# LIFE CYCLE ASSESSMENT ANALYSIS OF COAL VERSUS NUCLEAR POWER IN LEVY COUNTY, FLORIDA

By

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To my loving parents who have supported me throughout all of my academic endeavors

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LIST OF ABBREVIATIONS

| | |
|---|---|
| 1,4-DB | 1,4-dichlorobenzene |
| ADF | Abiotic Depletion Factor |
| AMD | acid mine drainage |
| AP | Acidification Potential |
| APME | Association of Plastics Manufacturers in Europe |
| $C_2H_4$ | ethylene |
| CFC-11 | trichlorofluromethane |
| CML | Centre of Environmental Science |
| $CO_2$ | carbon dioxide |
| COL | Combined License |
| DfE | Design for Environment |
| EA | Environmental Assessment |
| EIS | Environmental Impact Statement |
| EPS | Environmental Priority System |
| eq | equivalent |
| FAETP | Ecotoxicity Potential |
| GaBi 4.4 | Gabi 4.4 Software System and Database |
| GHG | greenhouse gases |
| GWP | global warming potential |
| GWP 100 | global warming potential over the span of 100 years |
| HHS | Health Hazard Scoring |
| HTP | Human Toxicity Potential |
| IPCC | Intergovernmental Panel on Climate Change |

| | |
|---|---|
| ISO | International Organization for Standardization |
| kWh | kilowatt hours |
| kg | kilograms |
| LCA | Life Cycle Assessment |
| LCC | Life Cycle Costing |
| LCI | Life Cycle Inventory |
| LCIA | Life Cycle Impact Assessment |
| MIPS | Material Input Per Service-unit |
| MW | megawatts |
| MWd-th | thermal megawatt-days |
| MWh | megawatt hours |
| N | Nitrogen |
| NEPA | National Environmental Policy Act |
| $NO_x$ | nitrogen oxides |
| PM | particulate matter |
| $PO_4$ | phosphate |
| POCP | Photochemical Ozone Creation Potential |
| PWR | pressurized water reactor |
| RAINS | Regional Air Pollution Information and Simulation |
| Sb | antimony |
| SEP | Swiss Eco-point |
| SLCA | Social Life Cycle Assessment |
| $SO_2$ | sulfur dioxide |

| | |
|---|---|
| TRACI | Tool for the Reduction and Assessment of Chemical and other Environmental Impacts |
| UNECE | United Nations Economic Commission for Europe |
| U.S. | United States |
| U.S. EIA | United States Energy Information Administration |
| U.S. EPA | United States Environmental Protection Agency |
| USES-LCA | Uniform System for the Evaluation of Substances adapted for LCA |
| U.S. NRC | United States Nuclear Regulatory Commission |
| UV-B | Ultraviolet B |
| WMO | World Meteorological Organization |

Abstract of Thesis Presented to the Graduate School
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LIFE CYCLE ASSESSMENT ANALYSIS OF COAL VERSUS NUCLEAR POWER IN LEVY COUNTY, FLORIDA

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In a world of rising pollution it is imperative to reduce environmental impacts from all sectors. Life Cycle Assessment (LCA) studies can be used to determine which processes and products produce less severe environmental impacts based on certain environmental impact categories. LCA is a scientific and informative tool that can be used by many practices for decision making and to aid in support, development, and implementation of policies. The use of LCA studies has occasionally been used in the practice of urban and regional planning but there is more room to increase the use of this methodology, allowing for more informed decisions on large scale projects that have significant environmental and community impacts.

In pursuit of reducing greenhouse gas (GHG) emissions, Progress Energy Florida is in the process of switching approximately 1,105 megawatts (MW) of their electricity generation from coal to nuclear power. To approximate the differences of environmental impacts that will be seen from the changing fuel mix, two LCA studies were conducted using different methodologies to determine if switching from coal to nuclear power will be more environmentally friendly, as intended. Overall, nuclear

power produces less severe environmental impacts. Nuclear power may produce more severe impacts in the depletion of the ozone and water quality. While data provided from LCAs are valuable, LCAs should not be the sole source of data for making decisions. Significant decisions should be based on social, cultural, and economic factors and analyses. The current tool of evaluating the impacts from proposed nuclear plants is an Environmental Impact Statement (EIS). An EIS is more costly and timely than a LCA but it provides site specific information and considers the social, economic, and environmental pillars of sustainability. These two tools are great supplements for one another. LCAs and EISs can be used as tools in determining which energy source should be pursued into the future.

# CHAPTER 1
# INTRODUCTION

Throughout history societies have died out due to due to over using their natural resources. Although the term “sustainability” has not always been used in the past, the idea of not over exploiting natural resources in order to sustain life and practices has been noted. In 1713, the German Hans-Carl von Carlowitz published his book titled “Sylvicultura Oeconomica,” (Kloepffer 2008). While foresting, Carlowitz noted that the high demand for timber during those times led to the forests being greatly degraded. He outlined the basic law of sylviculture, saying that more wood should not be used than what can be replaced in the long run and how if this is not followed there will be environmental, social, and economic consequences. During the past century, human consumption of natural resources has increased exponentially leading to the current political climate having a strong focus on sustainability. While there is now a term and widely recognized definition for sustainable development, the underlying ideas are the same as in Hans-Carl von Carlowitz’s book. The most coined definition of sustainable development first appeared in 1987 by the Brundtland Commission (Kloepffer 2008). The definition is, “development that meets the needs of the present without compromising the ability for future generations to meet their own needs,” (Kloepffer 2008).

Sustainable development has three equally weighted pillars: society, economy, and the environment (Kloepffer 2008). In order to achieve sustainable development all three of these pillars must be met. To determine if these pillars are met there must be appropriate and reliable tools to measure each pillar. A tool to measure social sustainability is being developed. This tool will be known as Social Life Cycle

Assessment (SLCA) (Kloepffer 2008). Life Cycling Costing (LCC) and Life Cycle Assessment (LCA) can be used to measure economic and environmental sustainability, respectively (Kloepffer 2008). LCA is an already internationally standardized tool for measuring environmental impacts. This methodology will be looked at in detail and applied to the case study of the Levy Nuclear Plant in Levy County, Florida.

LCA studies have been used in various fields of work to compare different products and processes. A LCA is the investigation and valuation of the environmental impacts of a given product or service caused or necessitated by its existence. LCA requires the assessment of raw material extraction, processing, manufacturing, distribution, use and disposal, including all intervening transportation steps necessary or caused by the product's existence to calculate environmental impacts (PE International 2010).

In efforts to reduce greenhouse gas (GHG) emissions and move towards more environmentally friendly energy sources, Progress Energy Florida is pursing the construction of two state-of-the-art 1,105 MW Westinghouse AP1000 pressurized water reactors (PWR) (Environmental News Service 2009). In August of 2009, the Florida Cabinet approved Progress Energy's proposal for the Levy Energy Complex comprised of the 2 new nuclear reactors (Environmental News Service 2009).

After the Levy Energy Complex is completed, Progress Energy will be required to retire its two oldest coal-fired units at the Crystal River Energy Complex in Citrus County, which together generate approximately 965 MW (Environmental News Service 2009). In essence, one of the new nuclear units will replace the two older coal-fired units, plus produce 140 MW of additional energy. The second nuclear unit will be providing an additional 1,105 MW, for a total increase of 1,245 MW of electricity production. This additional energy supply is stated as needed to help meet future rises in energy demand from an increasing population.

The retiring of the two coal-fired power plants is estimated to reduce Progress Energy's carbon dioxide ($CO_2$) emissions by more than 5,000,000 tons per year (Progress Energy 2010). This reduction in emissions is estimated to be an equivalent of removing more than 830,000 vehicles from Florida's roads.

While $CO_2$ emissions will be reduced from the switching fuel mix, there will be also be other environmental factors that will be impacted. Progress Energy Florida prepared an Environmental Impact Statement (EIS) to go through potential environmental, social, and economic implications due to the construction and operation of the two proposed nuclear units. The goal of my study was to utilize the LCA methodology to estimate the anticipated difference in environmental impacts that will be seen from Progress Energy switching part of their fuel mix from coal to nuclear power. The two power sources were compared based on their environmental impacts according to LCA tools. Two LCA programs were utilized. The first was SimaPro 7.1 Multiuser, using the Centre of Environmental Science (CML) methodology. GaBi 4.4 Software System and Database (GaBi 4.4) was the other LCA software used and the processes were examined using the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) methodology.

The use of an EIS and LCA were then compared to help determine their usefulness in the urban planning community. Information on environmental impacts between different products and processes can help planners make more educated, science-based planning decisions.  This LCA case study delves into some of this tool's opportunities.

# CHAPTER 2
# LITERATURE REVIEW

## Background

This literature review begins with background information on why environmental issues related to energy are such an important topic and Florida's current energy mix. After providing information on energy in Florida, this literature review goes into some of Progress Energy Florida's plans for future energy, environmental impacts, a tool for looking at environmental impacts, and how these tools relate to urban planning.

## Greenhouse Gases

In 2009, the U.S relied on fossil fuels to provide approximately 69% of their electricity demands (Figure 2-1) (United States Energy Information Administration (U.S. EIA) 2011). Fossil fuels were formed during the Carboniferous Period, part of the Paleozoic Era through a process of compressing decaying trees and plants under layers of sediment for millions of years, squeezing out the water and preserving the carbon and hydrogen compounds of the plants, and turning them into natural gas, coal, or oil (California Energy Commission 1994; Cocks 2009). When fossil fuels are combusted for electricity generation, the carbon, hydrogen, particles, and more that the fuels have stored for millions of years are released into our air, water, and soil. This is very significant, with approximately 33% of the nation's total greenhouse gas (GHG) emissions coming from the electric power sector according to the United States Environmental Protection Agency (U.S. EPA) (Progress Energy 2010). The pollution from electricity generation has added pressures onto our ecosystems and atmosphere. Many concerns have been raised about the overuse of fossil fuels. Some of these concerns include diminishing supplies of fossil fuels, dependence on foreign nations, rising electricity costs, human and environmental health impacts, and creation of GHG emissions and air pollution, which has been named as probable causes for climate change.

The issue of climate change is of particular importance to Florida. With its wealth of sandy beaches, coral reefs, rich marine ecosystems, the Everglades, fishing, springs, and endless natural beauty, Florida has more than 18 million residents and draws millions of more individuals into the state every year through tourism (U.S. Census Bureau 2011). In the business-as-usual case, Florida's residents and tourism economy will suffer greatly. With rising sea temperatures and levels, Florida is at risk of losing the Keys, coastal cities, the Everglades, beaches, mangroves, the coral reefs, and numerous native species (Ackerman and Stanton 2007). Not only will Florida lose parts of its land where citizens reside but also incomes will be impacted from loss of tourism (Ackerman and Stanton 2007). With losing a portion of eco-tourism within Florida and its temperature estimated to rise almost 10ºF over the next century, the already hot and sticky Florida weather is likely to look less appealing to the out of state visitors that make 85 million trips to Florida every year (Ackerman and Stanton 2007).

While it will take a global effort to slow down climate change, Florida is beginning to do its part to reduce emissions that are contributing to climate change. Reducing the production of GHGs is possible through certain actions. The first and most important tool to address these issues is reducing energy consumption. Reducing energy consumption is the first priority to meeting energy demands but Florida also needs to sequester more carbon and utilize energy sources that release less or no GHG emissions.

## Florida's Energy

With Florida's large population comes a large demand for energy. Florida consumes the third largest amount of energy in the U.S (U.S. Energy Information Administration (EIA) 2008). In 2010, the per capita kilowatt hour (kWh) usage equaled 12,379 kWh (California Energy Commission 2011). This is slightly higher than the U.S. average of 12,146 kWh per capita. This average per capita energy use is contributed to having relatively low energy use within the industrial sector and high energy use within the residential sector.

Currently Florida relies on fossil fuels to provide approximately 86% of their electricity demands (Figure 2-3) (U.S. EIA 2011). The remaining energy demand is supplied primarily by nuclear power and a small amount from renewable energies. Florida is the only state that still uses petroleum-fired power plant to produce electricity (U.S. EIA 2011). Three percent of Florida's electricity is produced in this manner, which is the most highly polluting fossil-fueled energy supply (U.S. EIA 2011).

The concerns of climate change have led efforts to diversify energy generation methods and to utilize sources that contribute less to climate change and pollution through releasing less GHG emissions. One way of reducing GHG emissions from electricity generation is to move towards energy sources that release smaller amounts of emissions per unit of production. With coal-fired power plants being one of the highest carbon emitters it is important to steer away from coal as a source of electricity generation (Cocks 2009). Natural gas has been noted as a "bridge fuel" or a fuel that works as a transition from coal to emission free sources but natural gas still produces GHG emissions. Renewable energy sources such as solar, wind, and hydropower are electricity generation methods that do not produce GHG emissions during electricity generation and are listed as ways to reduce GHG emissions (U.S. EIA 2011). In addition to those renewable energy methods, nuclear power does not produce GHG emissions during electricity production. Although a nuclear power plant has not been built in the U.S in over three decades, it is once again being looked at as a viable electricity source that can aid our country in reducing our GHG emissions (U.S. EIA 2011).

Progress Energy has stated their commitment to reducing GHG emissions within Florida through constructing two nuclear power plant units and retiring two coal-fired power plant units once construction is complete. Progress Energy Florida's president and chief executive officer Vincent M. Dolan said, "Carbon-free nuclear power is a strategic asset in our statewide effort to become energy-independent, to reduce our reliance on more volatile-priced fossil fuels, and to provide a balanced approach to meet the challenges of growth and climate change" (Progress Energy 2009).

**Progress Energy Florida**

Progress Energy Florida serves approximately 1.6 million customers with a population of over 5 million people in Florida (Progress Energy 2010). Their territory covers 20,000 square miles in central Florida (Figure 2-4) (Progress Energy 2010).

Progress Energy uses a mix of nuclear, coal-fired, oil-fired, and natural gas-fueled power plants to provide electricity for its consumers (Progress Energy 2010). Progress Energy owns 5 oil-fired, 4 coal-fired, 1 nuclear, and 56 natural-gas fueled power plants on 14 different sites within Florida. The combined capacity of all 66 units is 10,013 megawatts (MW) of electricity (Table 2-1) (Progress Energy 2010).

With the concerns about climate change, Progress Energy is actively working to reduce GHG emissions. In 2010, Progress Energy included a section titled "Climate

Change" in their Corporate Responsibility Report (Progress Energy 2010). This section of their report addresses their view on climate change. They believe that with a carbon restricted energy future it is imperative that they reduce their GHG emissions (Progress Energy 2010). Progress Energy's strategy for addressing climate change while also meeting their growing customer demand includes three parts (Progress Energy 2010). The first part is aggressive energy efficiency via improving existing infrastructure and processes and ensuring high energy efficiency in future endeavors (Progress Energy 2010). Innovative renewable and alternative energy is the second part with state-of-the-art power plants and delivery systems being the third part (Progress Energy 2010). One way they are moving forward with these steps includes increasing their use of nuclear energy to meet future energy needs (Progress Energy 2010). This is as an alternative to pursuing more fossil fueled energy sources. Nuclear energy is currently the only large-scale, base load electricity generation method that emits no carbon dioxide ($CO_2$) and is a viable option for Florida (Progress Energy 2010).

**Progress Energy Florida in the Future**

In Progress Energy's "2010 Corporate Responsibility Report" they stated that they are trying to reduce their GHG emissions to do their part in addressing climate change issues (Progress Energy 2010). They have set a goal of at least minimizing their $CO_2$ emissions to 42% below 2005 levels of $CO_2$ emissions by year 2030 (Figure 2-5) (Progress Energy 2010). This target goal set for 2030 is based on current climate change policy proposals (Progress Energy 2010). To meet this goal, Progress Energy must make significant reductions in their $CO_2$ emissions.

Progress Energy's $CO_2$ emissions peaked in 2005 (Progress Energy 2010). $CO_2$ makes up primarily all of their GHG emissions (Progress Energy 2010). Since 2005, Progress Energy has been reducing their emissions partly from the economic downturn and partly from the company's balanced strategy for emissions reductions (Progress Energy 2010). Their 2009 emissions were the lowest in more than a decade. Even with the reductions Progress Energy has made, they still have a far way to go to meet their 2030 target of 42% below 2005 $CO_2$ emissions.

In August of 2009, the Florida Cabinet approved Progress Energy's proposal for the Levy Energy Complex comprised of 2 new nuclear reactors (Environmental News Service 2009; Progress Energy 2010). It was the first nuclear facility that has made it through state approval since 1976 (Environmental News Service 2009). The new power plant's site is approximately 5,200 acres in Levy County and is only 8 miles north of Progress Energy's other nuclear reactor in Florida, the Crystal River Energy Complex in Citrus County (Figure 2-6) (Progress Energy 2010). The site was chosen based on its access to the already existing electric transmission system, sufficient quantities of water available from the Gulf of Mexico, its large land area, and overall environmental considerations (Progress Energy 2010). State-of-the-art 1,105 MW Westinghouse AP1000 pressurized water reactors (PWR) were chosen for the new energy complex (Progress Energy 2010).

Major construction on the Levy County Power Plant is being postponed until the federal licensing process is completed, which is expected to be completed by the earliest in late 2012 (Progress Energy 2010). Once approved, construction will resume and is estimated to be completed in 2016 (Progress Energy 2011).

After the Levy Energy Complex is completed, Progress Energy will retire its two oldest coal-fired units at the Crystal River Energy Complex in Citrus County

(Environmental News Service 2009). The retirement of the two coal-fired units must occur by December 31, 2020, assuming timely licensing and construction, according to a requirement that the Siting Board made upon approval of the new complex (Environmental News Service 2009). The oldest coal-fired plant at the Crystal River Energy Complex began providing service in 1966 and it produces 440.5 MW (Power Plant Jobs 2002). The complex's second oldest coal-fired plant produces approximately 523.8 MW and was built in 1969 (Power Plant Jobs 2002). Assuming the coal-fired power plants maintain the same level of efficiency, approximately 965 MW of electricity will be removed from the grid as a result of the decommissioning of the two coal-fired units. With each nuclear reactor having the ability to produce 1,105 MW, just one of the reactors will be used as a replacement for the lost electricity production from the retirement of the coal-fired units. Even with replacing the two coal units, the first nuclear unit will provide approximately 140 MW more energy than what was previously being produced. The second nuclear unit will be providing an additional 1,105 MW for a total increase of 1,245 MW of electricity production. This additional energy is stated as needed to help meet the future increase in energy demand from increasing population (Progress Energy 2011).

The retiring of the two coal-fired power plants is estimated to reduce Progress Energy's $CO_2$ emissions by more than 5 million tons per year (Environmental News Service 2009). This reduction in emissions is estimated to be an equivalent of removing more than 830,000 vehicles from Florida's roads (Environmental News Service 2009). While $CO_2$ emissions will be reduced there will also be numerous other changes to environmental impacts with this changing fuel mix.

## Environmental Impacts

According to the U.S. Environmental Protection Agency (EPA) an environmental impact is, “the effect of an activity or substance on the environment,” (U.S. EPA 2011). The impacts that energy sources have on the environment are numerous and occur throughout the many phases that are required to produce electricity including material extraction, transportation, material processing, disposal, and more.

In order to obtain a construction permit and operating license all nuclear power plants within the U.S are required to submit an Environmental Impact Statement (EIS) to the United States Nuclear Regulatory Commission (U.S. NRC) (U.S. NRC 2010). An EIS is a detailed document that is required by the National Environmental Policy Act (NEPA) for certain projects or actions that will “significantly affect the quality of the human environment” (U.S. NRC 2010). If the proposed action may not lead to “significant” environmental impacts than an Environmental Assessment (EA) may be required instead of a full EIS (U.S. NRC 2010). If it is found that a significant impact is possible after an EA than a full-scale EIS is required under U.S environmental law (U.S. NRC 2010). EAs and EISs describe both probable negative and positive environmental impacts as a result of a proposed action. The reports are used as decision making tools and do not prohibit the proposed action, even if severe environmental impacts are anticipated.

An EIS has four main sections. The first section goes into the purpose and need for the proposed action. The second is a description of anticipated impacts as a result of the proposed action. Environmental, social, and economic impacts are included in this section. The third section goes into possible alternatives including different sites and potential alternatives if the proposed action is not completed. For example, the EIS alternatives section completed for the Levy Nuclear Plant included alternative sites, as well as alternative energy sources. The alternative energy sources ranged from oil-fired power plants to renewable energies. The forth section includes the analyses of these alternative actions.

EISs are extremely detailed reports, often ranging from thousands to tens of thousands of pages. The EIS for the Levy Nuclear Plant is nearly 1,500 pages. These reports require the work of environmental and economic experts and introduce scientific procedures into the political decision making process. Overall, as a decision making tool an EIS is great for providing comprehensive and detailed, site specific information. However, compiling the data and writing an EIS is extremely timely and costly. It can take years to complete one. In the planning field it is not always possible to take such a timely and costly approach to determine environmental impacts. Various other environmental impact assessment tools can be utilized to more quickly gain information on potential environmental implications.

## Measuring Environmental Impacts

There are multiple methods to measure environmental impacts including Life Cycle Assessment (LCA), Design for Environment (DfE), Health Hazard Scoring (HHS), the Material Input Per Service-unit (MIPS), the Swiss Eco-point (SEP), and the Environmental Priority System (EPS) (Hertwich et al.1997). Both LCA and DfE concentrate on developing an inventory of emissions and raw materials required throughout the life cycle of a product or process, from material extraction till entering the waste stream (Hertwich et al.1997). The HHS calculates accident risks in the workplace along with giving weight to workplace toxic effects (Hertwich et al.1997). MIPS calculates the total mass of all material inputs required to produce a product or process

(Hertwich et al.1997). SEP scores pollutant loadings based on a source's environmental scarcity factor and an acceptable contribution to total pollution (Hertwich et al.1997). The EPS illustrates environmental damage caused by equivalency potentials and is expressed in monetary terms, derived from environmental economics (Hertwich et al.1997).

