WNA Report

Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources

World Nuclear Association

Contents

1 Introduction

The emission of greenhouse gases (GHGs) and their implications to climate change have sparked global interest in understanding the relative contribution of the electrical generation industry. According to the Intergovernmental Panel on Climate Change (IPCC), the world emits approximately 27 gigatonnes of CO_2e from multiple sources, with electrical production emitting 10 gigatonnes, or approximately 37% of global emissions[i]. In addition, electricity demand is expected to increase by 43% over the next 20 years[ii]. This substantial increase will require the construction of many new power generating facilities and offers the opportunity to construct these new facilities in a way to limit GHG emissions.

There are many different electrical generation methods, each having advantages and disadvantages with respect to operational cost, environmental impact, and other factors. In relation to GHG emissions, each generation method produces GHGs in varying quantities through construction, operation (including fuel supply activities), and decommissioning. Some generation methods such as coal fired power plants release the majority of GHGs during operation. Others, such as wind power and nuclear power, release the majority of emissions during construction and decommissioning. Accounting for emissions from all phases of the project (construction, operation, and decommissioning) is called a lifecycle approach. Normalizing the lifecycle emissions with electrical generation allows for a fair comparison of the different generation methods on a per gigawatt-hour basis. The lower the value, the less GHG emissions are emitted.

2 Scope and Objectives

The objective of this report is to provide a comparison of the lifecycle GHG emissions of different electricity generation facilities. The fuel types included in this report are:

- Nuclear;
- Coal;
- Natural Gas;
- Oil;
- Solar Photovoltaic;
- Biomass;
- Hydroelectric; and
- Wind.

Table 1 lists all studies utilized for the report, the organization that completed it, and the date the report was published.

Carbon Capture and Sequestration (CCS) is often cited as a technology that could dramatically reduce carbon emissions from coal fired power plants. Although this technology appears quite promising, it is currently in early developmental stages and does not have widespread commercial application. Therefore, the lifecycle GHG emissions can not be accurately estimated and have not been included in this report.

Title	Year Released	Publishing Organization	Type of Organization	Link
Hydropower-Internalised Costs and Externalised Benefits	2001	IEA	Government/ Agencies	http://www.nea.fr/globalsearch/search.php
Greenhouse Gas Emissions of Electricity Chains: Assessing the Difference	2000	IAEA	Government/ Agencies	http://www.iaea.org/Publications/Magazines/Bulletin/Bull422/article4.pdf
Comparison of Energy Systems Using Life Cycle Assessment	2004	World Energy Council	Government/ Agencies	http://www.worldenergy.org/documents/lca2.pdf
Uranium Mining, Processing and Nuclear Energy — Opportunities for Australia?	2006	Australian Government	Government/ Agencies	http://www.ansto.gov.au/__data/assets/pdf_file/0005/38975/Umpner_report_2006.pdf
European Commission Staff Working Document	2007	European Commission	Government/ Agencies	http://ec.europa.eu/energy
GHG Emissions and Avoidance Costs of Nuclear, Fossil Fuels and Renewable	2007	Öko-Institut (Institute for Applied Ecology)	Government/ Agencies	http://www.oeko.de
Environmental Impacts of PV Electricity Generation	2006	European Photovoltaic Solar Energy Conference	Universities	http://www.ecn.nl/docs/library/report/2006/rx06016.pdf
Externalities and Energy Policy	2001	OECD Nuclear Energy Agency	Government/ Agencies	http://www.nea.fr/html/ndd/reports/2002/nea3676-externalities.pdf
Greenhouse-gas Emissions from Solar Electric and Nuclear Power	2007	Columbia University	Universities	http://www.ecquologia.it/sito/energie/LCA_PV_nuc.pdf
Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis	2002	University of Wisconsin	Universities	http://fti.neep.wisc.edu/pdf/fdm1181.pdf
Nuclear Power - Greenhouse Gas Emissions and Risks a Comparative Life Cycle Analysis	2007	California Energy Commission Nuclear Issues Workshop	Government/ Agencies	http://www.energy.ca.gov/2007_energypolicy/documents/2007-06-25+28_workshop/presentations/panel_4/Vasilis_Fthenakis_Nuclear_Power-Greenhouse_Gas_Emission_Life_Cycle_Analysis.pdf

