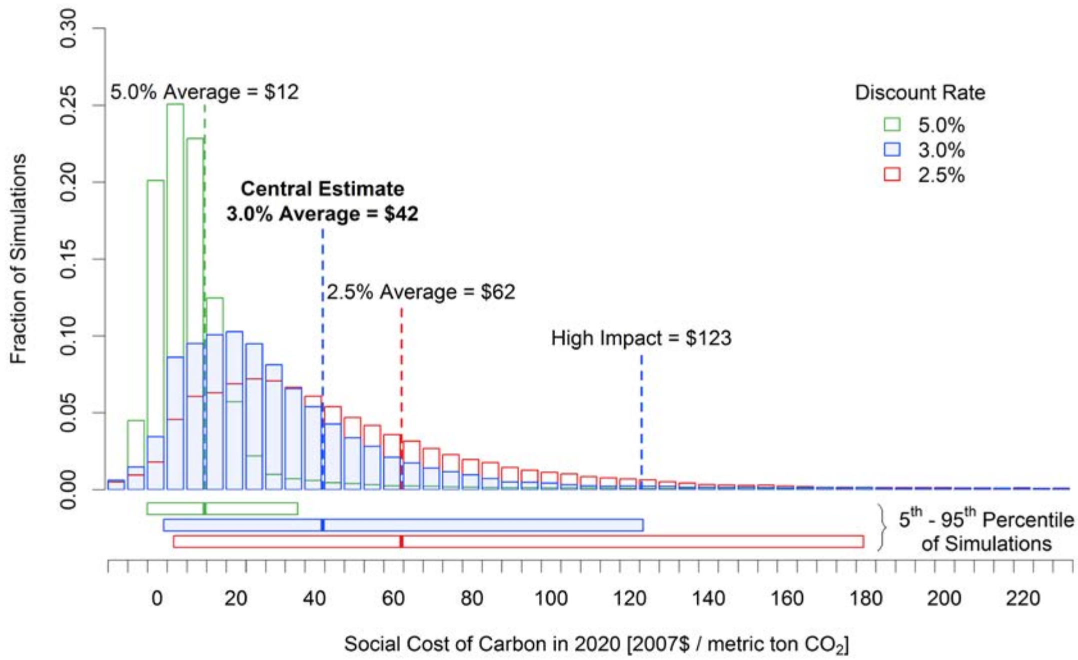
[11] DICE (Dynamic Integrated Climate-Economy model), William D. Nordhaus, Economic aspects of global warming in a post-Copenhagen environment, Proceedings of the National Academy of Sciences Jun 2010, 107 (26)

[12] FUND (Framework for Uncertainty, Negotiation and Distribution model); PAGE (Policy Analysis of the Greenhouse Effect model). Social Cost of Carbon: A Closer Look at Uncertainty. Global CCS Institute. https://hub.globalccsinstitute.com/publications/social-cost-carbon-closer-look-uncertainty/social-cost-carbon-closer-look-uncertainty

Figure 3. Frequency Distribution of SC-CO_2 Estimates for 2020



Referring to the Illinois CO_2 emissions data from the previous section, if the central estimate is applied, climate change related SC-CO_2 from coal-fired CO_2 emissions of approximately equals $4 billion (in 2007 dollars) for the year 2020. If Illinois can achieve its 2025 target for renewable energy production, this cost could potentially be reduced by half. A reduction in cost is equivalent to a benefit to the citizens of Illinois and other states affected by Illinois power generation.

As the IWG rightly points out in its 2016 Technical Support Document there is significant uncertainty in the cost estimates. However, these estimates must be taken seriously because the stakes are indeed high, and the analyses leading to these estimates are conservative and are backed by sound, peer reviewed science.

The Cost of Direct Health Impacts from Coal-Fired Power Plants

Direct non-GHG Associated Health Effects:

Reduction of GHG emissions is aimed at reducing the highly deleterious long-term, global damages from climate change. However, fossil-fuel based electric power generation is also a leading contributor to a variety of non-GHG ambient air pollutants with near-term adverse health consequence in areas proximal to the sources.

Health impacts constitute the largest fraction of economic damages of air pollution. In order of to be comprehensive, estimated health impacts include reduced organ functionality; increased asthma attacks; doctor visits, school and work absences; emergency room visits, hospital admission and heart attacks; and premature death. Emissions of *coarse* particulate matter ($PM_{10\text{-}2.5}$ – i.e., particulate matter that is between 10 and 2.5 micrometers in diameter) cause chronic obstructive pulmonary disease, asthma, and hospital respiratory and cardio-vascular admissions but have not been associated with increased mortality. However, fine particles ($PM_{2.5}$) are more harmful because they translocate from the lungs to blood and accumulate in other parts of the body, increasing short- and long-term mortality and morbidity[13].

Table 2 (extracted from reference (13)) summarizes the health effects associated with the most common pollutants associated with coal-fired power plants.