To adequately reach the goal of my study, in calculating the environmental impacts from producing electricity from coal and nuclear power, the LCA methodology was chosen. This was the chosen method based on its focus of purely environmental impacts, the availability of numerous LCA software programs, and the reasonable time frame it takes to complete a LCA.

## Life Cycle Assessment

A LCA is the investigation and valuation of the environmental impacts of a given product or service caused or necessitated by its existence (PRé Consultants 2006). The International Organization for Standardization (ISO) defines LCA as "the compiling and evaluation of the inputs and outputs and the potential environmental impacts of a product system during a product's lifetime," (PE International 2010). LCA requires the assessment of raw material extraction, processing, manufacturing, distribution, use and disposal, including all intervening transportation steps necessary or caused by the product's existence (Figure 2-7) (PRé Consultants 2006). The sum of all the phases is the life cycle of the product (PRé Consultants 2006).

## What is Calculated in a Life Cycle Assessment?

One of the required steps in conducting a LCA is choosing relevant impact categories that are consistent in reaching the goal and scope of the study. The two methodologies that were chosen for my study include the Centre of Environmental

Science (CML) baseline 2000 impact methodology and the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) methodology. Each methodology has impact categories that cover a range of environmental impacts, including air, water, and soil pollution (Table 2-2).

For the CML methodology the impact categories of the assessed damages include Global Warming Potential (GWP), Acidification, Smog, Ozone Layer Depletion, Eutrophication, Eco-Toxicological and Human-Toxicological Pollutants, and Abiotic Depletion.

The Abiotic Depletion category is concerned with extraction of minerals and fossil fuels from inputs for the system and how these extractions relate to ecosystem health, human health, and human welfare (PRé Consultants 2006). In my study the inputs of the system would be any minerals and fossil fuels required for the methods of electricity generation that Progress Energy Florida uses. To quantify these impacts an Abiotic Depletion Factor (ADF) is calculated for each mineral and fossil fuel extraction based on reserves concentration and rate of deaccumulation at the global scale (PRé Consultants 2006). Abiotic Depletion is measured in kilograms (kg) of antimony (Sb) equivalent (eq) per kg extraction.

The Acidification category is concerned with the impacts on soil, groundwater, surface water, organisms, ecosystems, and materials from acidifying substances over a time span of infinity and geographic scale varying from local to continental (PRé Consultants 2006). Using the adapted Regional Air Pollution Information and Simulation (RAINS) 10 model, describing the fate and deposition of acidifying substances, the Acidification Potential (AP) is calculated (PRé Consultants 2006). Acidification is measured in kg of sulfur dioxide ($SO_2$) eq per kg emission.

The Eutrophication impact category is also known as nitrification. It is concerned with the emissions of nutrients to the air, water, and soil from excessive levels of macronutrients in the environment (PRé Consultants 2006). Eutrophication is quantified using the stoichiometric procedure of Heijungs (1992) and referred to as Nitrification Potential (NP) (PRé Consultants 2006). The impacts are looked at over a time span of eternity with the geographic scale ranging from the local to continental scale (PRé Consultants 2006). Eutrophication is measured in kg of phosphate ($PO_4$) eq per kg emission.

The GWP impact category is concerned with climate change from GHG emissions to the air at the global scale (PRé Consultants 2006). This characterization model was developed by the Intergovernmental Panel on Climate Change (IPCC) (PRé Consultants 2006). The impacts are quantified by their GWP over the span of 100 years (GWP 100). GWP is measured in kg of $CO_2$ per kg emission.

Ozone Layer Depletion is the impact category that is concerned with the depletion of the stratospheric ozone layer at the geographic scale of global and the time scale of infinity (PRé Consultants 2006). The depletion of the stratospheric ozone layer allows more Ultraviolet B (UV-B) radiation to reach the earth's surface which can have adverse effects on human and animal health, terrestrial and aquatic ecosystems, biochemical cycles, and materials (PRé Consultants 2006). This characterization model was developed by the World Meteorological Organization (WMO) and defines the potential of ozone depletion from different gasses (PRé Consultants 2006). This impact category is based on IPCC factors (PE International 2010). Ozone Layer Depletion is measured in kg of trichlorofluromethane (CFC-11) eq per kg emission.

Human Toxicity is concerned with the effects on the human environment from toxic substances at both the local and global geographic scales over a time span of infinity (PRé Consultants 2006). Health risks from the working environment are not included. Human Toxicity is quantified using Uniform System for the Evaluation of Substances adapted for LCA purposes (USES-LCA), describing fate, exposure and effects of toxic substances to reach their Human Toxicity Potential (HTP) (PRé Consultants 2006). Human Toxicity is measured by 1,4-dichlorobenzene (1,4-DB) eq per kg of emission.

The impact category Fresh Water Aquatic Ecotoxicity is concerned with the impacts that emissions of toxic substances to the air, water, and soil have on fresh water ecosystems (PRé Consultants 2006). The impacts are looked at from the global, continental, regional, and local scales over an infinite time period (PRé Consultants 2006). Fresh Water Aquatic Toxicity is quantified using the Uniform System for the Evaluation of Substances adapted for LCA purposes (USES-LCA), describing fate, exposure and effects of toxic substances to reach their Ecotoxicity Potential (FAETP) (PRé Consultants 2006). Fresh Water Aquatic Ecotoxicity is measured in 1,4-DB eq per kg emission.

Marine Aquatic Ecotoxicity is calculated in the same way as Fresh Water Aquatic Ecotoxicity but is concerned with the impacts that toxic substance emissions to the air, water, and soil have on marine ecosystems (PRé Consultants 2006). Marine Aquatic Ecotoxicity is measured in 1,4-DB eq per kg emission.

The impact category Terrestrial Ecotoxicity is also calculated in the same way as Fresh Water Aquatic Ecotoxicity but is concerned with the impacts of toxic substances on terrestrial ecosystems (PRé Consultants 2006). Terrestrial Ecotoxicity is measured in 1,4-DB eq per kg emission.

Photochemical Oxidation is concerned with photo-oxidant formation that is the formation of reactive substances (mainly ozone) that have adverse impacts on human health, ecosystems, and crops (PRé Consultants 2006). This impact category is calculated using the United Nations Economic Commission for Europe (UNECE) Trajectory model to reach the Photochemical Ozone Creation Potential (POCP). The geographic scale varies from the local to continental scale for a time span of 5 days (PRé Consultants 2006). Photochemical Oxidation is measured in kg of ethylene ($C_2H_4$) eq per kg emission.

The environmental impact categories for the TRACI methodology are Global Warming Air, Ozone Depletion Air, Acidification Air, Eutrophication for Air and Water, Smog Air, Human Health Cancer for Air and Water, Ecotoxicity for Air and Water, and Human Health Criteria Air-Point Source (PE International 2010). Most of the impact categories are the same as the CML methodology. However, in the CML methodology there is only one category calculating the human health impacts (PE International 2010). In the TRACI methodology, the human health impacts are broken down into impacts for both air and water that are cancerous and non-cancerous.

To calculate these impact categories the inputs, outputs, and processes during the entire life cycle of a process are assessed. Before calculating the impact categories the life cycle of the processes of coal and nuclear power must be understood.

## Life Cycle of Producing Electricity from Coal

Coal is a solid that has the least amount of hydrogen per carbon atom of the fossil fuels (Cocks 2009). Coal is obtained primarily from surface and underground mining and is transported, normally by train or barge to power plants. Once at a power plant the raw coal is processed and burned to create steam , the steam spins a turbine to generate electricity (Figure 2-8) (Frumpkin 2010). During each step of the life cycle inputs and outputs can be identified and evaluated. The environmental impacts that result in the material extraction, transportation, processing, and combustion stages of generating electricity from coal are significant.

Perhaps the most environmentally damaging stage of the life cycle of coal for electricity production is material extraction, disturbing large areas of land while also potentially impacting neighboring land areas and water sources (Miller 2005). Mining coal can result in numerous environmental damages including polluting bodies of water, generation of acid mine drainage (AMD), fugitive dust emissions, and creation of large amounts of waste rock (Miller 2005). To begin with, obtaining coal is a tedious process of tearing up the earth; sometimes mountains are even destroyed, resulting in ecosystem and habit loss. Surface mines, typically less than 200 feet from the surface, create less environmental damage in getting to the coal (Miller 2005; Frumpkin 2010). However, they cause major problems with generation of AMD and possibly polluting underground and surface water sources if they are within the vicinity (Miller 2005; Frumpkin 2010). Pollution of water bodies is a serious problem because the water bodies may be used as a source for drinking (Frumpkin 2010).

After coal is mined the environmental damages continue with transportation and processing, requiring substantial energy and releasing GHG emissions (Miller 2005).

Coal is primarily transported by rail but it is also sometimes transported by truck, barge, slurry pipeline, or conveyor (Miller 2005).

Florida does not mine any of its own coal, so it relies on coal to be imported from other states. Approximately 46% of Florida's imported coal comes from Kentucky, approximately 34% comes from West Virginia, approximately 16% from Illinois, and the remaining coal comes from Pennsylvania, Virgina, Utah, and Colorado (Figure 2-9 and Table 2-3) (U.S. EIA 2010). Approximately 56.5% of the coal travels to Florida by railroad, an approximate distance of 775 miles. The remaining 43.5% travels to Florida on barges, an average distance of 900 nautical miles. Which state the coal comes from is dependent on the price. The travel method of the coal is dependent on the origin of the coal. Coal from Illinois and Western Kentucky primarily travels to Florida by barge, while coal from the eastern states travels to Florida by rail (U.S. EIA 2010).

During the transportation and loading processes, damage can be done to natural systems and infrastructure while also causing pollution (Miller 2005). The pollution generated is due to the emissions given off from the transportation method and fugitive dust that is given off during the coal's journey (Miller 2005). Depending on the mode of transportation and length of journey, coal loses an estimated 0.05% to 1% of coal during transit (Miller 2005).

Once the coal reaches its destination at the coal-fired power plant more damage is done to the environment from storing and processing the coal. However, the outputs generated from combusting the coal are the most environmentally damaging. The combustion of coal releases many emissions which are perhaps one of the greatest drawbacks of using coal for electricity generation. The main outputs include $CO_2$, $SO_2$, nitrogen oxides ($NO_x$), and particulate matter (PM) including ash and soot (Cocks 2009; Miller 2005). Carbon monoxide, water vapor, and nasty contaminants such as selenium, mercury, uranium oxides, and thorium oxides are also released but on smaller scales (Cocks 2009; Miller 2005).

In addition to releasing particulates and gases into the air, combustion of coal also produces solid by-products that must be addressed (Miller 2005). These by-products include fly ash, bottom ash, and boiler slag (Miller 2005). Fly ash is a by-product that is collected by fabric bag filters and used in the manufacturing of concrete; other uses of by-products include mine back-filling, agriculture uses, blasting grit, and wallboard production (Miller 2005). The remaining 70% of by-products that do not have another use are disposed of as waste (Miller 2005).

In addition to environmental health impacts from the production of electricity from coal, there are numerous human health impacts from producing electricity from coal. Coal mining has been noted as one of the most dangerous occupations. From 1985 to 1995 more than 100,000 miners died from occupational causes (Miller 2005). Injury and death rates from accidents were extremely high until recent decades when efforts have gone into improving safety for miners (Miller 2005). By 2002 deaths rates were drastically reduced, having 20 occupational deaths during that year (Miller 2005). While the fatality and injury rates have greatly decreased, coal mining is still noted as one of the most dangerous jobs with many job related health risks such as explosions from natural gas, injuries, nonmalignant respiratory disease and more (Frumpkin 2010).

One of the most significant health risks from mining coal is a non malignant respiratory disease known as coal workers pneumoconiosis or black lung (Miller 2005).

The lung disease is developed through dust penetrating and accumulating in the lungs from breathing in coal dust (Frumpkin 2010). Workers can experience difficulty breathing, coughing, and weakness which can progress even after exposure to the coal dust has ended (Frumpkin 2010).

In addition to the serious health problems associated with mining coal, combusting coal also causes adverse health effects to humans. Serious health risks are associated with coal-fired power plants from the release of GHGs and particulates and the formation of nitrogen oxides ($NO_x$) and sulfur oxides (Frumpkin 2010). Health impacts related to the $NO_x$ and sulfur oxides include respiratory and eye irritation, asthma, cardiopulmonary disease, and cancer (Frumpkin 2010). Increased risk for atherosclerosis, dysrhythmias, deep vein thrombosis, and sudden cardiac death are all cardiovascular health effects associated with the particulates that are released during coal combustion, posing serious risks to workers and neighbors of coal-fired power plants (Frumpkin 2010). In addition to the adverse health effects to the cardiovascular system, the particulates that are released also have been shown to cause respiratory effects, including decreased lung function and increased incidence of chronic obstructive pulmonary disease (Frumpkin 2010). Overall, numerous and serious health effects are associated with electricity generation from coal. The problems affect not only coal workers but the public as well.

## Life Cycle of Producing Electricity from Nuclear Power

Energy can be produced both from the fusing together of light elements and fissioning apart heavy elements (Cocks 2009). Nuclear power is generated through the later, fissioning heavy elements such as uranium (Cocks 2009). When uranium is broken apart it releases some of the energy that was used when it was fused together

(Cocks 2009). When uranium-235 is broken apart and hit with a neutron it forms uranium-236, a very unstable atom (Cocks 2009). This atom quickly splits into smaller atoms and one to three neutrons, releasing lots of energy (Cocks 2009). The released neutrons can then continue the process by breaking apart other U-235 atoms (Cocks 2009). When the energy is released from the fissioning, heat is also released; that heat is used to boil water and generate steam to spin a turbine to produce electricity (Figure 2-10) (Cocks 2009).

Mining uranium poses environmental risks of releasing radioactive dust, mine water seepage, and creation of large amounts of mine waste containing low levels of radioactivity (Consortium on Energy Restructuring 2007). Once uranium is obtained it is processed. The next stage, processing, creates toxic metal, chemical, radiological, and radioactive waste (Consortium on Energy Restructuring 2007). Transporting uranium both before and after use poses environmental hazards of releasing radioactive particles into the environment (Consortium on Energy Restructuring 2007).

Nuclear power plants release no emissions into the atmosphere but the major output it does produce is highly dangerous. After the uranium-235 is used for electricity generation the spent fuel must be stored in its fuel rods in highly secure locations for hundreds of thousands of years until they are no longer radioactive (Cocks 2009). The challenges in assuring that the enormous radioactivity of the spent fuel is securely contained with no risks of escape, is perhaps the greatest disadvantage of nuclear power generation (Fay and Golomb 2002). If an accident were to occur at a nuclear power plant, in transportation of the spent fuel, or in storage of the used fuel rods it could result in the release of large amounts of radioactive particles which could result in massive environmental and human health impacts (Consortium on Energy Restructuring 2007).

The human health impacts from the mining, refinement, and transport of uranium all pose some form of occupational hazards to the workers (Frumpkin 2010). Injuries, nonmalignant pulmonary diseases such as silicosis, and several cancers including lung cancer, lymphoma, and leukemia are risks associated with the mining of uranium through exposure to the radioactive substance (Frumpkin 2010). These health impacts have not been seen in the communities surrounding uranium mining (Frumpkin 2010).

Exposure to uranium in nuclear power plants has other risks; the workers show increased rates of cancer and preliminary evidence of a small risk increase of circulatory disease (Frumpkin 2010). Communities adjacent to nuclear power plants may have slightly higher risk for childhood blood cancers (Frumpkin 2010).

Nuclear power is also known as being hazardous to human health from several high-profile nuclear incidents in the past such as Three Mile Island and Chernobyl (Frumpkin 2010). Chernobyl was the largest nuclear accident, with a reactor exploding causing acute and chronic health impacts (Frumpkin 2010). The most significant health impacts were acute radiation sickness and pediatric thyroid cancers, along with acute and chronic mental health effects (Frumpkin 2010). Since these accidents, the safety of nuclear power plants has drastically improved (Frumpkin, 2010).

The main output of nuclear electricity production is the spent fuel. Transport and storage of the spent fuel rods raises concerns over site contamination and radiation exposure even though there are significant safeguards to prevent contamination (Frumpkin 2010).

## Life Cycle Assessment in Planning

LCAs currently are primarily performed within the private sector. However, LCA studies have been completed within the public sector to aid in urban planning decisions. LCA studies can be used as a planning tool by both the public and private sectors to help make scientific and educated decisions. LCA has been used in numerous contexts by industry, governments, and education. LCA studies can be used within the industrial context. Large and small corporations can use LCA studies to identify areas of environmental concern caused by their processes or products (PE International 2010). Identifying these areas can provide insight on which environmental areas can achieve the greatest improvements. Strategic planning can be implemented to achieve the improvements in the environmental sectors of concern. Industries also use LCA to help determine which materials or processes can be used to produce the least amount of environmental impacts. Companies that utilize LCA sometimes also market their environmental management strategies and show how their products or processes are better than alternatives (PE International 2010). Governments can utilize LCA studies for data collection, developing more effective environmental policies, aiding in decision making, creating policies to meet environmental mandates, determining which sectors of the environment need remediation or preventative measures to protect or restore environmental integrity, and more (PE International 2010). Many universities use LCA methodology for research and education (PE International 2010). LCA software can be used to aid in support, development, and implementation of policies while it can also be used to help meet regulations (PE International 2010).

The basis of urban planning is preparing policies and plans to provide for present needs while also preparing the community for the future. With the world's growing population it is imperative to consider environmental impacts when making urban planning decisions. Without considering the environment when making planning decisions we risk polluting the environment or over using natural resources. This can lead to detrimental effects such as severe human health impacts and leading to land becoming inhabitable, both scenarios have been seen in the past. In order to avoid or minimize environmental impacts it is important to plan for them. When making urban planning decisions they are typically many options to choose from. The goal of a planner is to choose the option that will provide the greatest benefits to the population with the fewest costs. To achieve this goal it is extremely important for urban planners to have as much information about potential options. A LCA is a planning tool to provide crucial information for decision making about alternative future scenarios. It is important to know the environmental impacts of various options in order to make informed decisions that will greatly impact the future. The data from LCAs are displayed by different impact categories to further improve the usefulness of the data. Planners can use this information to determine which environmental impacts will be the easiest or most cost effective to prevent or remediate. If the LCA says that one source causes a lot of pollution to one section the planner can take that information and help prevent or mitigate impacts. Planners can take data from LCA studies to help make informed decisions about alternative scenarios for the future.

In addition to helping make future decisions, data from LCA studies could also be used to determine where environmental remediation is needed from prior decisions. With pollution levels rising, new policies have been and are coming out to mandate the reduction of pollution from facilities that are known to cause large amounts of pollution.

Power plants are just one type of facility that are mandated on pollution levels. If changing to a different source or option is not feasible and reductions need to be made, LCA studies can provide information that can aid in the decision making process of where remediation needs to occur. LCA studies not only have the option of breaking up environmental impacts into different categories. There is also the option of seeing at which stage of a production or procedure environmental impacts are occurring the most. Knowing when and what kind of environmental impacts are occurring can lead to more informed decisions on which areas and what kind of remediation needs to be done to reduce pollution.

Overall, LCA studies can be used by urban planners as a technical environmental tool to make informed decisions based on environmental impacts. This tool can be used to determine where potential environmental remediation needs to occur from prior decisions and it can be used to compare alternative future scenarios to determine which will provide residents the greatest benefits at the least cost.

**Summary**

Pollution and overuse of natural resources has led to a focus on sustainable development. In order to develop sustainably, the three pillars of sustainability must all be met, economy, society, and environment. This case study solely focuses on the environmental pillar. To determine the anticipated and potential environmental impacts of the construction and operation of the proposed Levy Nuclear Plant the government required an EIS to be submitted to the NRC. This document is extremely detailed and site specific providing a great decision making tool. However, compiling the data and writing the report is timely and costly. Alternative environmental impact measuring methodologies were explored and it was found that the LCA methodology has the potential to provide detailed and quantified environmental impact information as another form of a decision making tool.