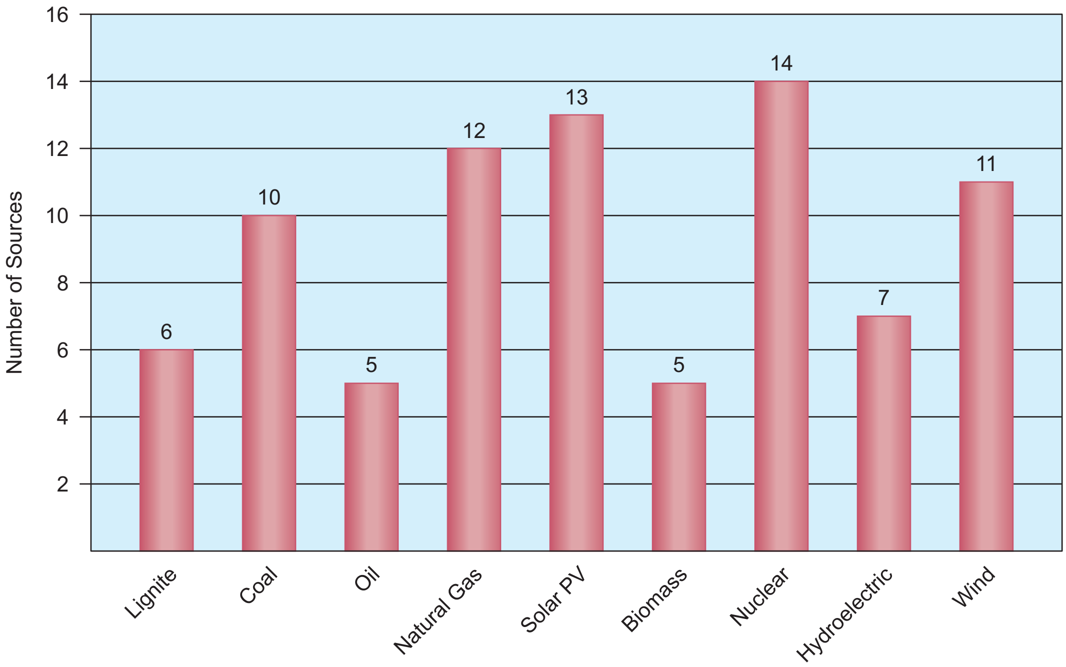
Title	Year Released	Publishing Organization	Type of Organization	Link
Quantifying the Life-Cycle Environmental Profile of Photovoltaics and Comparisons with Other Electricity-Generating Technologies	2006	National PV EH&S Research Center	Industry/ Associations	http://www.bnl.gov/pv/files/pdf/abs_195.pdf
ExternE National Implementation Germany	1997	IER	Universities	http://www.regie-energie.qc.ca/audiences/3526-04/MemoiresParticip3526/Memoire_CCVK_75_ExternE_Germany.pdf
Climate Declaration for Electricity from Wind Power (ENEL)	2008	Swedish Environmental Management Council	Industry/ Associations	http://www.klimatdeklaration.se/Documents/decl/CD66.pdf
Climate Declaration for Electricity from Nuclear Power (Axpo)	2008	Swedish Environmental Management Council	Industry/ Associations	http://www.klimatdeklaration.se/Documents/decl/CD144.pdf
Climate Declaration for Electricity from Nuclear Power (Vattenfall)	2007	Swedish Environmental Management Council	Industry/ Associations	http://www.klimatdeklaration.se/Documents/decl/CD21.pdf
Climate Declaration: Product: 1kWh net Electricity from Wind Power (Vattenfall)	2010	Swedish Environmental Management Council	Industry/ Associations	http://www.klimatdeklaration.se/PageFiles/383/epdc115e.pdf
Climate Declaration for Electricity from Hydropower (Vattenfall)	2008	Swedish Environmental Management Council	Industry/ Associations	http://www.klimatdeklaration.se/Documents/decl/CD88.pdf
Climate Declaration for Electricity and District Heat from Danish Coal Fired CHP Units (Vattenfall)	2008	Swedish Environmental Management Council	Industry/ Associations	http://www.klimatdeklaration.se/Documents/decl/CD152.pdf
EDP Otelfinger Kompogas Biomass (Axpo)	2008	Swedish Environmental Management Council	Industry/ Associations	http://www.environdec.com/reg/epd176.pdf
EDP of Electricity from Torness Nuclear Power Station (British Energy)	2009	British Energy/ AEA	Industry/ Associations	http://www.british-energy.com/documents/Torness_EPD_Report_Final.pdf

3 Methodology

This report is a secondary research compilation of literature in which lifecycle GHG emissions associated with electricity generation have been accounted for. To be included within this compilation, the source needed to meet the following requirements:

- Be from a credible source. Studies published by governments and universities were sought out, and industry publications used when independently verified.
- Clearly define the term "lifecycle" used in the assessment. Although the definition of lifecycle can vary, to be considered credible, the source needed to clearly state what definition was being used.
- Include nuclear power generation and at least one other electricity generation method. This would ensure that the comparison to nuclear was relevant.
- Express GHG emissions as a function of electricity production (e.g. kg CO_2e/kWh or equivalent). This would ensure that the comparison across electricity generation was relevant.