[13] Environmental Quality and the U.S. Power Sector: Air Quality, Water Quality, Land Use and Environmental Justice. Oak Ridge National Laboratory Report ORNL/SPR-2016/772 https://www.energy.gov/sites/prod/files/2017/01/f34/Environment%20Baseline%20Vol.%202--Environmental%20Quality%20and%20the%20U.S.%20Power%20Sector--Air%20Quality%2C%20Water%20Quality%2C%20Land%20Use%2C%20and%20Environmental%20Justice.pdf

Table 2. Health Effects of Common Air Pollutants	
Pollutant	Health Effect
NOx	COPD
	IHD
SO_2	Asthma
	Cardiac
O_3	Chronic asthma
	Acute-exposure mortality
	Respiratory problems
	Acute asthma attacks
$PM_{2.5}$	Premature death
	Non-fatal heart attacks
	Hospital admissions
	ER visits for asthma, acute bronchitis, upper aqn lower respiratory symptoms

Table 3 (extracted from reference (14)) below lists the current National Ambient Air Quality Standards under CAA 1990 for criteria air pollutants.

Pollutant		Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide (CO)		primary	8 hours	9 ppm	Not to be exceeded more than once per year
Carbon Monoxide (CO)		primary	1 hour	35 ppm	Not to be exceeded more than once per year
Lead (Pb)		primary and secondary	Rolling 3 month average	0.15 μg/m^3 [1]	Not to be exceeded
Nitrogen Dioxide (NO_2)		primary	1 hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
Nitrogen Dioxide (NO_2)		primary and secondary	1 year	53 ppb [2]	Annual Mean
Ozone (O_3)		primary and secondary	8 hours	0.070 ppm [3]	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle Pollution (PM)	$PM_{2.5}$	primary	1 year	12.0 μg/m^3	annual mean, averaged over 3 years
Particle Pollution (PM)	$PM_{2.5}$	secondary	1 year	15.0 μg/m^3	annual mean, averaged over 3 years
Particle Pollution (PM)	$PM_{2.5}$	primary and secondary	24 hours	35 μg/m^3	98th percentile, averaged over 3 years
Particle Pollution (PM)	PM_{10}	primary and secondary	24 hours	150 μg/m^3	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		primary	1 hour	75 ppb [4]	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
Sulfur Dioxide (SO_2)		secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

Table 3. National Ambient Air Quality Standards[14]

The EPA established the NAAQS according to Sections 108 and 109 of the U.S. Clean Air Act, which was last amended in 1990 (1990 CAA).[15] These sections require the EPA "(1) to list widespread air pollutants that reasonably may be expected to endanger public health or welfare; (2) to issue air quality criteria for them that assess the latest available scientific information on nature and effects of ambient exposure to them; (3) to set primary NAAQS to protect human health with adequate margin of safety and to set secondary NAAQS to protect against welfare effects (e.g., effects on vegetation, ecosystems, visibility, climate, manmade materials, etc); and (4) to periodically review and revise, as appropriate, the criteria and NAAQS for a given listed pollutant or class of pollutants."[16] The air quality criteria documents EPA issues for each criteria pollutant include extensive summaries of the documented health effects supported by scientific research published in the open peer-reviewed literature. The cited health research generally includes studies involving human clinical, animal toxicological, and population epidemiological studies. Production of criteria documents is done under the oversight of EPA's Clean Air Science Advisory Committee (CASAC) composed of outside experts in appropriate scientific disciplines. The findings from criteria documents are used by EPA's Office of Air and Radiation to produce integrated assessment models, which form the bases of recommendations to the EPA Administrator for air quality standards.

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[14] US EPA, Office of Air and Radiation https://www.epa.gov/criteria-air-pollutants Retrieved 2018-6-5
[15] http://www.epa.gov/ttnnaaqs/
[16] http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=158823

Costs of Emissions:

Estimating the pollution impact of any given power plant requires three components: the spatial distribution of emissions and sources; the ability to track pollution and chemical transformations of pollution in the atmosphere; and the exposure and response of individuals and assets to pollution. IAMs that combine all these components in a single coherent framework are usually complex and costly assessment tools. For this reason, the literature relies only on a few of them. IAMs can be used to determine either average or marginal impacts of pollution. Model outputs are sensitive to the assumptions, and data inputs used by the models can result in a range of estimates of air pollution damages.

Three recent studies assess the cost of air pollution from power generation in the U.S.: the EPA 2011 Second Prospective Study of the Clean Air Act;[17] a set of studies developed using the Air Pollution Emission Experiments and Policy (APEEP) model;[18] and a review on the externalities of electricity generation by the National Research Council.[19] The latter two studies assess the impact on human health, visibility, agriculture, and other sectors of SO_2, NO_x, $PM_{2.5}$, and PM_{10}. A more recent assessment [20] uses an updated version of the AEEP model (AP2) that connects emissions within the U.S. to monetary damages using six sequentially integrated modules: emissions, air quality modeling, concentration, exposure, dose-response, and valuation. The assessment leads to model predictions of damages for the years 2002, 2005, 2008, and 2011.