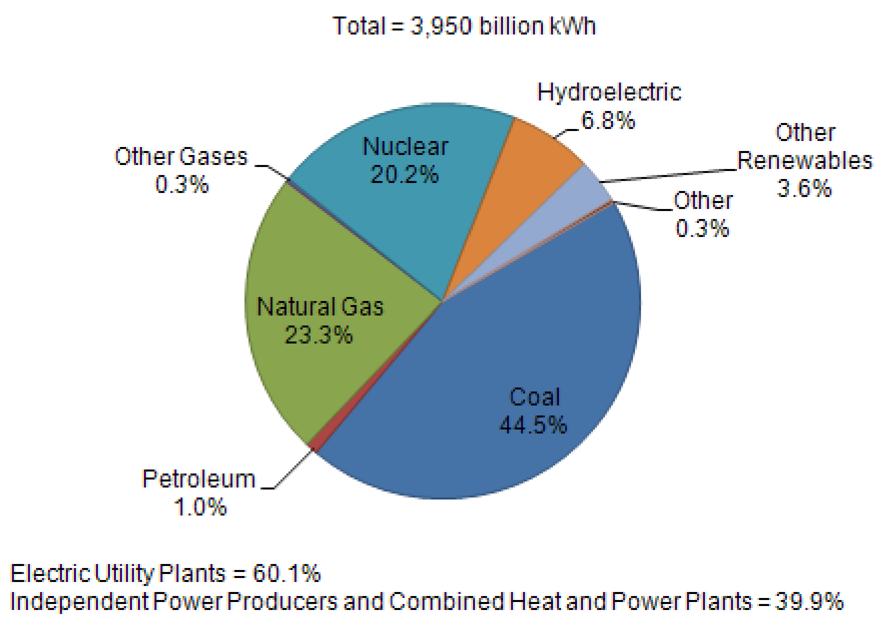


Figure 2-1. U.S. electricity power sources, 2009 (Adapted from U.S. EIA 2010)

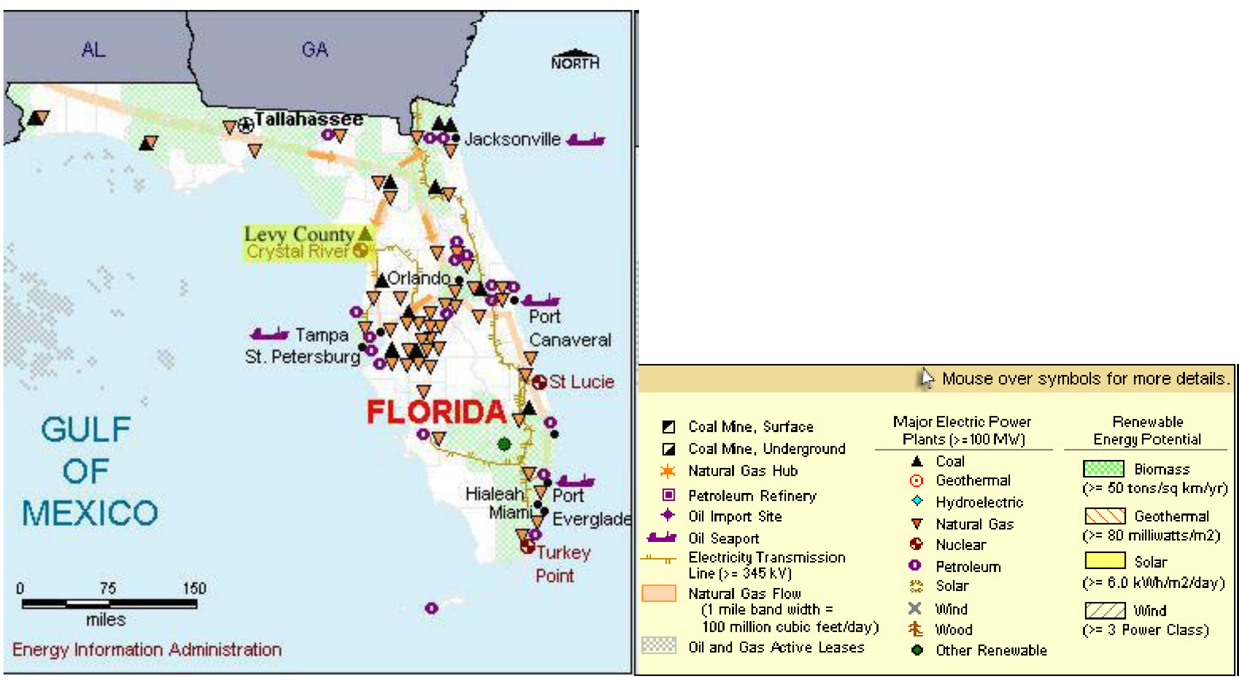

Figure 2-2. Florida energy sources (Adapted from EIA 2010)

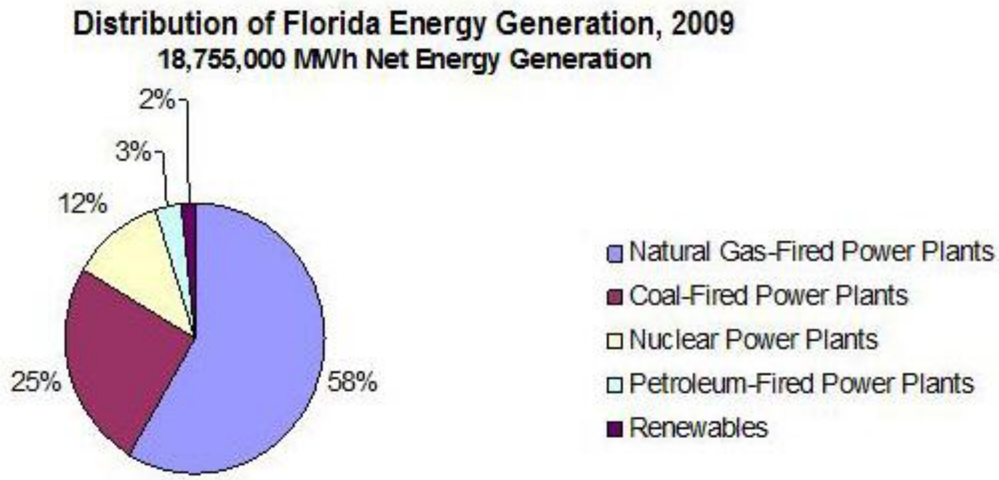


Figure 2-3. Distribution of Florida energy generation for 2009 (Adapted from U.S. EIA 2010)


Figure 2-4. Progress Energy's Florida territory and power plants (Adapted from Progress Energy 2010)

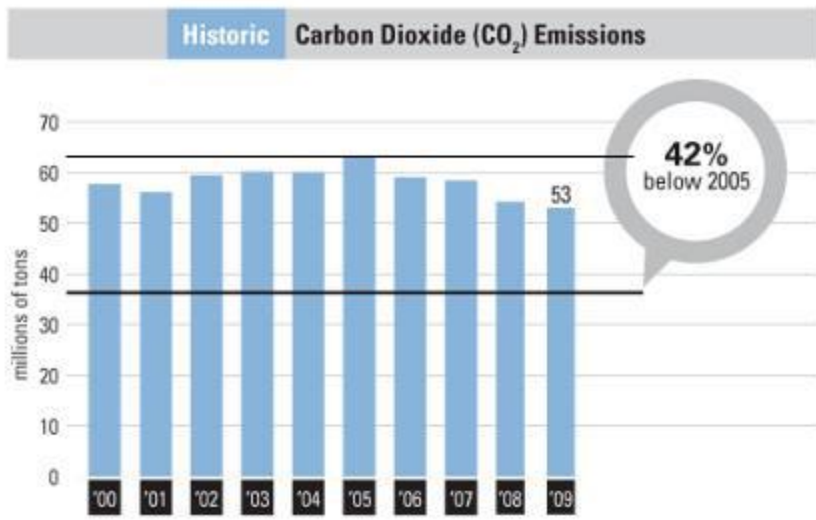


Figure 2-5. Historic carbon dioxide ($CO_2$) emissions for Progress Energy (Adapted from Progress Energy 2010)


Figure 2-6. Proposed Levy County power plant site (Adapted from Progress Energy 2010)

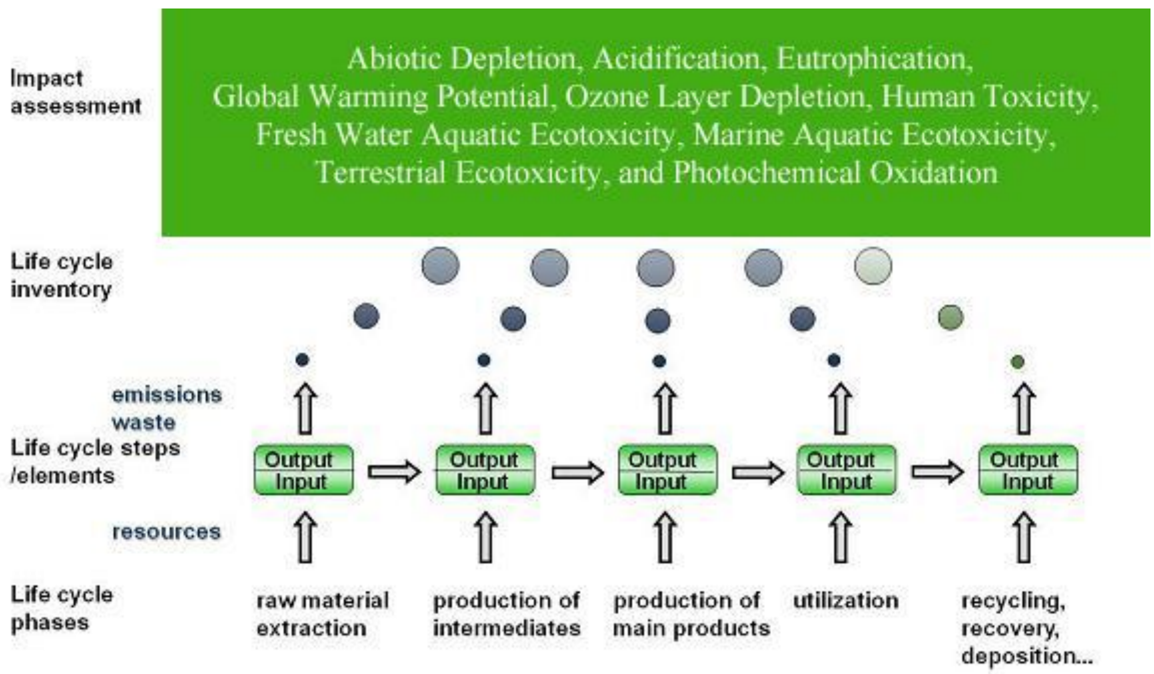


Figure 2-7. Overview of Life Cycle Assessment (Adapted from PE International 2010)

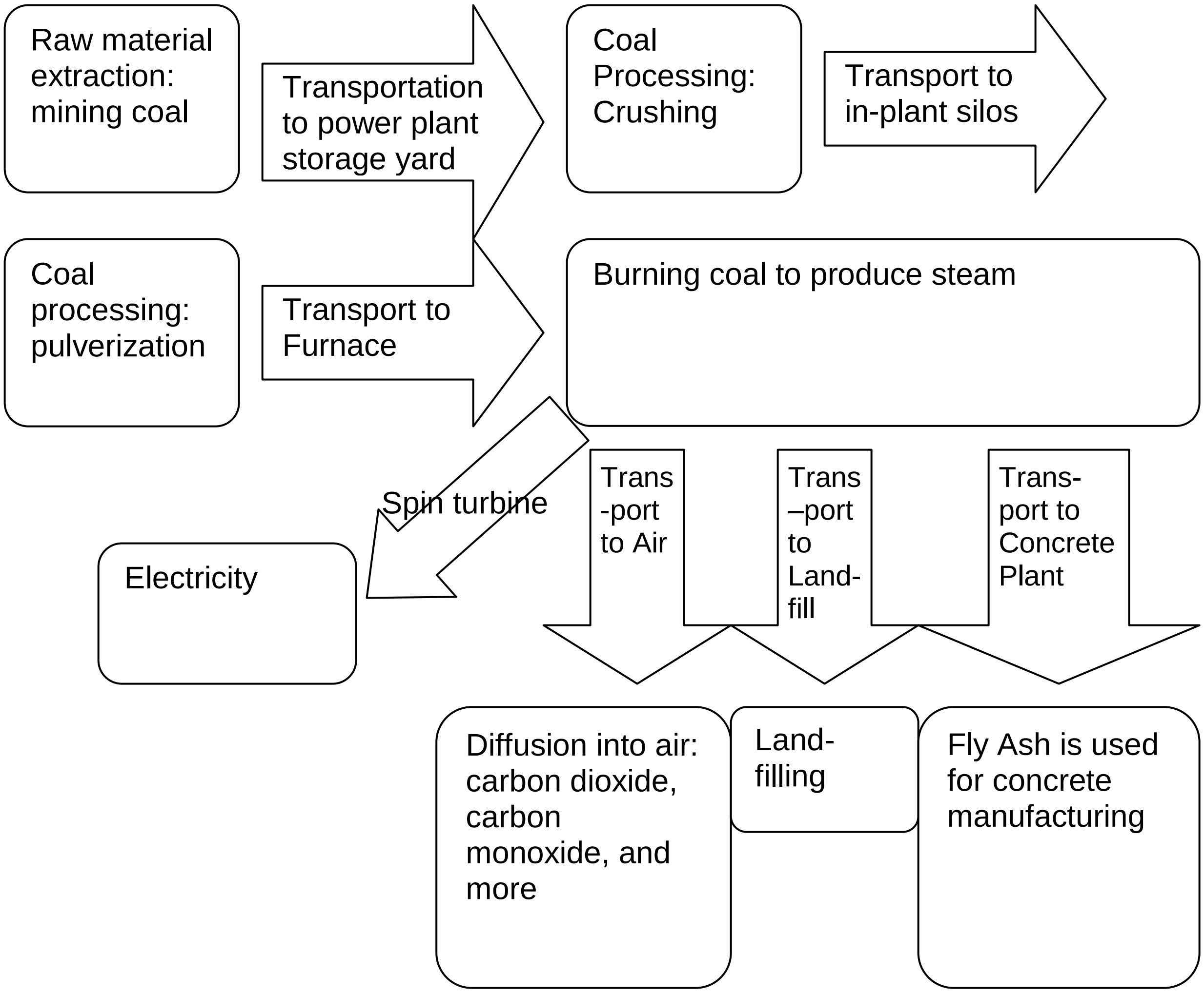


Figure 2-8. Life cycle of coal for electricity production

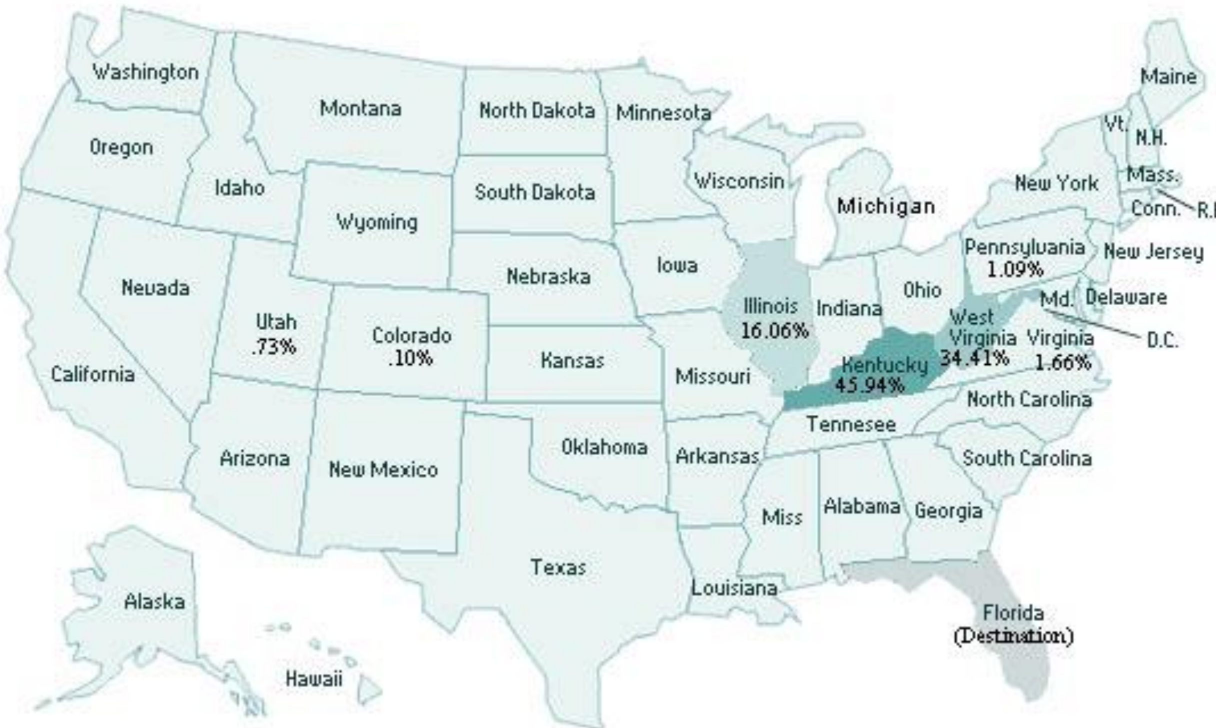


Figure 2-9. U.S. map depicting states supplying coal to Florida (Adapted from Chinese English Dictionary and Study Center 2007)

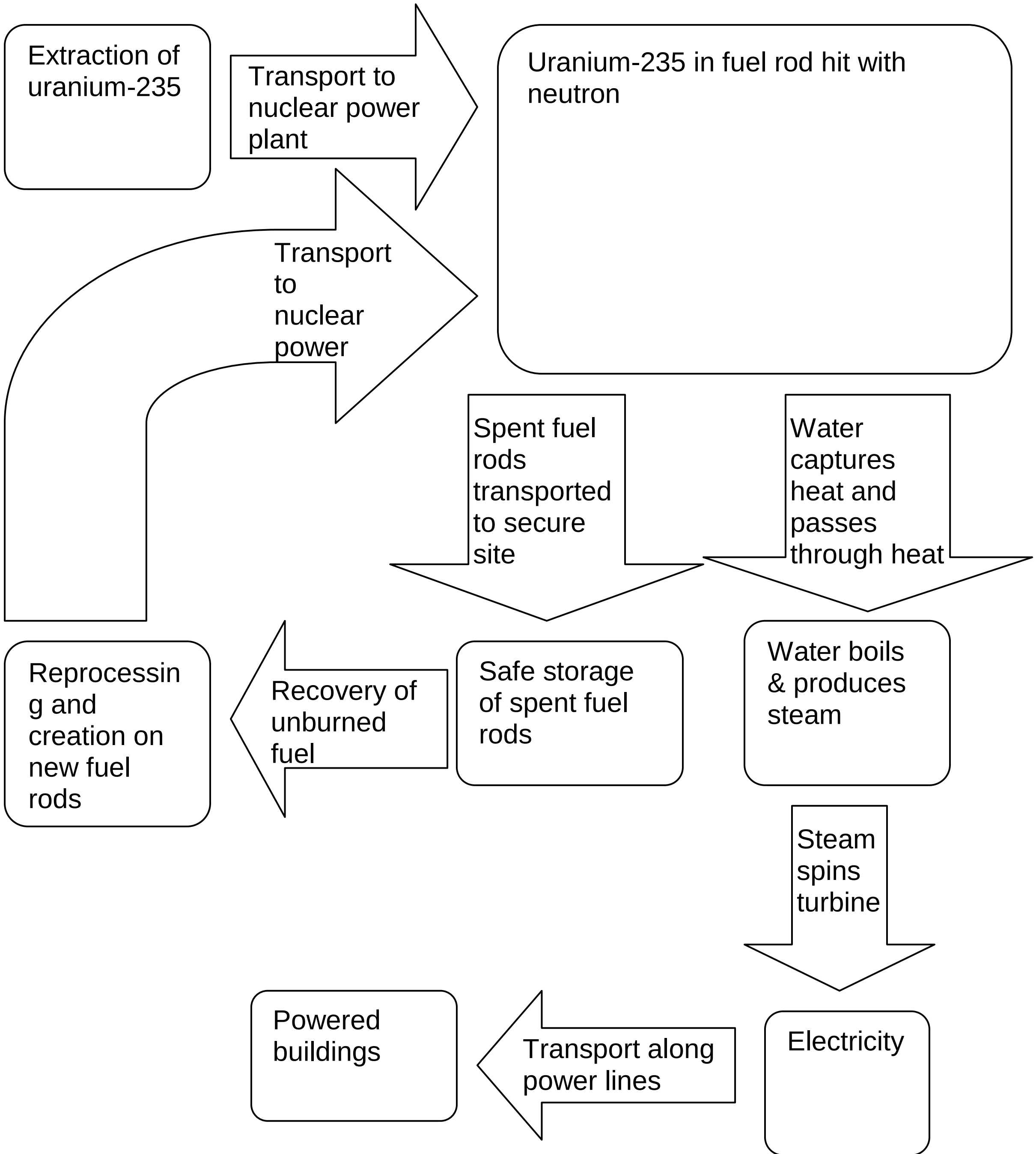


Figure 2-10. Life cycle of uranium in producing electricity by nuclear power

Table 2-1. Progress Energy's Florida power plants

| Source | Capacity (MW) | Number of Units | Location |
|---|---|---|---|
| Steam (oil) | 1,011 | 2 | Anclote |
| Steam (oil) | 131 | 3 | Suwannee |
| Sum steam (oil) | 1,142 | 5 | |
| Steam (coal) | 2,267 | 4 | Crystal River |
| Sum steam (coal) | 2,267 | 4 | |
| nuclear | 860 | 1 | Crystal River |
| Sum nuclear | 860 | 1 | |
| Combustion (natural gas) | 153 | 3 | Suwannee |
| Combustion (natural gas) | 642 | 10 | DeBary |
| Combustion (natural gas) | 147 | 4 | Turner |
| Combustion (natural gas) | 12 | 1 | Rio Pinar |
| Combustion (natural gas) | 980 | 14 | Intercession City |
| Combustion (natural gas) | 48 | 2 | Avon Park |
| Combustion (natural gas) | 174 | 4 | Bayboro |
| Combustion (natural gas) | 178 | 4 | Bartow |
| Combustion (natural gas) | 114 | 4 | Higgins |
| Combustion (natural gas) | 46 | 1 | University of Florida (cogeneration) |
| Sum combustion (natural gas) | 2494 | 47 | |
| Combined-cycle (natural gas) | 205 | 1 | Tiger Bay |
| Combined-cycle (natural gas) | 1,912 | 4 | Hines |
| Combined-cycle (natural gas) | 1,133 | 4 | Bartow |
| Sum combined-cycle (natural gas) | 3,250 | 9 | |
| Sum (natural gas) | 5,744 | 56 | |
| Total of all Sources | 10,013 | 122 | |

Table 2-2. Centre of Environmental Science (CML) and the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) impact categories with units (Adapted from PE International 2010)

| CML Impact Category | Unit | TRACI | Unit |
|---|---|---|---|
| Abiotic Depletion | kg Sb eq | Human health criteria air-point source | kg PM2,5 eq |
| Acidification Potential | kg $SO_2$ eq | Acidification air | mol H+ eq |
| Eutrophication Potential | kg $PO_4$ eq | Eutrophication (air and water) | kg N eq |
| Global warming (GWP100) | kg $CO_2$ eq | Global warming air | kg $CO_2$ eq |
| Ozone Layer Depletion | kg CFC-11 eq | Ozone Layer Depletion | kg CFC-11 eq |
| Human Toxicity | kg 1,4-DB eq | Human health cancer (air and water) | kg Benzene eq |
| Ecotoxicity (Marine Aquatic, Fresh Aquatic, and Terrestrial) | kg 1,4-DB eq | Ecotoxicity (air and water) | kg 2,4-Dichloro-phenoxyace |
| Photochemical Oxidation | kg $C_2H_4$ | Smog Air | kg $NO_x$ eq |
| | | Human Health Non Cancer (Air and Water) | kg Toluene eq |

Table 2-3. Coal supply and transportation to Florida, 1st Quarter of 2010

| Origin State | Coal Distribution by Railroad (Thousand Short Tons) | Coal Distribution by Barge (Thousand Short Tons) | Coal Distribution Total (Thousand Short Tons) | Supply to Florida by Rail | Supply to Florida by Barge | Total |
|---|---|---|---|---|---|---|
| Colorado | 0 | 6 | 6 | 0.00% | 0.10% | 0.10% |
| Illinois | 0 | 985 | 985 | 0.00% | 16.06% | 16.06% |
| Kentucky | 2337 | 481 | 2818 | 38.10% | 7.84% | 45.94% |
| Pennsylvania | 67 | 0 | 67 | 1.09% | 0.00% | 1.09% |
| Utah | 0 | 45 | 45 | 0.00% | 0.73% | 0.73% |
| Virginia | 102 | 0 | 102 | 1.66% | 0.00% | 1.66% |
| West Virginia | 961 | 1150 | 2111 | 15.67% | 18.75% | 34.41% |
| Totals | 3467 | 2667 | 6134 | 56.52% | 43.48% | 100.00% |

# CHAPTER 3
# METHODOLOGY

## Why Progress Energy Florida?

Huge potentials exist in Florida for decreasing greenhouse gases (GHGs) within the energy sector. Some energy sources that produce little to no GHGs include solar, wind, hydropower, and nuclear. Out of these sources, nuclear energy is the only large-scale, base load electricity generation method that emits no carbon dioxide ($CO_2$) (Progress Energy 2010). Other sources such as wind and solar do not provide electricity at the same scale as nuclear power. Progress Energy is currently in the process of finishing the approvals to construct two nuclear power units (Progress Energy 2011). Once the construction of the units is completed, Progress Energy will be committed to retiring their two oldest coal-fired units at their Crystal River Power Plant location (Progress Energy 2010). Progress Energy's literature on the changing fuel mix states that part of their reasoning of doing this is to move towards energy sources that emit less pollution and are better for the environment. While they stated this, there is limited information on how much the environmental impacts will be decreased. Wanting to obtain this information led to my study.