Figure 1 summarizes the number of literature sources evaluated for each generation method.



*iii, iv, v, vi, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi, xvii, xviii, xix, xx, xxi, xxii, xxiii

Figure 1: Number of Sources for each Generation Type

4 Summary of Assessment Findings

Lifecycle GHG emissions for the different electricity generation methods are provided in Table 2 and shown graphically in Figure 2. Although the relative magnitude of GHG emissions between different generation methods is consistent throughout the various studies, the absolute emission intensity fluctuates. This is due to the differences in the scope of the studies.

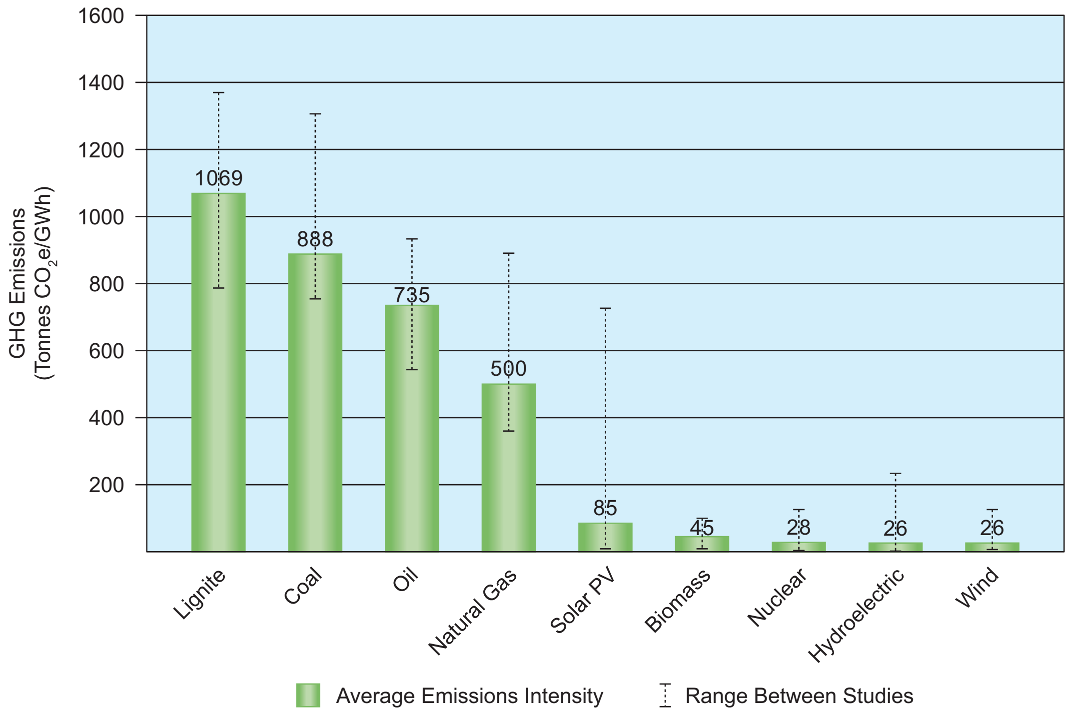
The most prominent factor influencing the results was the selection of facilities included in the study. Emission rates from power generation plants are unique to the individual facility and have site-specific and region-specific factors influencing emission rates. For example, enrichment of nuclear fuel by gaseous diffusion has a higher electrical load, and therefore, lifecycle emissions are typically higher than those associated with centrifuge enrichment. However, emissions can vary even between enrichment facilities dependant upon local electrical supply (i.e. is electricity provided by coal fired power plants or a low carbon source).

Another factor influencing results was the definition of lifecycle. For example, some studies included waste management and treatment in the scope, while some excluded waste. When the study was completed, also led to a broader range in results, and was most prevalent for solar power. This is assumed to be primarily due to the rapid advancement of solar photovoltaic panels over the past decade. As the technology and manufacturing processes become more efficient, the lifecycle emissions of solar photovoltaic panels will continue to decrease. This is evident in the older studies estimating solar photovoltaic lifecycle emission to be comparable to fossil fuel generation methods, while recent studies being more comparable to other forms of renewable energy. The range between the studies is illustrated within the figure.