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[17] The Benefits and Costs of the Clean Air Act from 1990 – 2020 https://www.epa.gov/sites/production/files/2015-07/documents/fullreport_rev_a.pdf

[18] Health and Welfare Benefits Analyses to Support the Second Section 812 Benefit-Cost Analysis of the Clean Air Act https://www.epa.gov/sites/production/files/2015-07/documents/benefitsfullreport.pdf

[19] The Hidden Costs of Energy https://www.nap.edu/catalog/12794/hidden-costs-of-energy-unpriced-consequences-of-energy-production-and

[20] Jaramillo, P and Muller, N. 2016. Air pollution emissions and damages from energy production in the U.S.: 2002-2011. Energy Policy 90, 202-221. https://www.sciencedirect.com/science/article/pii/S0301421515302494

The majority of studies find that the largest negative monetary impacts due to air pollution from power plants are from increased morbidity and mortality. For example, $PM_{2.5}$ causes the largest number of deaths, non-fatal heart attacks, and emergency room visits.

Monetizing these impacts is challenging. Increased morbidity is typically estimated by the cost of health care, such as emergency room visits, hospital admissions, and increased medication usage (e.g., for asthma and COPD).

Estimating the cost of a human life is probably the most difficult to model. Economists typically do this by computing a metric called the value of a statistical life (VSL). VSL is the amount of money individuals are willing to pay to reduce mortality risk by a small amount. If, for example, a worker requires a wage increase of $600 in exchange for an increased risk of death from 0.0001 to 0.0002 (or one extra death for every 10,000 workers), the aggregate compensation for that one excess death is $6 million. EPA estimations use $620 for a risk reduction equal to 1/10,000 implying a VSL of $6.2 million. Viscusi and Aldy [21] find that most U.S. studies use a VSL between $6-9 million.

For each of the years 2002, 2005, 2008, and 2011 Jaramillo and Muller (2016) computed a Gross External Damage (GED) by multiplying the marginal damage by source and pollutant times the reported emissions by source, pollutant, and industrial sector. Nationally, they estimate that electricity generation was responsible for $100 billion (in 2005$) in marginal damages in 2011. It is notable, and encouraging, that this is a decrease from $155 billion in 2002.

Table 4 shows the estimated weighted average marginal damages from electricity generation by year for SO_2, $PM_{2.5}$, and NO_x in 2011.

[21] Viscusi, W.K.,Aldy,J.E.,2003.The value of a statistical life: a critical review of market estimates throughout the world. J.Risk Uncertain.27,5–76. https://link.springer.com/article/10.1023%2FA%3A1025598106257

Table 4. Weighted Average Marginal Damages from Electricity Generation in 2011

Table Units ($/ton)	SO_2	$PM_{2.5}$	NO_x
	$24,489	$28,032	$3,236

By multiplying the 2011 damages in Table 4 by the imputed NEI emissions for 2014 from above, we arrive at estimated damages for 2014 of $3.3 billion from SO_2, $133 million from $PM_{2.5}$, and $127 million from NO_x.

Without making any adjustments for the different years under consideration, the total social costs from combined GHG and non-GHG emissions are on the order of $6-7 billion per year due to coal-fired electricity generation.

Mitigating the Costs

As has already been discussed, these costs are externalities borne by citizens of Illinois and countless others. To individual consumers, these are costs that are not in proportion to their consumption of electricity but related more to their individual vulnerabilities to the health consequences of emissions (particularly coal-fired emissions) from power generation. Elderly and the young; and people with pre-existing health conditions such as asthma, chronic obstructive pulmonary disease, and coronary artery disease bear a disproportionate cost and quality of life burden. Furthermore, other factors lead to further maldistribution of the cost burdens. A disproportionate number of African Americans and Latinos live near coal-fired power plants, natural gas power plants, petroleum refineries, and other ambient air pollution sources, thus putting them at a disproportionate risk to the adverse health consequences of these pollutants[22]. Going forward, the NextGrid Study must consider the persistent injustices imposed upon the most at-risk members of our population by the energy production industries.

As the NextGrid Study proceeds, many factors will come into play as a picture for Illinois' future grid unfolds. This author hopes that those involved in the Study, and the ICC, take serious account of the need to design a grid that strikes a balance between purely economic costs and benefits and the need for justice with respect to the allocation of environmental impacts upon Illinois' citizens and others. Illinois has a unique opportunity at this time to become a model for the rest of the country in how it deals with environmental life and death issues as it maps out a course for future energy production, distribution, and consumption.

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[22] NAACP, Fumes Across the Fence Line. http://www.naacp.org/wp-content/uploads/2017/11/Fumes-Across-the-Fence-Line_NAACP-and-CATF-Study.pdf