## Choosing Life Cycle Assessment Programs

Various Life Cycle Assessment (LCA) software and databases were considered for use in my study. The initial list of possible programs was taken from the non-endorsed listing of LCA software and databases from the United States Environmental Protection Agency (U.S. EPA) website shown in Table 2-1. The programs were narrowed down to two based on if the program provided life cycle information on coal and nuclear power, their availability, and their cost. Two programs were used rather than one so that the results of the programs could validate and be compared to one another. In addition to increasing validity of the study, two programs were desired so different methodologies were able to be used. The table below shows the software and databases listed on the U.S. EPA site and their criteria listings. Descriptions on how the programs were assessed based on their criteria listing is explained following the table.

The databases and software were first narrowed down to include only those programs containing life cycle data for energy sources. Containing life cycle data for energy sources was a nonnegotiable feature within the programs because without these data the study's validity would be compromised. The discrediting of the study would be based on the inability to accurately gather all environmental inputs, outputs, and flows for the complex processes of electricity generation from coal and nuclear power within the timeframe of my study. The databases and software that were still in the running are the programs that have an "O" under the Energy Data column. The top choice programs, shown with an "O" under the Top Choice column, were the databases and programs that had the most to offer to this project beyond having energy data. The program features that were looked for in addition to having energy data include ease of use, adequate manuals, amount of data, and detailed data specific to the United States (U.S.). Eco-Indicator 99, the ecoinvent Centre, and ECO-it 1.3 were not selected as top programs because all three are included within the SimaPro software, making it unnecessary to consider them as separate tools (PRé Consultants 2006). The Boustead Model 5.0, GaBi 4.4 Software System and Databases (GaBi 4.4), GEMIS (Global Emission Model for Integrated Systems), Life-Cycle Inventory Database, SimaPro 7, and Umberto were the top choices for programs. The top choice programs were then looked at based on their costs to see if they would be financially feasible for the study. The Boustead Model 5.0 and Umberto were both eliminated as possible programs because they were not financially feasible, which was based on being able to use the program for under $100. The remaining top four choices are described below.

1. The GaBi 4.4 Software System and Databases was created by PE Europe GmbH and IKP University of Stuttgart (U.S. EPA 2010). GaBi 4.4 calculates life cycle environmental, economic and social profiles of products, processes and technologies via Life Cycle Analysis (U.S. EPA 2010). The software contains worldwide data, Ecoinvent data, and the comprehensive GaBi 4.4 database (U.S. EPA 2010).

2. GEMIS was created by Öko-Institut (U.S. EPA 2010). The life cycle analysis program and database is for energy, material, and transport systems (U.S. EPA 2010).

3. The Life-Cycle Inventory Database was created by the Centre of Environmental Science (CML) (U.S. EPA 2010). The program can estimate Life Cycle Inventory (LCI) data with up-to-date U.S. input-out table and environmental data (U.S. EPA 2010).

4. SimaPro by PRé Consultants is a professional LCA software tool (U.S. EPA 2010). SimaPro has several inventory databases and impact assessment methods (U.S. EPA 2010). SimaPro allows for editing and customization for a particular study and allows for analysis and comparisons of complex life cycles.

After comparing the top four LCA software choices the final decision was to use GaBi 4.4 and SimaPro 7.1. GaBi 4.4 was chosen for having the Tool for the Reduction and Assessment of Chemical and Environmental Impacts (TRACI) method (PE International 2010). This method is a problem-oriented method that was developed by the U.S. EPA and has data that is specific to the U.S. (PE International 2010).

The SimaPro 7.1 software was chosen for its wide range of options, customization, and information. It was also chosen for its reputation as being the most widely accepted LCA tool (U.S. EPA 2010).

## Life Cycle Assessment Methodology by the International Organization for Standardization

The International Organization for Standardization (ISO) created standards - ISO 14040: Principles and Framework and ISO 14044: Requirements and Guidelines (PRé Consultants 2006) – for the application of LCA. The ISO 14044 standard replaced the original ISO 14041, 14042, and 14043 standards in September 2006 (PRé Consultants 2006).

A LCA includes four steps that are outlined by the ISO (Figure 3-1). Each step has strict requirements. Three different tests were done, some of which require different definitions. The first test was conducted within SimaPro, calculating the life cycle environmental impacts from producing 1,105 megawatt hours (MWh) of electricity from coal and nuclear. The second test, which was done as a sensitivity analysis to the first test, was also completed in SimaPro but tested the life cycle environmental impacts of producing 965 MWh of electricity from coal and nuclear. The third test was conducted in the GaBi 4.4 program, looking at the environmental impacts of producing 1,105 MWh of electricity from coal and nuclear. When definitions are required for proper documentation of the tests, the definitions are supplied for each test.

### Goal and Scope Definition

According to the ISO 14040 standard, the first step in conducting a LCA is defining the goal and scope of the study (PRé Consultants 2006). The goal and scope should be clearly defined and must be consistent with the intended application (PE International 2010). The goal and scope is allowed to be adjusted as needed based on the interpretation of results (PE International 2010). The goal and scope for this report is defined as follows.

**Goal definition**

The goal of my study is to determine the difference in environmental impacts that can be anticipated from Progress Energy switching part of their fuel mix from coal to nuclear power. The ISO requires that the goal must address the study's intended application, the purpose of the LCA study, the intended audience, and usage for comparative analysis (PE International 2010). The responses to these questions are the same for both the SimaPro 7.1 and Gabi 4.4 studies. The intended application of the study is to demonstrate how LCA methodology can be used within the field of urban planning. The purpose of the study is to fulfill the research needed to complete a thesis. The intended audience of the study is the academic and urban planning community. The use of the study for comparison purposes is to show the changes in environmental impacts that can be anticipated from Progress Energy's changing fuel mix.

**Scope definition**

The scope of the study defines the product or process system characteristics. The factors that are needed to be described to define the scope of the study include the following eleven descriptions: function of the process system, the functional unit, a description of the system, system boundaries, allocation procedures, impact categories and the impact assessment method, data assumptions, limitations, data quality requirements, and peer review. All of these factors were defined for the LCA of producing 1,105 MWh calculated in SimaPro 7.1, producing 965 MWh calculated in SimaPro 7.1, and producing 1,105 MWh calculated in GaBi 4.4. In some cases the factors are the same for all of the LCAs, other factors have different responses for each factor, and sometimes two of the cases will have the same response for a factor while one of the cases will have a different response.

The function of the process system is the first factor to be defined for each LCA case. The function of my study is to provide electricity to consumers.

The second factor to be defined is the functional unit. The functional unit of this process system is the quantified definition of the function of the process. The functional unit of 1,105 MWh was used for one of the SimaPro 7.1 LCAs and it was used for the LCA calculation in GaBi 4.4. The other LCA that was calculated in SimaPro 7.1 used the functional unit of 965 MWh.

Third, the description of the system, the general explanation of what information the LCA software uses to calculate the LCA, needs to be defined for the scope of the study. Since two software programs were utilized different descriptions of the system are required for each program. For SimaPro 7.1, the data that is used to calculate the LCA for producing electricity from coal is modeled from 8 coal power plants in the U.S in year 2004 (Ecoinvent Centre 2007). The process includes mining, processing, electricity production, waste, and all intervening transportation steps all based on data for U.S. coal power plants (Ecoinvent Centre 2007). For electricity produced from nuclear power the SimaPro 7.1 based its calculations off of the typical U.S. Pressurized Water Reactor (PWR) with an average burn up of 37.5 thermal megawatt-days (MWd-th) per kilogram (kg) heavy metal (Ecoinvent Centre 2007). This burn up corresponds with an average enrichment of 3.8% Uranium-235 for fuel elements, using only fresh uranium because the reprocessing of uranium is not yet permitted in the U.S (Ecoinvent Centre 2007). The life of the plant is assumed to be 40 years with an average load factor of 85%, which is based on U.S. averages (Ecoinvent Centre 2007). The material requirements are based on the Swiss PWR process by the ratio of capacity factors

(Ecoinvent Centre 2007). Transport requirements are calculated with the ecoinvent standard distances for Europe (Ecoinvent Centre 2007). The process includes the mining and processing of uranium, fuel elements, chemicals, water use (fresh from the sea and decarbonized) for cooling, electricity production, waste, and gasoline from the intervening transportation steps (Ecoinvent Centre 2007). Non-radioactive and radioactive waste streams are accounted for (Ecoinvent Centre 2007). Radioactive waste streams that are considered include spent fuel to conditioning (no reprocessing), operational low active waste for condition in the intermediate repository, and contaminated waste from dismantling (Ecoinvent Centre 2007). Radioactive wastes were calculated from the averages of all PWR units in the U.S. in 2007 (Ecoinvent Centre 2007). For Gabi 4.4, the systems were the same with the exception of using U.S. averages for material calculations in the nuclear power scenario.

Forth, the descriptions of the system boundaries, which processes are included and excluded from the system when calculating the LCA, were defined. Cradle to grave tests were completed (Figure 2-8 and Figure 2-10).

The fifth factor to be defined for the scope of the study is allocation procedures. Allocation was avoided, as recommended by the ISO.

The impact categories and the impact assessment method need to be defined as the sixth and seventh steps. For the LCAs completed in SimaPro 7.1, the CML baseline 2000 impact methodology was utilized and normalized against total output of the Netherlands in 1997. The impact categories are shown in Table 2-2. For the LCA completed in Gabi 4.4 the TRACI methodology was used.

Eighth, data assumptions must be defined for the scope of the study. For the study of producing 1,105 MWh in SimaPro 7.1 it is assumed that when 1,105 MWh of electricity is being produced by nuclear power then the amount of electricity produced by coal 965 MWh in SimaPro 7.1 it is assumed that when 965 MWh of electricity is no longer being produced by coal-powered units that it will be produced by nuclear power. For the study in GaBi 4.4 It is assumed that when 1,105 MWh of electricity is being produced by nuclear power then the amount of electricity produced by coal power by Progress Energy will decreased by 1,105 MWh. For all of the studies, it is assumed that the coal power plant efficiencies within the coal process are similar to the coal units that will be retired by Progress Energy. It was assumed that the data on inputs, outputs, flows, and transportation within the database were assumed to be accurate for my study. It was assumed that the coal-fired power plants will still be producing 965 MWh when the nuclear plant is built.

The limitations must be defined for the scope of the study as the ninth step. The nuclear power plant that Progress Energy has plans to build uses more efficient and improved technology. The averages calculated from the SimaPro database were utilized; however, that database uses historical data from earlier generations of nuclear power plants. In addition, the databases may not have all the up-to-date information on the flows from producing electricity via coal and nuclear power. In addition, the amount of electricity that will be produced by the new nuclear units does not directly correspond to the amount of electricity production that will be decreased from retiring the coal-fired power plants.

The tenth item that needs to be defined for the scope of the study is the data quality requirements.  The primary data for my study includes the output of electricity being 1,105 MWh for one of the SimaPro 7.1 studies and the Gabi 4.4 study.  The primary data for the second SimaPro 7.1 study has an electricity output of 965 MWh. The data must be specific for the U.S.

The final item that needs to be defined for the scope of the study is peer review. The study has been reviewed by the committee members, Ruth L. Steiner, Ph. D. and Dawn Jourdan, Ph. D.

**Inventory Analysis**

The second step of a LCA is the Inventory Analysis (PE International 2010). During this stage it is necessary to collect both the qualitative and quantitative data for every process in the LCA.  The type of data that is needed is energy inputs, raw material inputs, ancillary inputs, other physical inputs, products, co-products, wastes, emissions to air, water, and soil, and other environmental aspects (PE International 2010).  After the data is collected a model can be made to show all the environmental inputs and outputs during the life cycle of the product or action (PRé Consultants 2006). A list of quantified emissions and raw materials is compiled and put into a LCI table (PE International 2010).

The LCA programs used automatically generate the LCIs from the inputted processes.  Conclusions are hard to draw from LCIs because they are lengthy and each input and output is listed in a different unit.  While a LCI table is difficult to interpret it is a vital step that must be completed before the Life Cycle Impact Assessment (LCIA) phase.  Due to the length and difficulty in assessing the information from LCIs, the information gathered from them will be shown in characterization charts, explained in the Section: Impact Assessment.

**Impact Assessment**

The third step is to understand the environmental relevance for all of the inputs and outputs. This is the LCIA phase (PRé Consultants 2006). According to the ISO 14044 standards the required steps within this stage include selection of relevant impact categories, classification, and characterization (PE International 2010). Optional steps include normalization, grouping, and weighting (PE International 2010). The LCIA phase is where the environmental impacts are quantified and shown under their impact categories such as climate change and Marine Aquatic Ecotoxicity (PRé Consultants 2006). The impacts are quantified by first assigning each input and output, from the processes, an impact category; this is the characterization stage (PE International 2010). The potential impacts are then quantified according to the characterization factor for the impact category (PE International 2010). Each impact category is assigned its reference substance based on the impact category methods, the CML and TRACI methods were used for my study (PE International 2010). As an example, $CO_2$ is the reference substance for the impact category Global Warming Potential (GWP) (PE International 2010). Since each input or output for the impact category GWP is not $CO_2$ each substance is converted to a $CO_2$ equivalent (eq) (PE International 2010). The final reference unit for “GWP” would then be “kg $CO_2$ eq” (PE International 2010). Each impact category has its own relevant reference substance and unit. Figure 3-2 shows how the inputs and outputs are placed into impact categories and then quantified.

Process trees, showing which materials and flows contributed to calculating each impact category, for each test that was conducted in SimPro 7.1 were completed. A cut-off threshold of 0.1% was set so that only processes that contributed at least 0.1% of the total environmental load for each impact category would be displayed. Setting this cut-off threshold leaves approximately 10 to 30% of the processes that contribute to the environmental impact out of the table (PRé Consultants 2006). Minimizing the process tree to only show the processes that contribute at least 0.1% of the environmental load makes it easier to view relevant issues and processes.

Table 3-2 shows the process tree for producing 1,105 MWh of electricity at the coal power plant with a cut-off threshold of 0.1% for the environmental impact category Fresh Water Aquatic Ecotoxicity. The environmental impacts for producing 1,105 MWh at a PWR nuclear plant are also shown in the process tree but the processes shown do not necessarily contribute at least 0.1% of the environmental load for nuclear. The flows for nuclear are kept in the table for comparison purposes only. Looking at Table 3-2 it can be seen that there is a total flow of 85,740.87 kg 1,4-dichlorobenzene (1,4-DB eq that contributes to the environmental impact Fresh Water Aquatic Ecotoxicity. The ion vanadium contributes more to this environmental impact category, for the process of producing electricity from coal, than any other substance. There are 14 substances shown, meaning that 14 substances contribute at least 0.1% to the environmental impact load.

Gabi 4.4 also has a cut-off threshold but it is referred to as a Weak Point Analysis. In Table 3-3 the Weak Point Analysis for the impact category Eutrophication is shown for producing 1,105 MWh of electricity from coal. Only substances or flows contributing at least 0.1% to the environmental load of the impact category are shown. The flows and substances that are shown in red are the “weak points” of the life cycle of producing electricity from coal.  These points contribute 10% or more to the total sum of the reference unit.  These flows and substances are the most relevant from the LCI.

Once all of the substances and flows are put into impact categories it is possible to compare processes based on their impact categories to determine which process has the larger environmental impact.  These graphs are shown in Chapter 4 Findings & Results.

Once flows are put into impact categories based on their reference unit they can then by normalized, an optional step according to the ISO standards (PE International 2010).  Normalization allows the impact category indicator results to be compared by a reference value and shows the magnitude to which an impact category has to the overall environmental problems (PRé Consultants 2004 and PRé Consultants 2006). There are two reasons for normalizing data.

1. The impact categories can be compared based on their contribution to overall environmental problems.  The order of magnitude of the environmental impacts can be generated to show the categories of the most concern (PRé Consultants 2006).

2. Through doing this, impact categories that minimally contribute to the overall environmental impacts can be left out of consideration or emphasis can be placed on the categories with the largest environmental impacts (PRé Consultants 2006). This reduces the number of issues that need to be evaluated (PRé Consultants 2006).

Normalization is done by dividing the impact category by a reference value (PRé Consultants 2004).  For example the average yearly environmental load in a country may be divided by the number of inhabitants within the country.  After normalization is completed, all impact categories have the same unit, which makes it easier to compare the categories.  Now the different impact categories can be all put on one graph and compared even though they originally all had different units (PRé Consultants 2004).

For the tests run in SimaPro the data was normalized against total output of the Netherlands in 1997. The normalized data graphs comparing the processes of producing electricity from coal versus nuclear power are shown in Chapter 4: Findings & Results.

**Interpretation**

The last stage of a LCA is the interpretation of the study (PRé Consultants 2006). This stage consists of checking and evaluating the results to ensure they are consistent with the goal and scope defined within the study (PE International 2010). Two main steps within the interpretation stage are identification of significant issues and evaluation (PE International 2010).

**Identification of significant issues**

The identification of significant issues involves looking at the LCI and LCIA results and determining the elements that contribute the highest environmental impacts, also known as the "significant issues" (PE International 2010). The following can be significant issues:

1. Essential contributions to the LCI or LCIA results from life cycle stages (PE International 2010). For example, the stages can include transportation or processing.
2. Impact category indicators that show areas of high concern (PE International 2010).
3. Impact category that is of particular interest to the study (PE International 2010).
4. Specific inventory elements such as material flows, wastes, and emissions (PE International 2010).

The results can be presented as graphs, tables, data lists, or other forms (PE International 2010). They can be organized according to the relevant issues of the study such as types of environment impacts, processes, raw materials, or whatever is the most relevant data for the study (PE International 2010). The identification of significant issues is shown in Chapter 5: Discussion.

**Evaluation**

This step of the interpretation stage is to increase the reliability of the study (PE International 2010). The means to complete the evaluation step includes a completeness check, a sensitivity check, and a consistency check (PE International 2010).

The completeness check is done to see if any data that is missing or incomplete is required to meet the goal and scope of the study (PE International 2010). If there is missing data that is needed the study must be redone including this information or the goal and scope of the study needs to be adjusted (PE International 2010).

To determine if the results are affected by uncertainties within the study such as assumptions, calculation procedures, etc. a sensitivity check is completed (PE International 2010). This is an important stage for studies that are comparing alternative products or processes (PE International 2010). Since my study is comparing the use of nuclear and coal as electricity generation sources, a sensitivity check was done. The switching from the coal-fired units to the nuclear unit is not an exact match of electricity generation measured in MW. Two coal-fired units producing 965 MWh will be retired and replaced with a nuclear unit producing 1,105 MWh. As a sensitivity check two tests were completed within SimaPro, one with 965 MWh being the functional unit and another with 1,105 MWh being the functional unit. The information gained from the sensitivity check is discussed in Chapter 4: Findings & Results.

A consistency check consists of looking at the consistency of the methods and the goal and scope of the study (PE International 2010). This is an overall check of the method of the study to ensure it correct.

After the study is looked at for significant issues and evaluated then the final steps can be completed including making conclusions, recommendations, and reports. After going through the previous steps and making sure the information gathered throughout the study is consistent and complete then final conclusions can be reported. From the final conclusions, recommendations can be made that are logical and reasonable with regards to the conclusions. Finally, the last step of a LCA is reporting the data in a transparent and comprehensive report. This report is the fulfillment of the final requirement for my study.