Technology	Mean	Low	High
	tonnes CO_2e/GWh		
Lignite	**1,054**	790	1,372
Coal	**888**	756	1,310
Oil	**733**	547	935
Natural Gas	**499**	362	891
Solar PV	**85**	13	731
Biomass	**45**	10	101
Nuclear	**29**	2	130
Hydroelectric	**26**	2	237
Wind	**26**	6	124

*iii, iv, v, vi, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi, xvii, xviii, xix, xx, xxi, xxii, xxiii

Table 2: Summary of Lifecycle GHG Emission Intensity



*iii, iv, v, vi, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi, xvii, xviii, xix, xx, xxi, xxii, xxiii

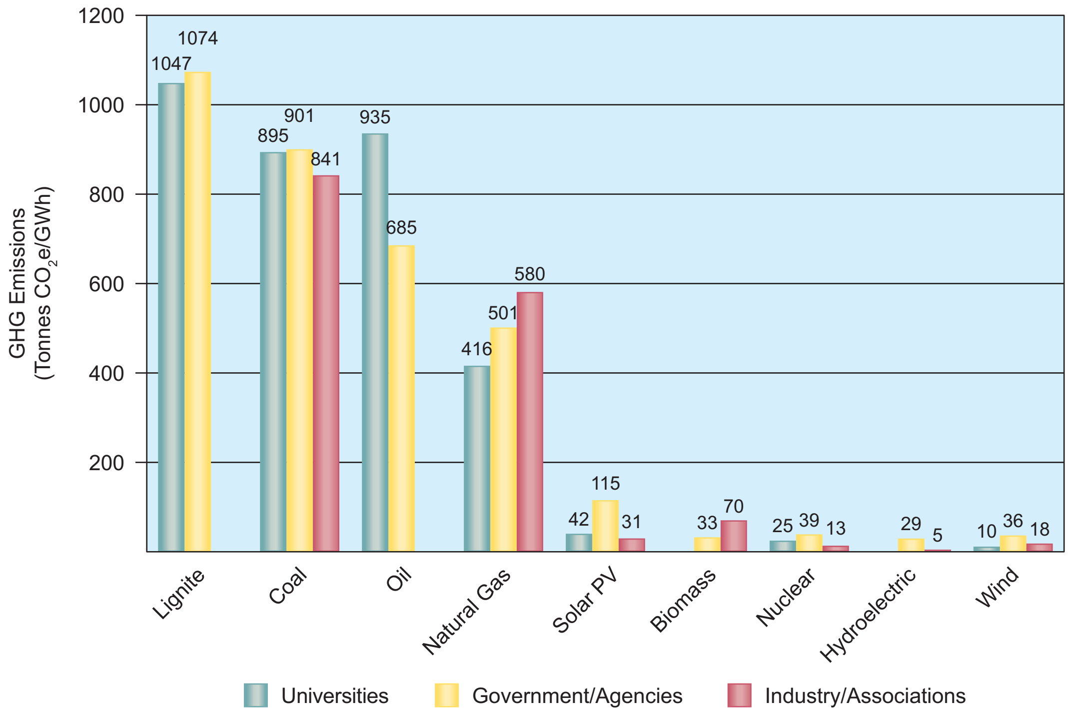
Figure 2: Lifecycle GHG Emissions Intensity of Electricity Generation Methods

Coal fired power plants have the highest GHG emission intensities on a lifecycle basis. Although natural gas, and to some degree oil, had noticeably lower GHG emissions, biomass, nuclear, hydroelectric, wind, and solar photovoltaic all had lifecycle GHG emission intensities that are significantly lower than fossil fuel based generation.

Nuclear power plants achieve a high degree of safety through the defence-in-depth approach where, among other things, the plant is designed with multiple physical barriers. These additional physical barriers are generally not built within other electrical generating systems, and as such, the greenhouse gas emissions attributed to construction of a nuclear power plant are higher than emissions resulting from construction of other generation methods. These additional emissions are accounted for in each of the studies included in Figure 2. Even when emissions from the additional safety barriers are included, the lifecycle emissions of nuclear energy are considerably lower than fossil fuel based generation methods. Averaging the results of the studies places nuclear energy's 30 tonnes CO2e/GWh emission intensity at 7% of the emission intensity of natural gas, and only 3% of the emission intensity of coal fired power plants. In addition, the lifecycle GHG emission intensity of nuclear power generation is consistent with renewable energy sources including biomass, hydroelectric and wind.