**SimaPro 7.1 Methodology Summary**

The first step in producing a LCA, comparing coal and nuclear power utilizing the SimaPro 7.1 software, was to create a plan. This plan included all of the processes and flows over the life cycle of producing electricity from coal within the U.S. Another plan was created for the flows and processes of producing electricity from a PWR nuclear plant within the U.S. Once plans were created for each electricity generation method, they could be compared. Two comparisons were completed, one with producing at an output of 1,105 MWh of electricity. As a sensitivity analysis another comparison was completed with an output of 965 MWh of electricity. The electricity generation methods were estimated using the CML baseline 2000 impact methodology. Once that was completed the impact categories were normalized against total output of the Netherlands in 1997. The two fuel mixes for Progress Energy were able to be compared based on their environmental impact categories. The energy scenarios were compared to determine the differences in environmental impacts between producing electricity from coal versus nuclear power (PRé Consultants 2004).

### GaBi 4.4 Software System and Database Methodology Summary

The first step in producing a LCA, comparing coal and nuclear power utilizing the Gabi 4.4 software, was to create a plan for both coal and nuclear. Each plan included all of the processes and flows over the life cycle of producing electricity from coal within the U.S. Once plans were created for each electricity generation method, a LCI was completed using the TRACI methodology. The data from the LCI was characterized and placed into impact categories. The total flows for the impact categories for coal and nuclear were compared to view the differences in environmental impacts that are produced between the two different energy sources.

### Life Cycle Assessment Methodology in Answering Research Question

The strict guidelines set up by the ISO standards provide a method to determine environmental impacts of a product or process. When the function of a product or process is the same they can be compared to determine which product or process produces the least amount of environmental impacts. For my study this methodology was used to determine the differences in environmental impacts between two electricity generation methods, coal and nuclear.

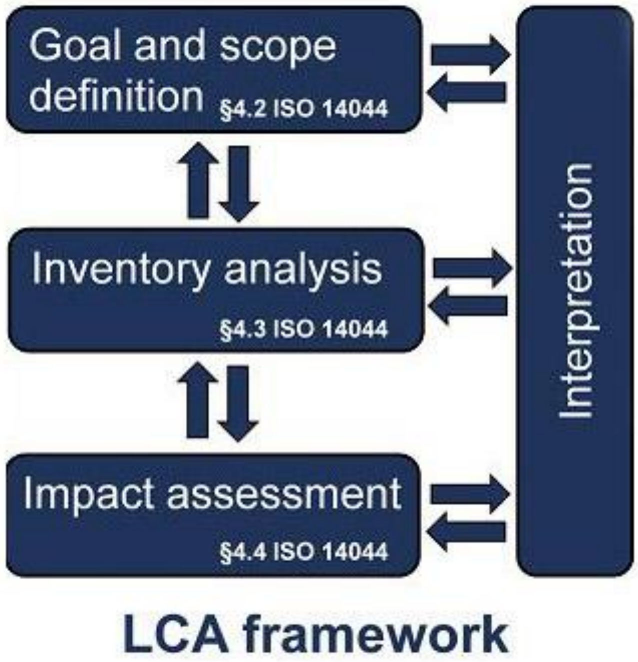


Figure 3-1. Steps of a Life Cycle Assessment according to ISO 14044 (Adapted from PE International 2010)

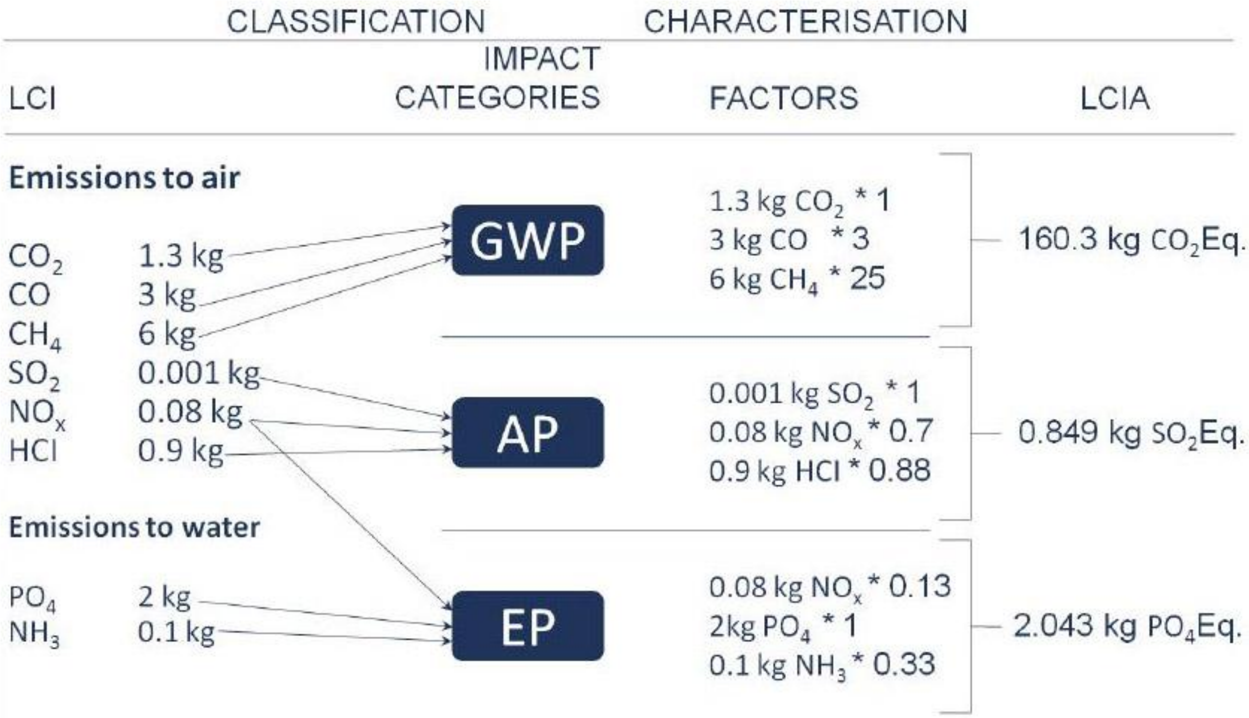


Figure 3-2. Classification to characterization process (Adapted from PE International 2010)

Table 3-1. LCA software and databases selection criteria

| LCA Program | Energy Data | Top Choice | Affordable | Affordable Top Choices |
|---|---|---|---|---|
| The Association of Plastics Manufacturers in Europe (APME) | X | | | |
| The Environmental Impact Estimator | X | | | |
| BEES 3.0 | X | | | |
| The Boustead Model 5.0 | O | O | X | |
| CMLCA | X | | | |
| Eco-Indicator 99 | O | X | O | |
| The ecoinvent Centre | O | X | O | |
| ECO-it 1.3 | O | X | O | |
| EcoScan 3.0 | X | | | |
| Economic Input-Output Life Cycle Assessment | X | | | |
| EDIP PC-tool | X | | | |
| The Environmental Impact Estimator | X | | | |
| EPS 2000 Design System | X | | | |
| GaBi 4 Software System and Databases | O | O | O | O |
| GEMIS (Global Emission Model for Integrated Systems) | O | O | O | O |
| GREET Model | X | | | |
| IDEMAT 2005 | X | | | |
| IVAM LCA Data 4.0 | X | | | |
| KCL-ECO 4.0 | O | X | O | |
| LCAiT 4 | O | X | O | |
| LCAPIX | X | | | |
| Life-Cycle Inventory Database | O | O | O | O |
| MIET 3.0 - Missing Inventory Estimation Tool | O | X | O | |
| REGIS | X | | | |
| SimaPro 7.1 | O | O | O | O |
| SPINE@CPM | X | | | |
| SPOLD Data Exchange Software | X | | | |
| TEAM™ | X | | | |
| Umberto | O | O | X | |
| WISARD™ | X | | | |

The symbol “X” indicates that the software or database did not meet the column criteria. The symbol “O” indicates that the column criteria was met. If a cell is blank that indicates that meeting the column criteria was not checked for because the program or database was already eliminated due to previously not meeting a column criteria.

Table 3-2. Process tree for producing 1,105 MWh of electricity by coal with a cut-off threshold of 0.1% for the impact category “Fresh Water Aquatic Ecotoxicity”

| Substance | Compartment | Unit | Coal | Nuclear |
|---|---|---|---|---|
| Total substances | | kg 1,4-DB eq | 85740.87 | 6338.79 |
| Remainder of substances | | kg 1,4-DB eq | 448.04 | 55.99 |
| Vanadium, ion | Water | kg 1,4-DB eq | 57880.43 | 3143.75 |
| Beryllium | Water | kg 1,4-DB eq | 13644.25 | 124.84 |
| Nickel, ion | Water | kg 1,4-DB eq | 8573.25 | 1840.11 |
| Cobalt | Water | kg 1,4-DB eq | 1573.77 | 500.56 |
| Selenium | Water | kg 1,4-DB eq | 902.93 | 186.74 |
| Copper, ion | Water | kg 1,4-DB eq | 720.14 | 84.96 |
| Molybdenum | Water | kg 1,4-DB eq | 532.79 | 205.48 |
| Thallium | Water | kg 1,4-DB eq | 385.39 | 2.39 |
| Arsenic, ion | Water | kg 1,4-DB eq | 281.37 | 6.31 |
| Barium | Water | kg 1,4-DB eq | 253 | 138.01 |
| Selenium | Air | kg 1,4-DB eq | 180.39 | 1.08 |
| Hydrogen fluoride | Air | kg 1,4-DB eq | 177.28 | 1.15 |
| Vanadium | Air | kg 1,4-DB eq | 96.05 | 46.52 |
| Beryllium | Air | kg 1,4-DB eq | 91.73 | 0.84 |

Table 3-3. Weak Point Analysis for the impact category “Eutrophication” for producing 1,105 MWh of electricity from coal, measured in kg N equivalent

| Flows | Flow Amount |
|---|---|
| Emissions to air | 150.08440 |
| Inorganic emissions to air | 150.08440 |
| Ammonia (emissions to air) | 0.02344 |
| Nitrogen oxides (emissions to air) | 150.06100 |
| Emissions to fresh water | 0.98093 |
| Analytical measures to fresh water (emissions to fresh water) | 0.97961 |
| Biological oxygen demand (BOD) (emissions to fresh water) | 0.34068 |
| Chemical oxygen demand (COD) (emissions to fresh water) | 0.63894 |
| Inorganic emissions to fresh water (emissions to fresh water) | 0.00132 |
| Ammonium / ammonia (emissions to fresh water) | 0.00132 |
| Nitrate (emissions to fresh water) | 0.00000 |

# CHAPTER 4
# FINDINGS AND RESULTS

## Comparison of Coal Versus Nuclear Power Producing 1,105 MWh of Electricity Using SimaPro 7.1

The findings and results of the environmental impacts from producing 1,105 megawatt hours (MWh) of electricity from coal and nuclear power are provided below. First the characterized results are shown, followed by the normalized results.

### Characterized results

Table 4-1 shows the characterized totals for each impact category. The totals were calculated in SimaPro 7.1 using the Centre of Environmental Science (CML) baseline 2000 impact methodology. In one category, nuclear power would produce a more severe environmental impact.

Figure 4-1 shows the characterized data graphed. With the data graphed in this format it is possible to tell which electricity source has a larger impact. Out of the ten impact categories assessed in SimaPro 7.1, nuclear only had a higher environmental impact in the category Ozone Layer Depletion. This is depicted in Figure 4-1, where the green bar representing nuclear power extends higher than the red bar representing coal-fired power. Figure 4-2 compares the characterized values of coal versus nuclear power for the environmental impact category Ozone Layer Depletion. Out of the impact categories, Ozone Layer Depletion is the least affected by producing electricity by coal. For nuclear power, Ozone Layer Depletion is the sixth highest impacted category, which puts it on the lower half of impacted categories.

### Normalized results

With the characterized data is graphed it is possible to tell which electricity source has a larger impact. However, it is not possible to determine which impact categories have the largest environmental impact based on their scale. To determine this, the characterized data is normalized against total output of the Netherlands in 1997. Table 4-2 displays the normalized results.

Figure 4-3, which compares the normalized results for the chosen environmental impact categories for producing electricity from coal versus nuclear, shows that the environmental impacts from coal are much larger than the impacts from nuclear. Marine Aquatic Ecotoxicity is the largest impact category for both coal and nuclear power. While this is the impact category with the largest impact for both coal and nuclear, coal's impact on this category is 19.74 times greater than nuclear power's impact.

After Marine Aquatic Ecotoxicity, the most significant environmental impacts associated with the production of electricity from coal are Acidification, Fresh Water Aquatic Ecotoxicity, Abiotic Depletion, and then Global Warming Potential (GWP). These are listed from largest impact to smallest (Table 4-3).

For nuclear power Fresh Water Aquatic Ecotoxicity is the most significant impact category after Marine Aquatic Ecotoxicity. When looking at Figure 4-3 it appears that nuclear power has no impact on any other categories besides Marine Aquatic Ecotoxicity and Fresh Water Aquatic Ecotoxicity but that is not the case. When comparing the impact categories between coal and nuclear, the impacts from nuclear are so miniscule when compared to coal that they are not visible on the graph. To see quantified environmental impact amounts for each impact category (Table 4-4).

**Substances Contributing to Impact Categories**

Once the impact categories causing or potentially causing the greatest environmental impacts are determined, then those specific categories can be focused on to gain further information. To determine why these impact categories are causing the most significant consequence, the materials and processes that contribute to these impact categories can be further assessed. The highest contributing substances for each impact category were calculated for both coal and nuclear power. The cut-off threshold for substances was set at 0.1%. This means that only substances that contributed at least 0.1% of the impact will be displayed.

Since Marine Aquatic Ecotoxicity was the impact category that displayed the largest impact for both the coal and nuclear scenarios it is important to look further into this category. The substances with the greatest contributions to the Marine Aquatic Ecotoxicity impact category are shown in Figure 4-4 for coal and Figure 4-5 for nuclear. As shown, for the coal scenario the substances contributing the most to the Marine Aquatic Ecotoxicity impact category include Beryllium and Vanadium. For Nuclear, Vanadium contributes the most to the impact of Marine Aquatic Ecotoxicity, with Selenium and Nickel, ion also contributing significantly. This information could be taken further to find out exactly how these substances impact marine water and what the consequences are.

For coal, the impact category that poses the second largest impact to the environment is Acidification (Figure 4-6). Sulfur dioxide ($SO_2$) is the substance that contributes the most to acidification when producing electricity from coal.

Fresh Water Aquatic Ecotoxicity is the third and second most significant impact category for producing electricity from coal and nuclear, respectively. With Marine Aquatic Ecotoxicity being the first most significant category for producing electricity from both coal and nuclear and Fresh Water Aquatic Ecotoxicity being the second and third most significant categories, it is clear that water bodies are of significant concern for generating electricity from both coal and nuclear power. Vanadium contributes the most to Fresh Water Aquatic Ecotoxicity in producing electricity from coal (Figure 4-7). For nuclear power, Vanadium contributes about 50% to the impact category Fresh Water Ecotoxicity and Nickel, ion contributes more than 25% to the impacts of Fresh Water Aquatic Ecotoxicity (Figure 4-8). Vanadium is the substance that has largely impacted both fresh and salt water bodies of water from producing electricity from coal and nuclear. The substances contributing the most to causing Ozone Layer Depletion from producing electricity from coal versus nuclear power are shown in Figures 4-9 and 4-10.

Determining which substances contribute to the pollution of a potential energy source or to any current or future scenario is extremely important information for a planner. Knowing what kind of pollution to expect allows for planning to prevent, mitigate, or alleviate the future problem.

## Sensitivity Analysis

As a sensitivity analysis, two LCAs were completed with different functional units. This was completed to determine if the results would vary when a different amount of electricity is produced. The first study has the functional unit of 1,105 MWh. The second study utilizes the functional unit of 965 MWh. The results of the two studies completed in SimaPro 7.1 can be compared for the sensitivity analysis.

When comparing the characterized graph of producing 1,105 MWh of electricity from coal and nuclear (Figure 4-1) and the characterized graph of producing 965 MWh of electricity from coal and nuclear (Figure 4-11), the results are the same. In addition, the normalized graphs all have the same ratio for magnitude of environmental impacts both from producing 965 MWh and 1,105 MWh (Figures 4-3 and 4-12). The difference in the data is that the environmental impacts are slightly elevated in the 1,105 MWh scenario due to the additional electricity produced. The differing environmental loads can be compared in both the characterized results (Tables 4-1 and 4-5) and in the normalized results (Tables 4-2 and 4-6). From the sensitivity analysis it can be said that even though it is estimated that one of the new nuclear units will produce 1,105 MWh of electricity and the estimated decrease in coal will be 965 MWh, the environmental impacts of producing electricity from coal versus nuclear power can be compared at either 1,105 MWh or 965 MWh without changing the results.

### Comparison of Coal Versus Nuclear Power Producing 1,105 MWh of Electricity Using GaBi 4.4

In the results that were calculated within GaBi 4.4 Software System and Database (GaBi 4.4) (Figures 4-13 through 4-24), the impacts that coal had on the environment were more severe than nuclear except for three categories. Each of these categories is water related. The impact categories that show nuclear having more severe environmental impacts include Human Health Cancer Water, Human Health Non Cancer Water, and Ecotoxicity Water (Figure 4-19, Figure 4-21, and Figure 4-23).

The Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) methodology that was used in GaBi 4.4 has 4 separate categories for human health indicators. These impact categories are Human Health Cancer Water, Human Health Cancer Air, Human Health Non Cancer Water, and Human Health Non Cancer Air. The two impact categories that provide information on how human health is impacted by air quality both say that electricity produced from coal will lead to more harmful impacts in humans. However, the results from the impact categories related to human health impacts from pollution to water both say that electricity produced by nuclear power is worse for humans.

### Comparison of SimaPro 7.1 and Gabi 4.4 Results

Figure 4-25 is a comparative graph showing the results for GWP calculated with the two methodologies used for my study, TRACI and CML. This figure comparing the GWP results of coal versus nuclear power shows a ratio of 91:1 for coal to nuclear power calculated from the TRACI methodology and a ratio of 89:1 in the CML methodology. This ratio difference of only 2% indicates that even though two different methodologies and programs were used, the results for GWP were consistent. The results between the two programs are primarily the same for most environmental impact categories. However this is not the case with three categories. These categories include Human Toxicity, Ecotoxicity Water, and Ozone Layer Depletion.

Pollution to water is what caused the varying results for Human Toxicity and Ecotoxicity Water. While Vanadium is the most contributing substance to the environmental impacts of water shown in the CML methodology, Aluminum is the most contributing substance in the TRACI methodology. This discrepancy is something that could be further evaluated in future studies. The difference in results for Human Toxicity may also be explained by the two methodologies breaking up the human health impacts differently. The TRACI methodology that was used in GaBi 4.4 has 4 separate categories for human health indicators including Human Health Cancer Water, Human Health Cancer Air, Human Health Non Cancer Water, and Human Health Non Cancer Air. The CML methodology used in SimaPro 7.1 has one impact category for an overall human health indicator.

The final environmental impact category that had varying results between the TRACI and CML methodologies was Ozone Layer Depletion. In the study conducted in SimaPro 7.1 program with the CML methodology, the result was that nuclear power will lead to more depletion of the ozone. However, in the Gabi 4.4 program using the TRACI methodology, it was predicted that producing electricity at a coal-fired power plant will lead to more ozone layer depletion. These differing results could be studied further in future studies.

**Summary of Results**

Through my study it was learned that overall producing electricity from coal causes larger environmental consequences according to the studied environmental impact categories. The results show that Progress Energy Florida will produce less severe environmental impacts by utilizing nuclear power rather than coal.

From the CML methodology used in SimaPro, the results showed that nuclear power was the better electricity source when regarding environmental impacts. Nine out of the ten impact categories showed larger environmental impacts when electricity is produced by coal rather than nuclear power for the Progress Energy Levy, County site. The impact category that showed a larger environmental impact when producing electricity from nuclear power opposed to coal was Ozone Layer Depletion. For that category it was shown that producing electricity from nuclear power will cause more depletion of the ozone layer when compared to producing electricity from coal. When comparing this impact category to the other impact categories, Ozone layer Depletion had the lowest impact.

For the results from the TRACI methodology in GaBi 4.4 it was shown that nuclear power would impact three impact categories related to water more severely than power from coal would.  These three impact categories include Human Health Cancer Water, Human Health Non Cancer Water, and Ecotoxicity of Water.

The differing results of human health impacts between the two methodologies are attributed to the CML methodology only having only impact category for human health and TRACI breaking up human health into four different categories.  The differences in results for Ozone Layer Depletion and Ecotoxicity of Water most likely occurred by the different methods focusing more on different pollution sources.

Overall, it was shown from both methodologies that Progress Energy Florida's environmental impacts will be decreased through switching part of their fuel mix from coal to nuclear power for electricity generation.

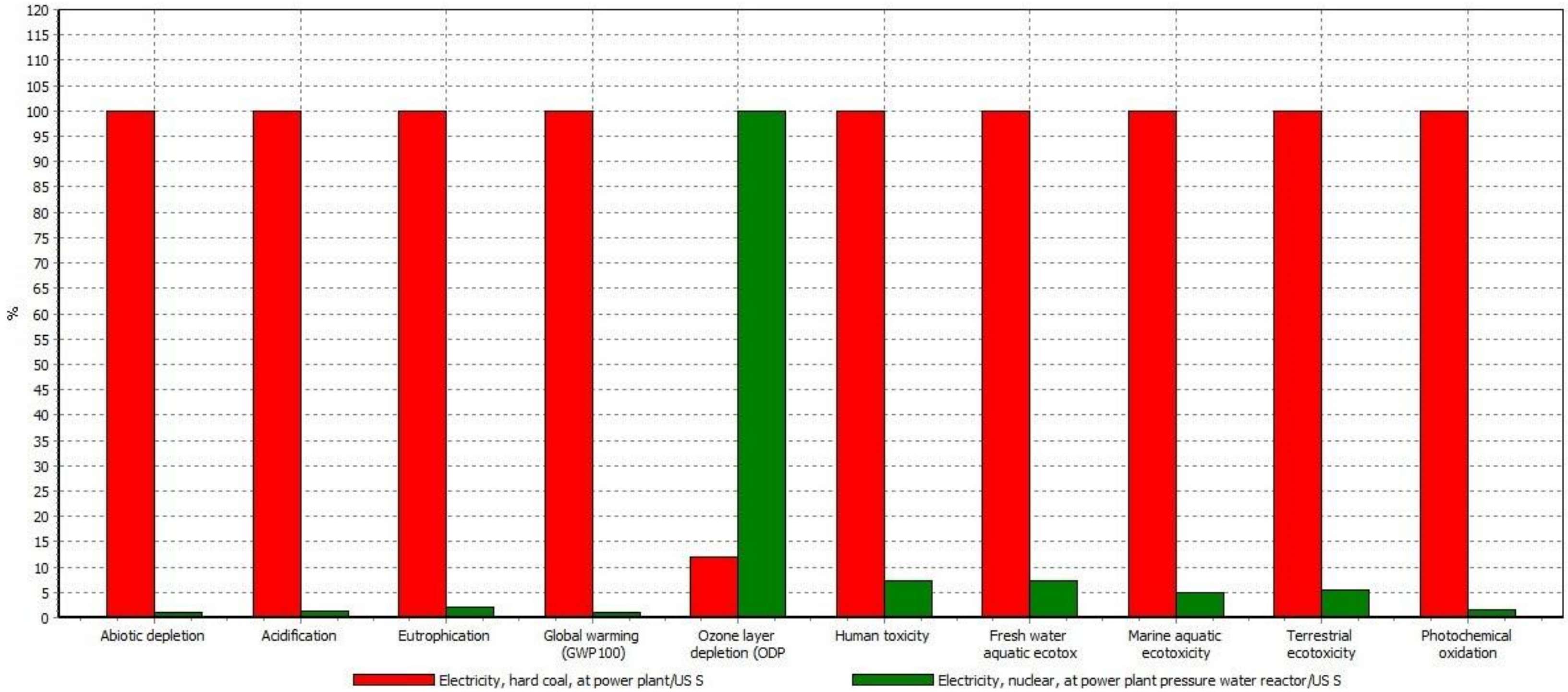


Figure 4-1. Characterization of impact categories, 1,105 MWh, coal versus nuclear power

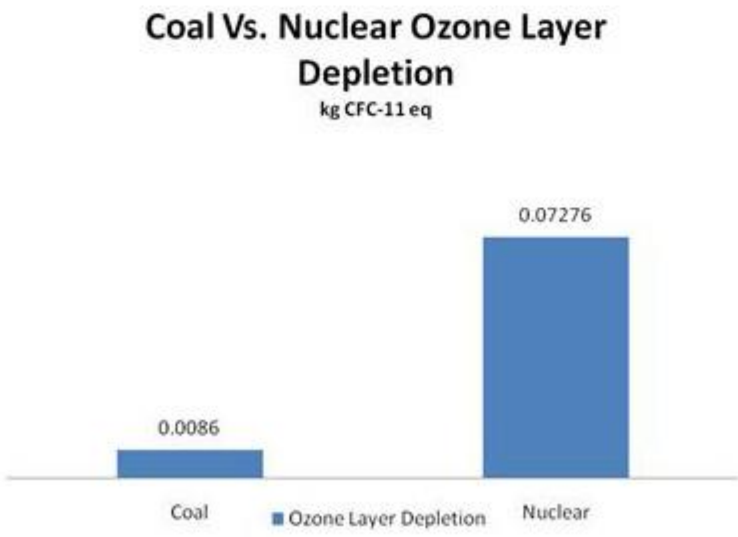


Figure 4-2.  Coal versus nuclear, Ozone Layer Depletion

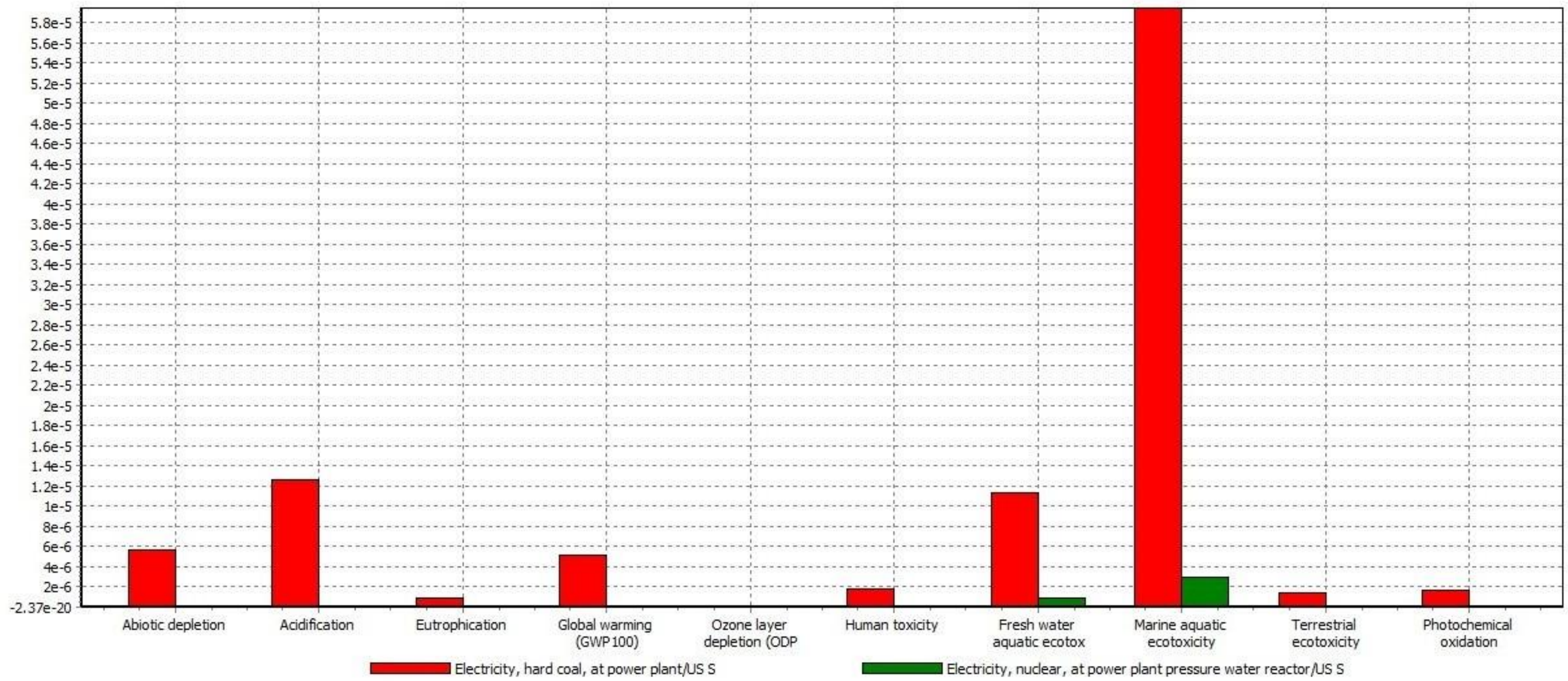


Figure 4-3. Normalization of impact categories, 1,105 MWh, coal versus nuclear power

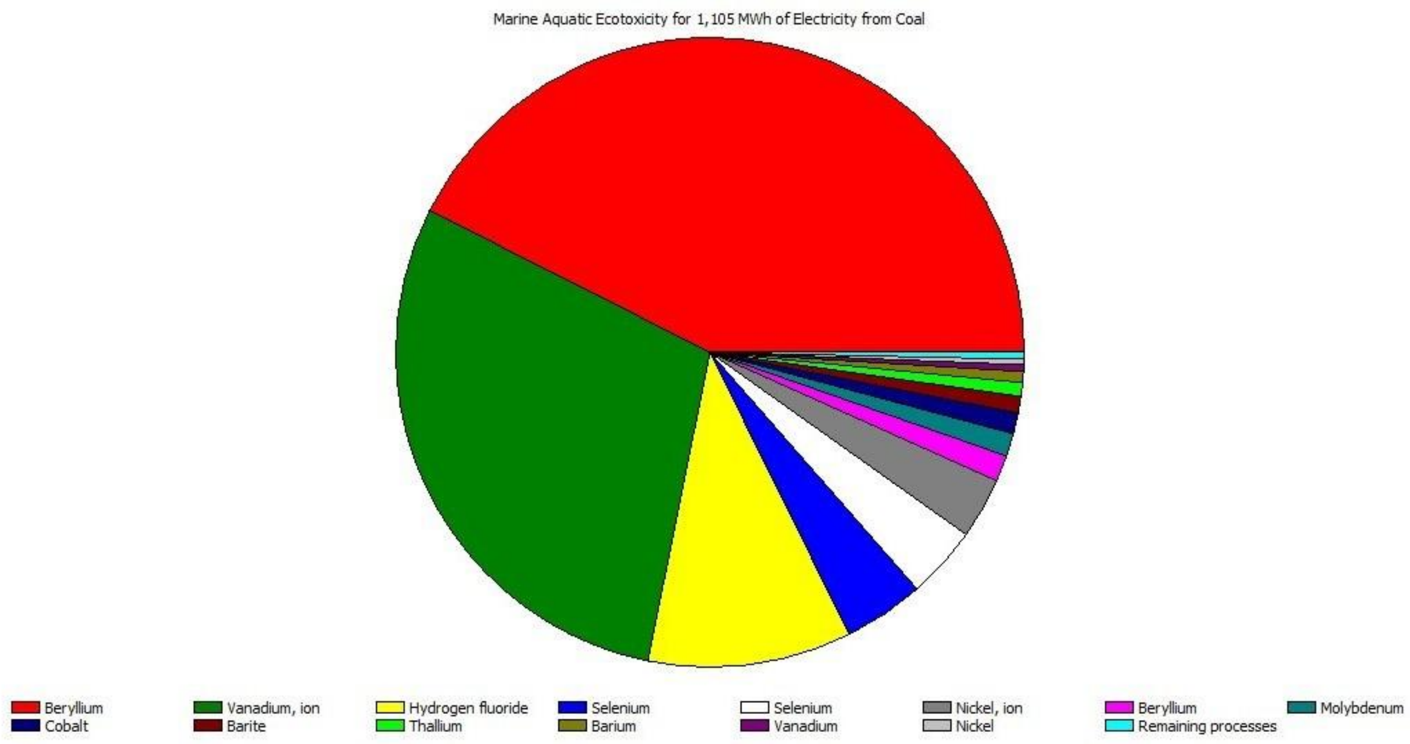


Figure 4-4.  Substances contributing at least 0.1% to Marine Aquatic Ecotoxicity for electricity from coal

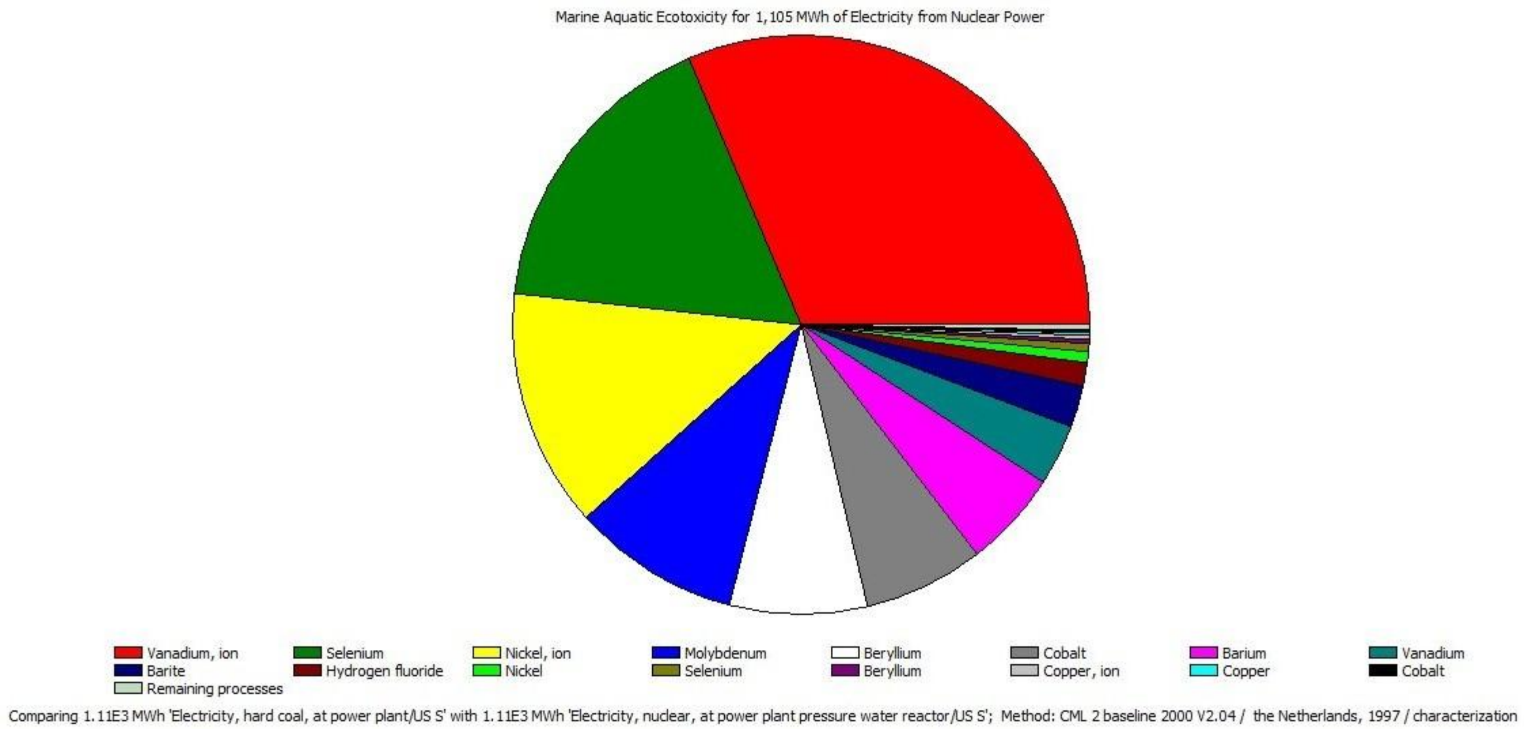


Figure 4-5. Substances contributing at least 0.1% to Marine Aquatic Ecotoxicity for electricity from nuclear power

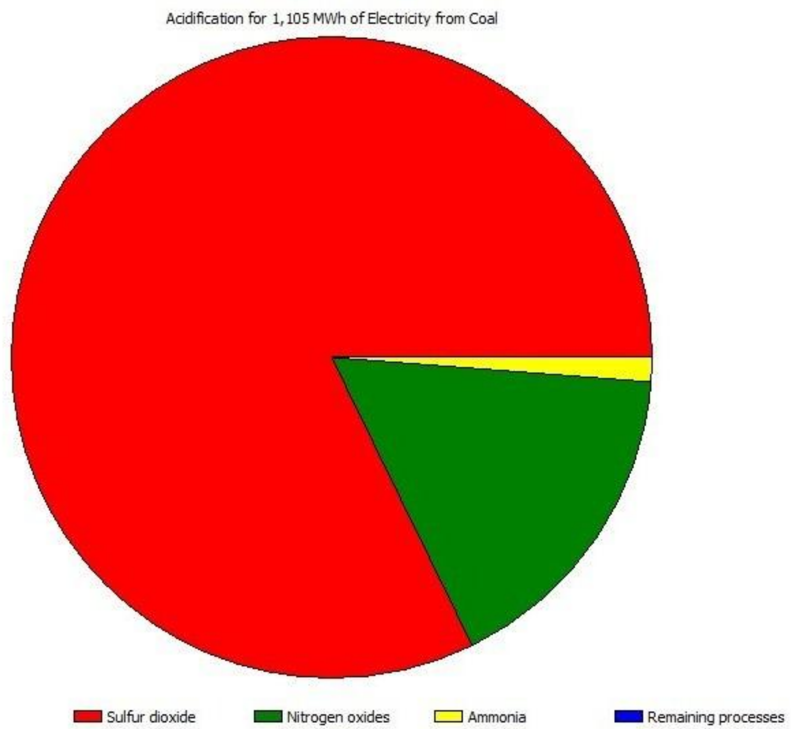


Figure 4-6.  Substances contributing at least 0.1% to Acidification for electricity from coal

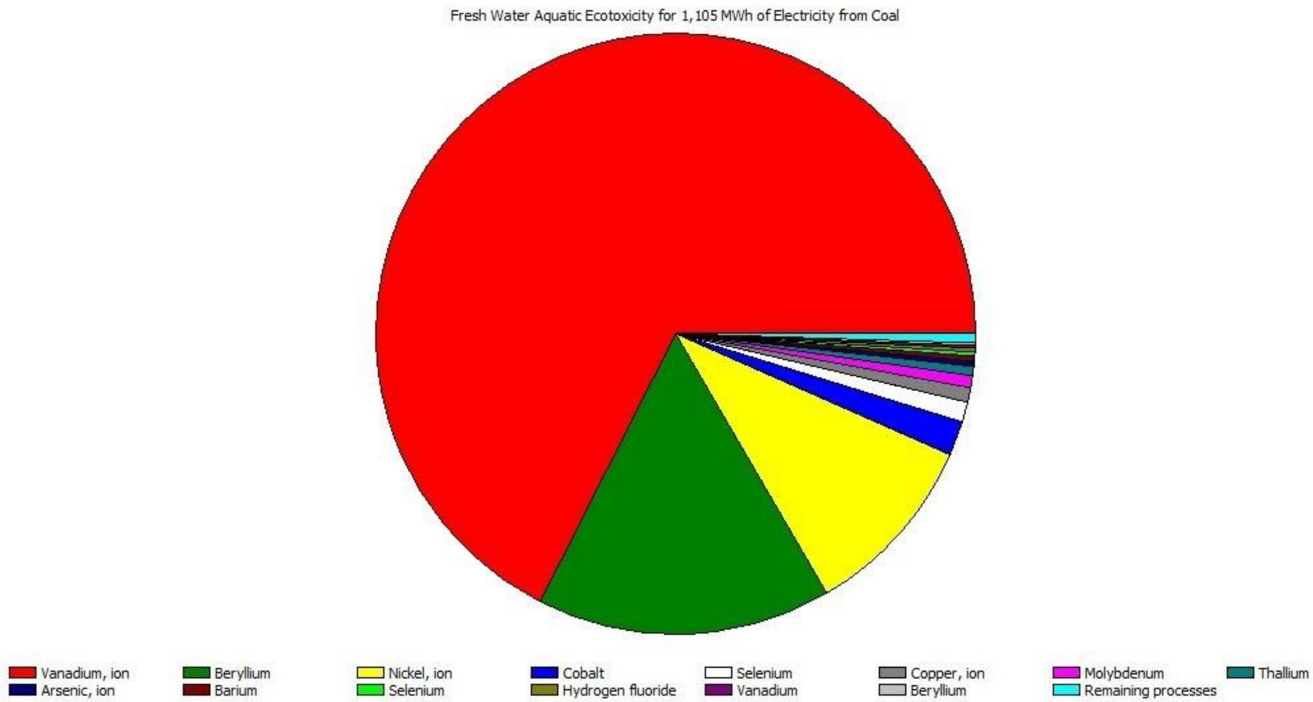


Figure 4-7. Substances contributing at least 0.1% to Fresh Water Aquatic Ecotoxicity for electricity from coal

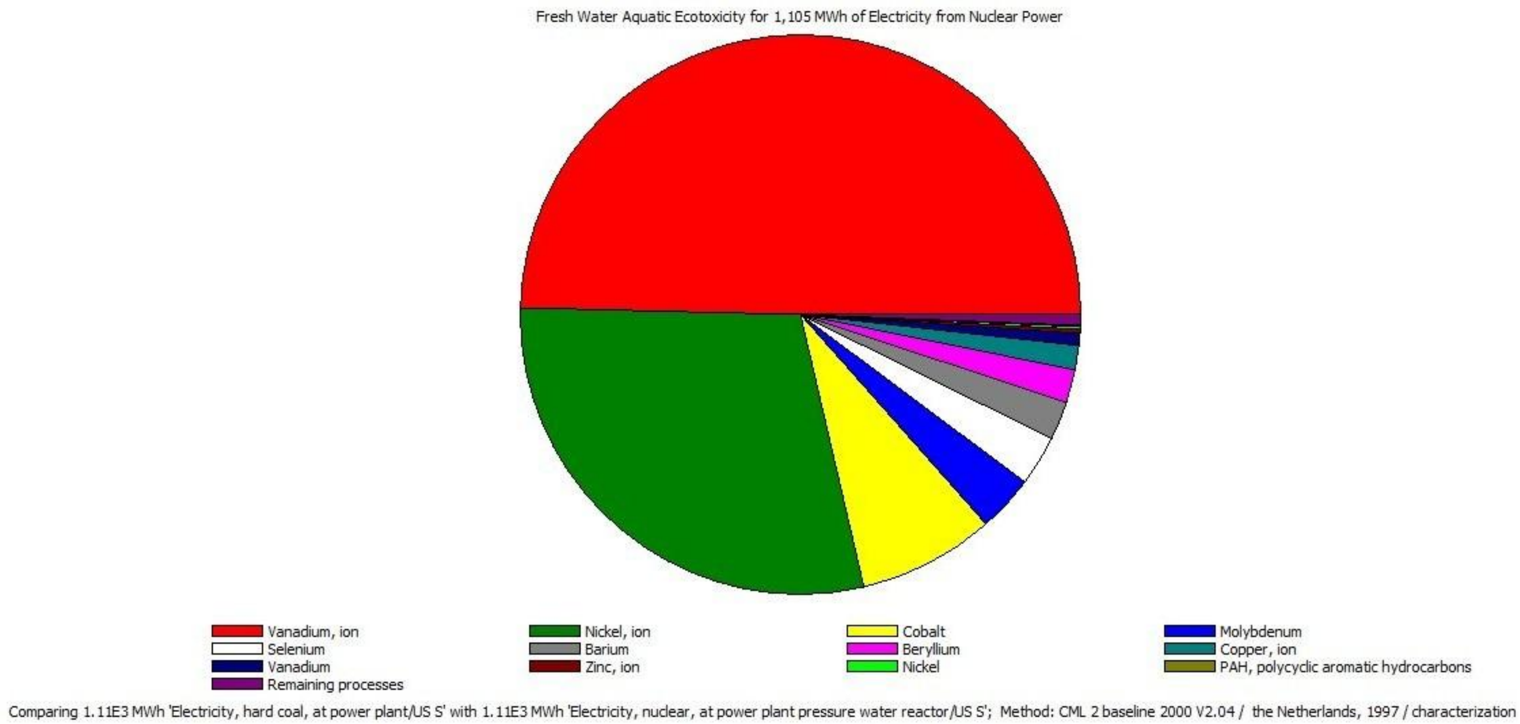


Figure 4-8. Substances contributing at least 0.1% to Fresh Water Aquatic Ecotoxicity for electricity from nuclear power