Figure 3 illustrates source evaluation data by study group. Using linear regression, the coefficient of correlation between industry and university sources was 0.98, between industry and government was 0.98, and between university and government was 0.95. This shows that emission intensities are consistent regardless of the data source.

Figure 4 illustrates averaged source data subdivided into those organizations specializing in nuclear energy and those groups specialising in other energy options and those addressing energy in general.



*iii, iv, v, vi, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi, xvii, xviii, xix, xx, xxi, xxii, xxiii

Figure 3: Comparison of LCA Results Between Sources

The main difference between the two sets of results is that on average the nuclear specialist studies tend to have somewhat lower LCA GHG emissions, particularly for fossil fuels. However, the overall conclusions with regards the comparative emissions of fossil fuels, nuclear and renewables are consistent.

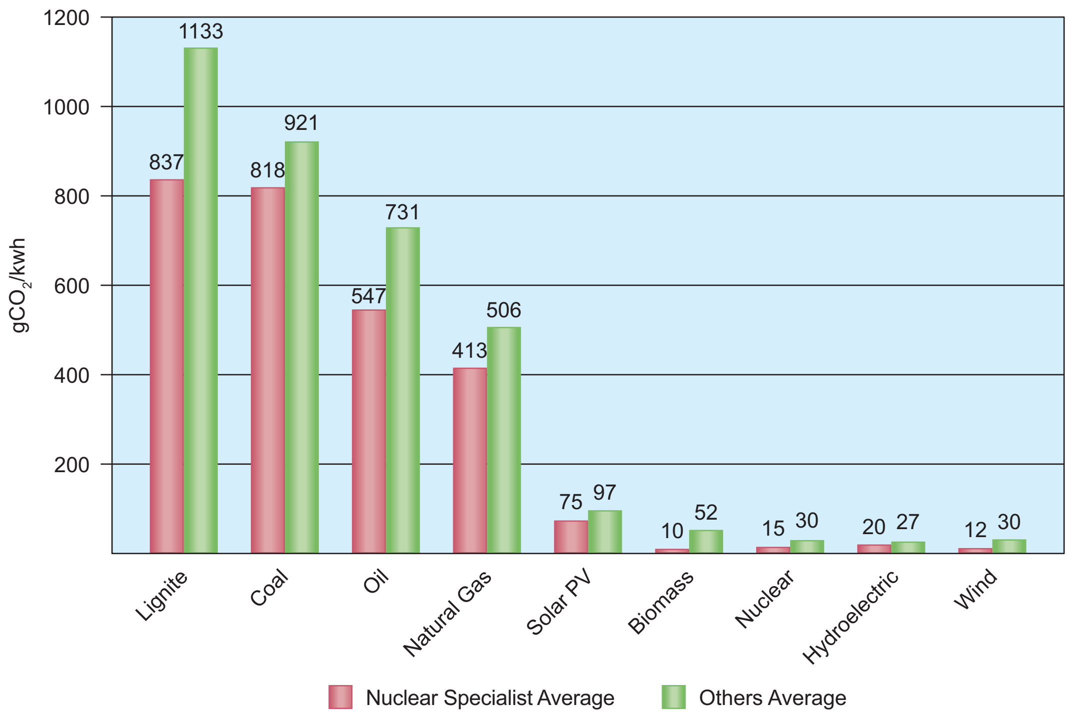


Figure 4: Comparison of LCA Results between nuclear specialists and other sources

5 Conclusions

Based on the studies reviewed, the following observations can be made:

- Greenhouse gas emissions of nuclear power plants are among the lowest of any electricity generation method and on a lifecycle basis are comparable to wind, hydro-electricity and biomass.
- Lifecycle emissions of natural gas generation are 15 times greater then nuclear.
- Lifecycle emissions of coal generation are 30 times greater then nuclear.
- There is strong agreement in the published studies on life cycle GHG intensities for each generation method. However, the data demonstrates the sensitivity of lifecycle analysis to assumptions for each electricity generation source.
- The range of results is influenced by the primary assumptions made in the lifecycle analysis. For instance, assuming either gaseous diffusion or gas centrifuge enrichment has a bearing on the life cycle results for nuclear.

6 Acknowledgement

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