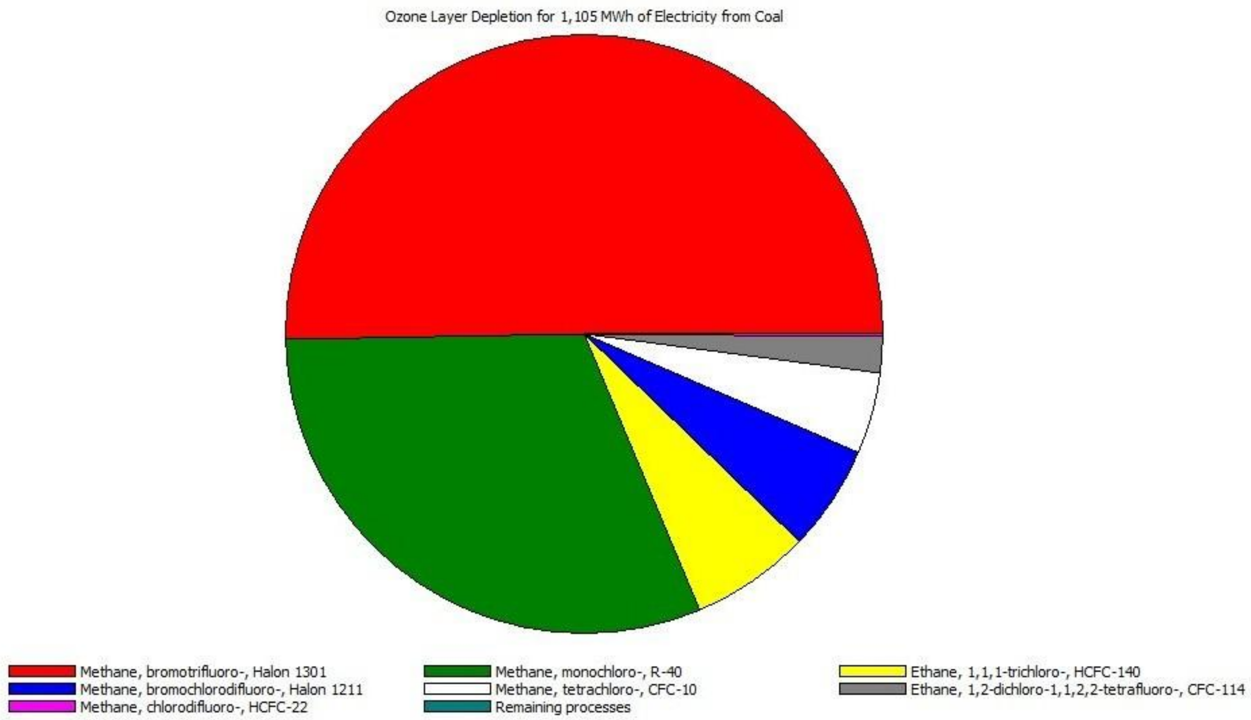


Figure 4-9.  Substances contributing at least 0.1% to Ozone Layer Depletion for electricity from coal

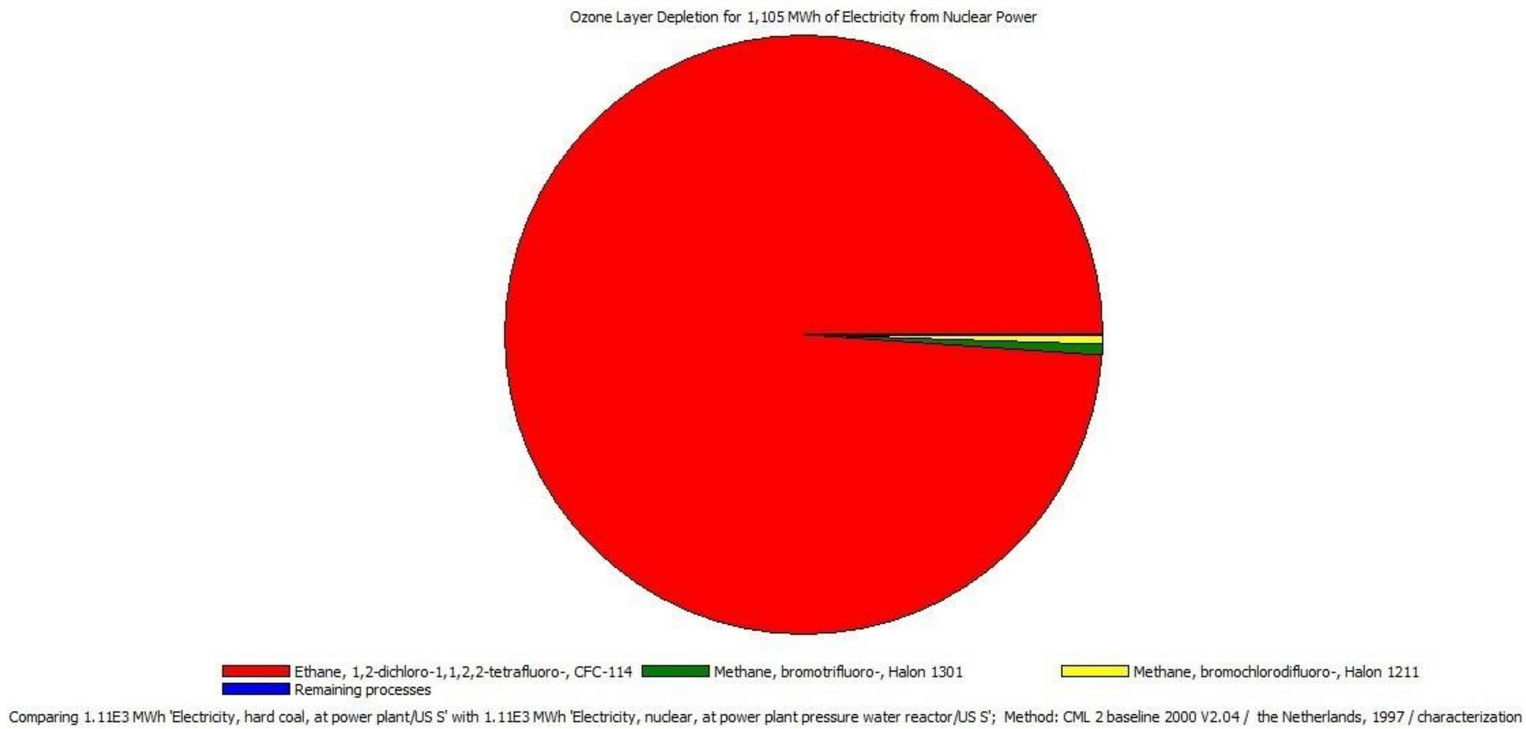


Figure 4-10. Substances contributing at least 0.1% to Ozone Layer Depletion for electricity from nuclear power

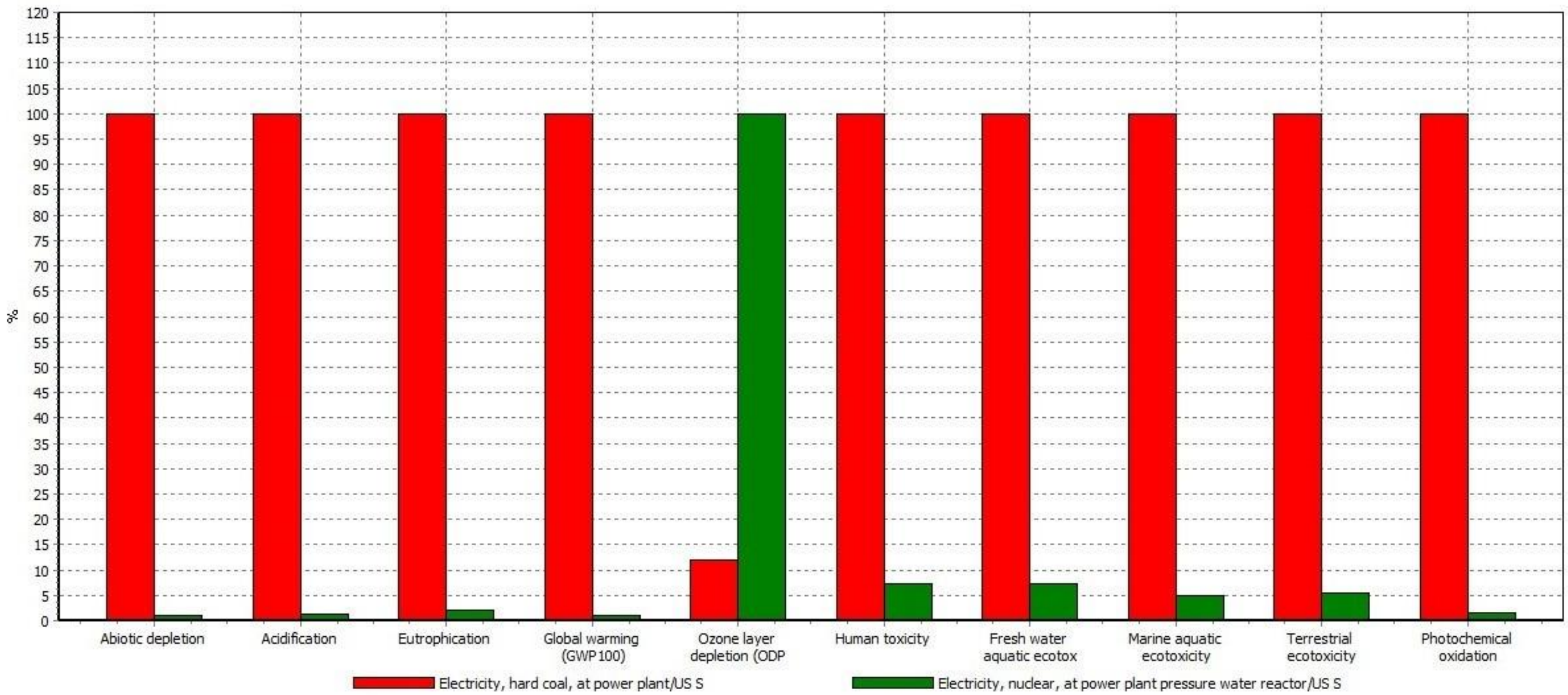


Figure 4-11. Characterization of impact categories, 965 MWh, coal versus nuclear power

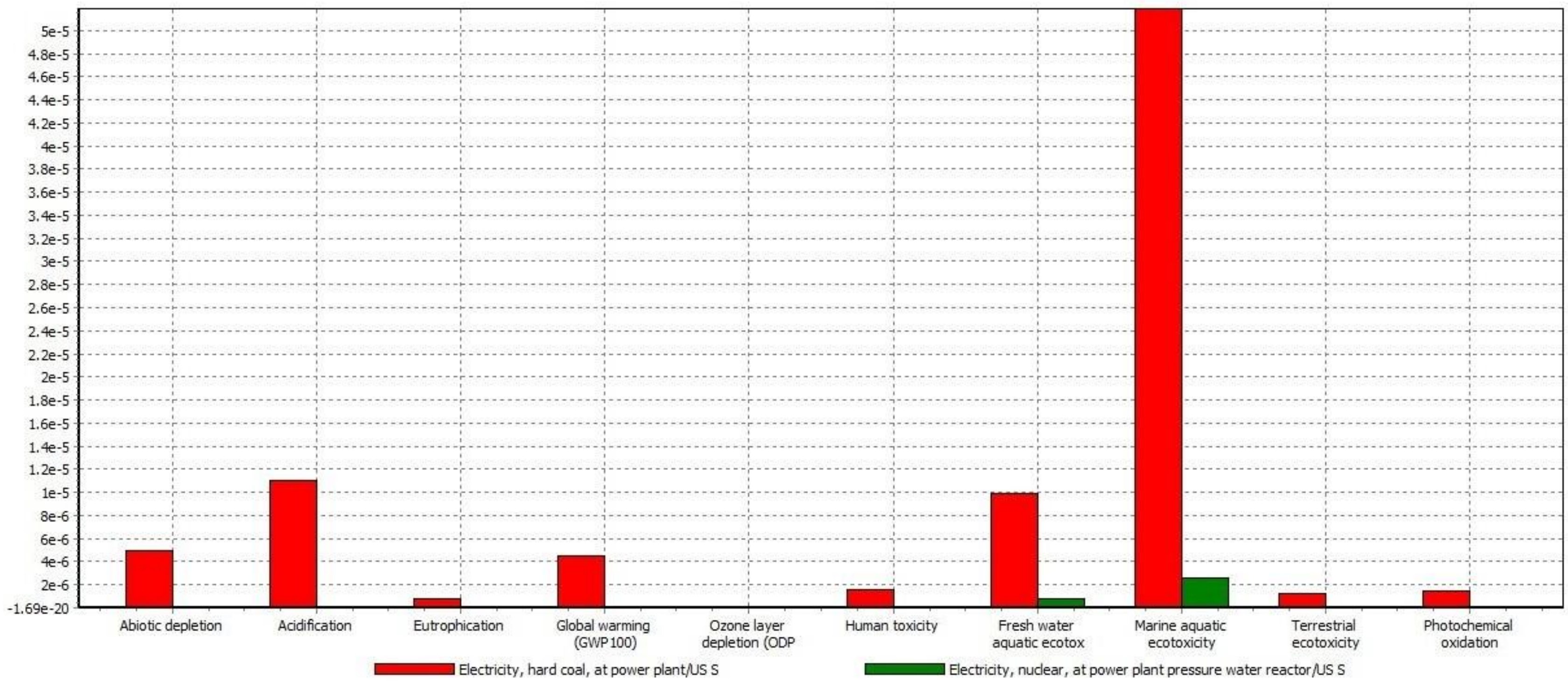


Figure 4-12. Normalization of impact categories, 965 MWh, coal versus nuclear power

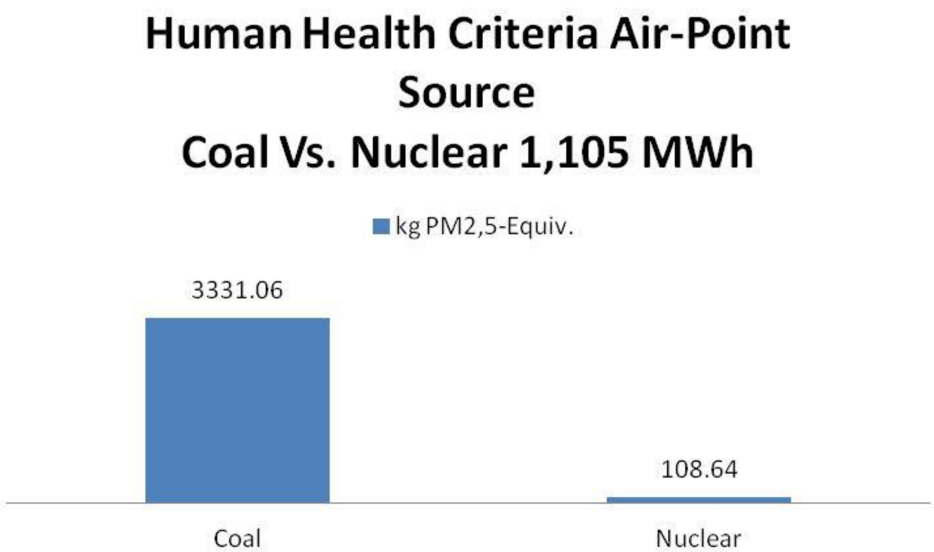


Figure 4-13. Human-Health Criteria Air-Point Source comparison of coal versus nuclear power 1,105 MWh

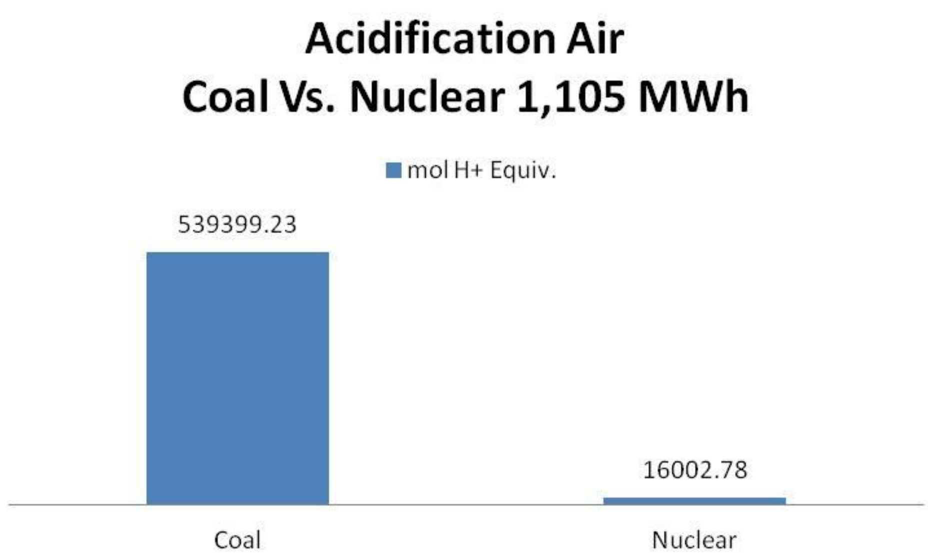


Figure 4-14. Acidification Air comparison of coal versus nuclear power 1,105 MWh

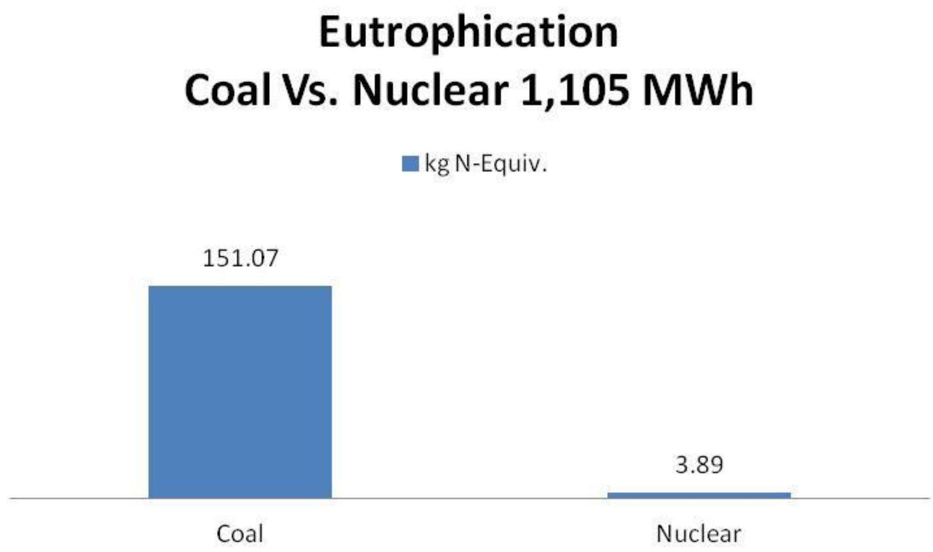


Figure 4-15. Eutrophication comparison of coal versus nuclear power 1,105 MWh

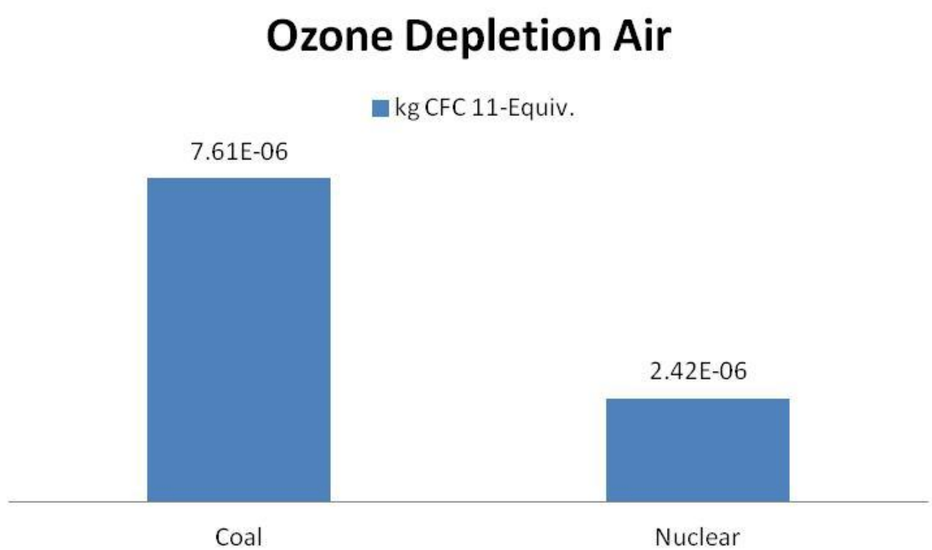


Figure 4-16. Ozone Layer Depletion Air comparison of coal versus nuclear power 1,105 MWh

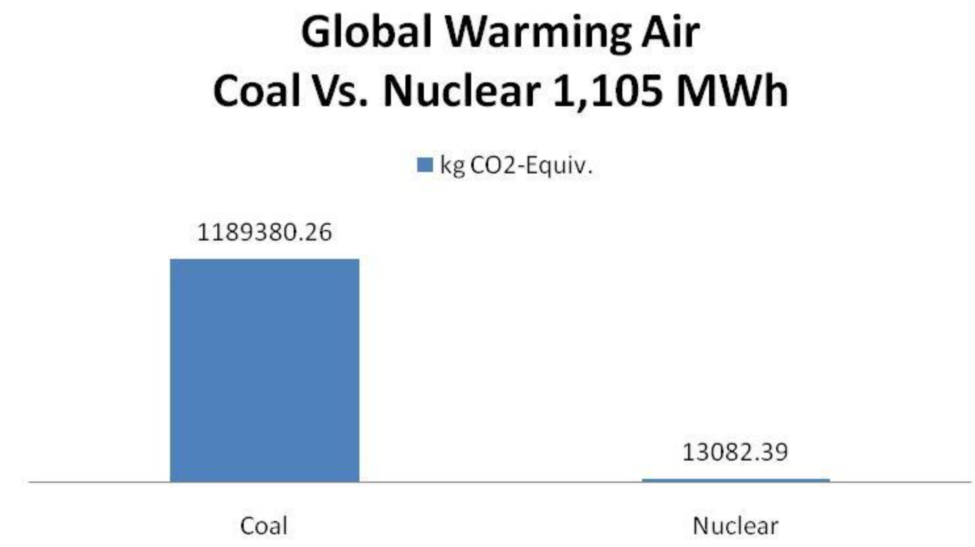


Figure 4-17. Global Warming Air comparison of coal versus nuclear power 1,105 MWh

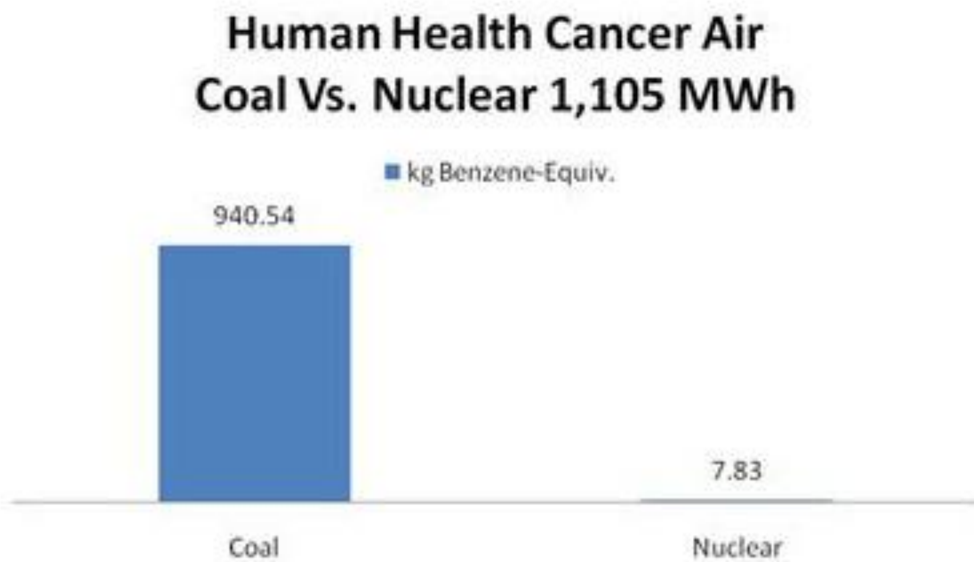


Figure 4-18. Human Health Cancer Air comparison of coal versus nuclear power 1,105 MWh

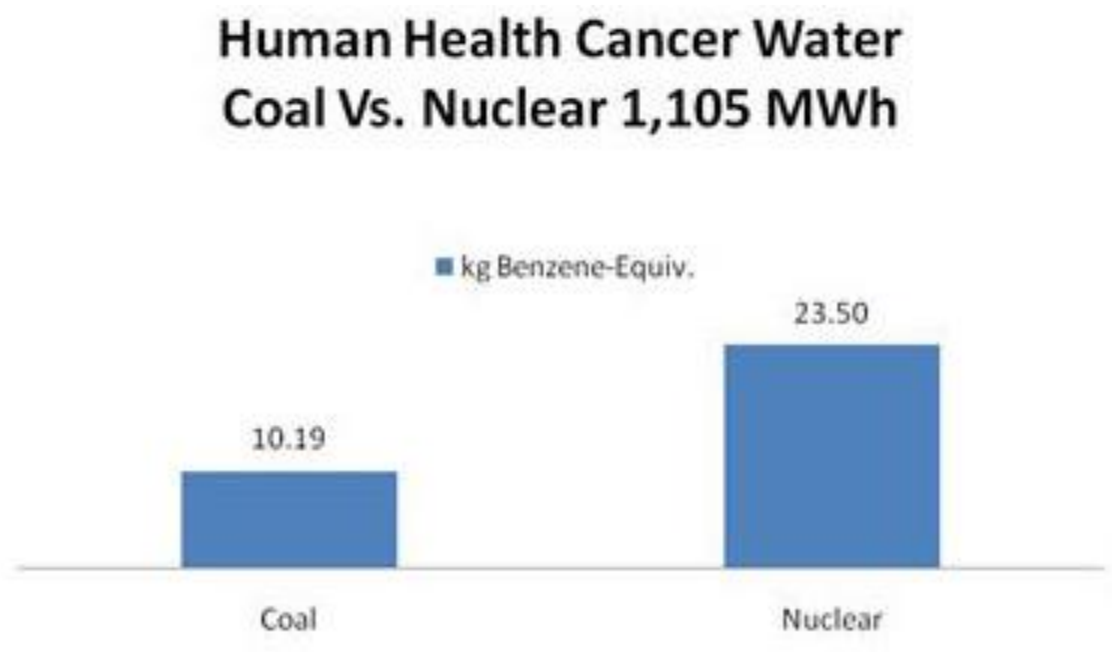


Figure 4-19. Human Health Cancer Water comparison of coal versus nuclear power 1,105 MWh

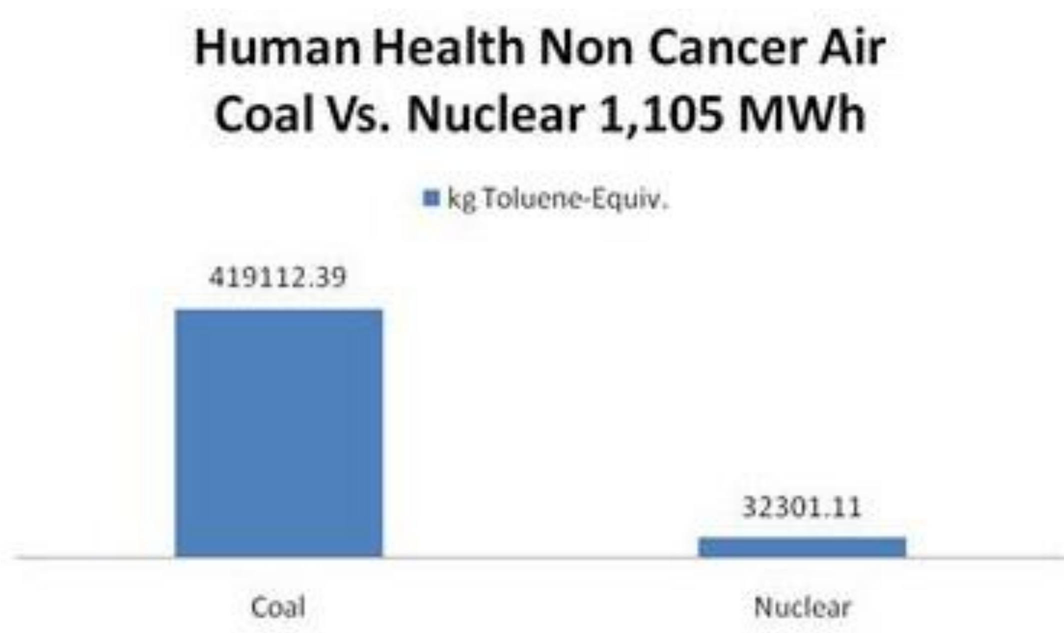


Figure 4-20. Human Health Non Cancer Air comparison of coal versus nuclear power 1,105 MWh

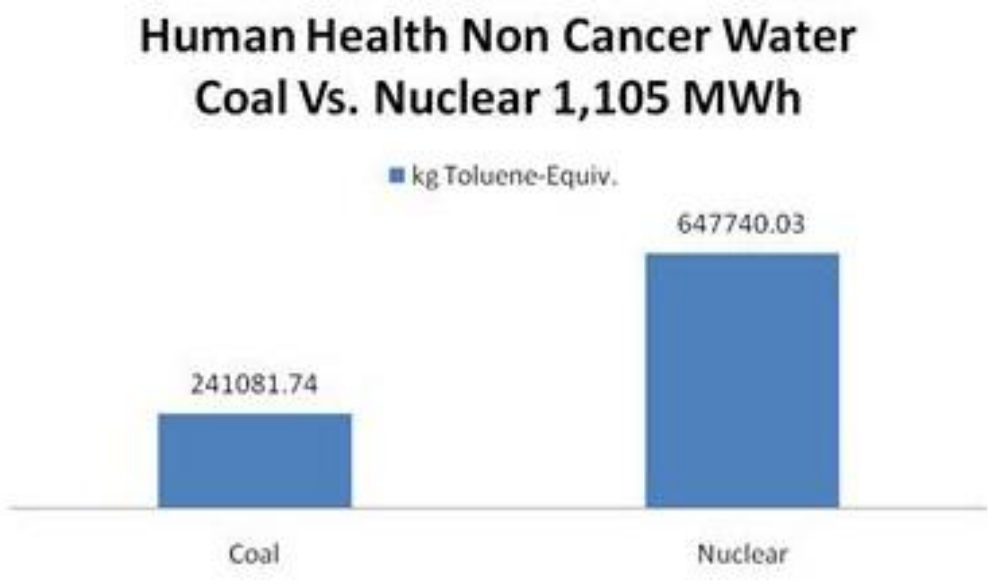


Figure 4-21. Human Health Non Cancer Water comparison of coal versus nuclear power 1,105 MWh

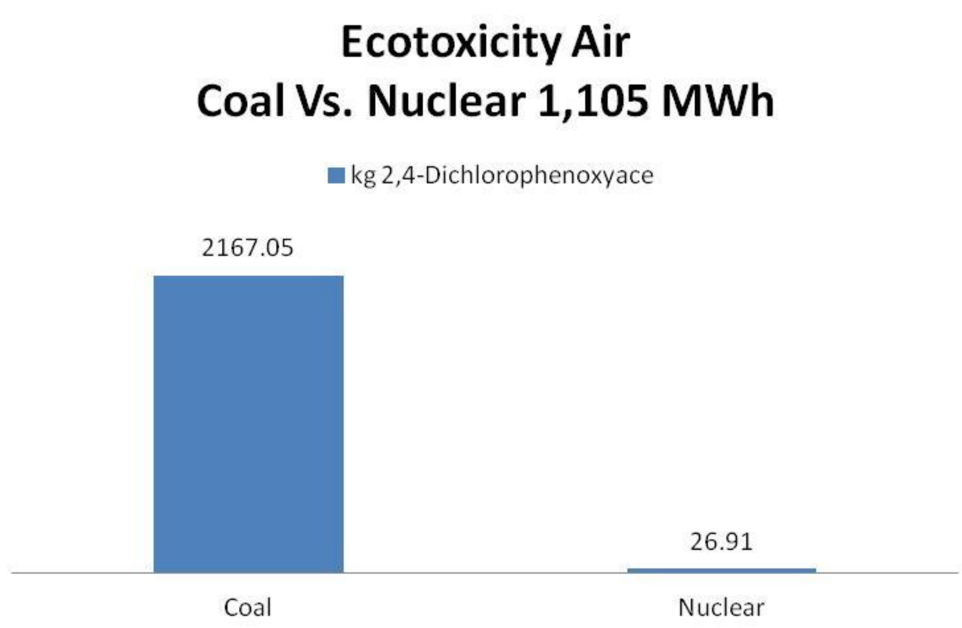


Figure 4-22. Ecotoxicity Air comparison of coal versus nuclear power 1,105 MWh

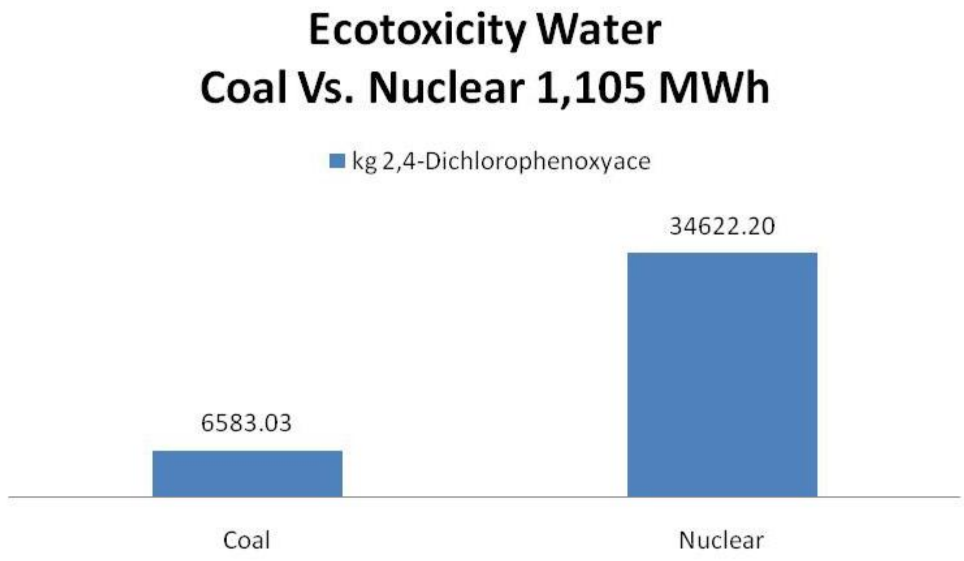


Figure 4-23. Ecotoxicity Water comparison of coal versus nuclear power 1,105 MWh

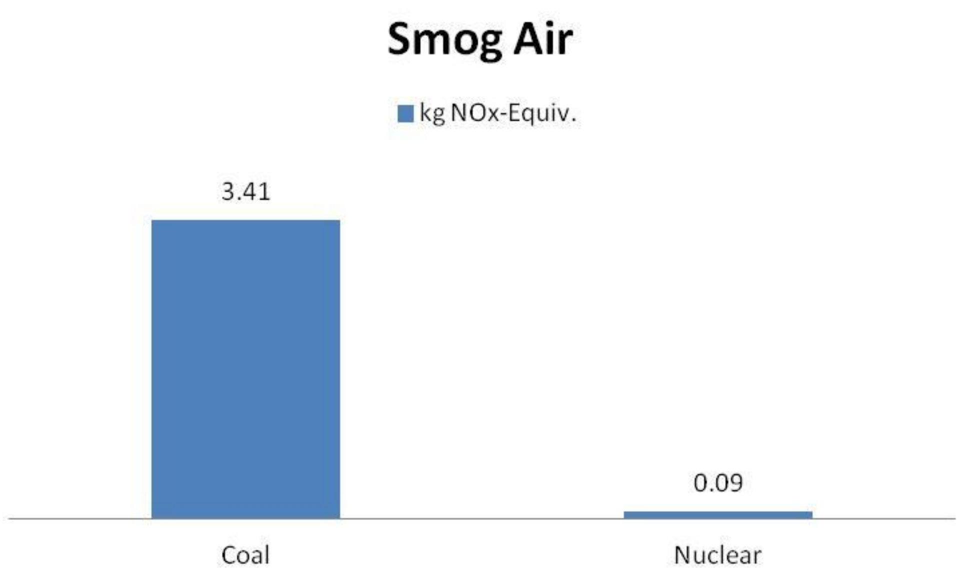


Figure 4-24. Smog Air comparison of coal versus nuclear power 1,105 MWh

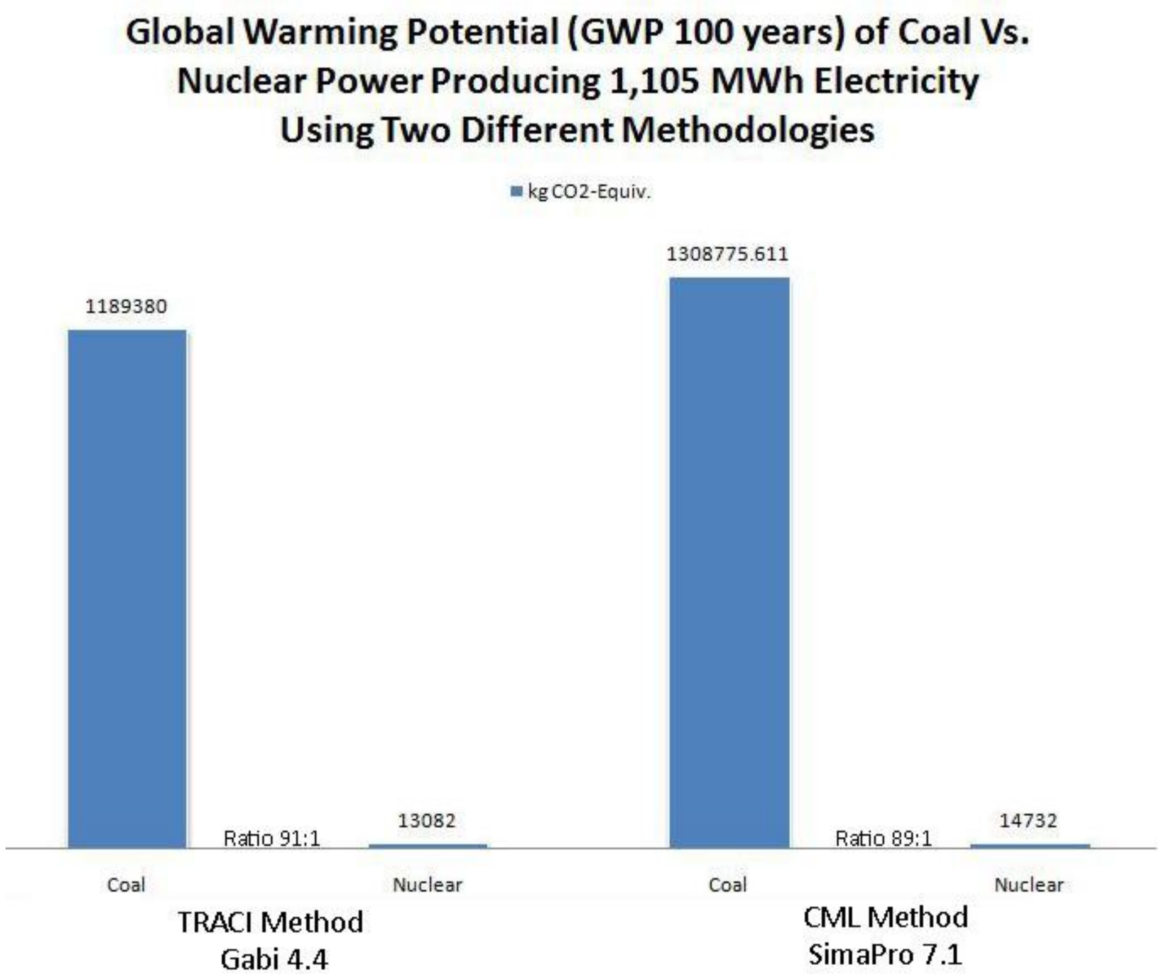


Figure 4-25. GWP results from TRACI versus CML methodologies

Table 4-1. Characterization of impact categories for producing 1,105 MWh of electricity from coal versus nuclear power

| Impact Category | Unit | Coal, 1,105 MWh | Nuclear, 1,105 MWh |
|---|---|---|---|
| Abiotic Depletion | kg Sb eq | 9,598.81 | 101.28 |
| Acidification | kg $SO_2$ eq | 8,494.93 | 102.82 |
| Eutrophication | kg $PO_4$eq | 430.64 | 9.50 |
| Global Warming (GWP100) | kg $CO_2$ eq | 1,308,775.61 | 14,731.62 |
| Ozone Layer Depletion | kg CFC-11 eq | 0.01 | 0.07 |
| Human Toxicity | kg 1,4-DB eq | 341,447.20 | 25,156.94 |
| Fresh Water Aquatic Ecotoxicity | kg 1,4-DB eq | 85,740.87 | 6,338.79 |
| Marine Aquatic Ecotoxicity | kg 1,4-DB eq | 189,247,434.50 | 9,584,679.13 |
| Terrestrial Ecotoxicity | kg 1,4-DB eq | 1,314.24 | 72.12 |
| Photochemical Oxidation | kg $C_2H_4$ | 302.64 | 4.51 |

Table 4-2. Normalized data for producing 1,105 MWh of electricity from coal versus nuclear

| Impact Category | Coal, 1,105 MWh | Nuclear, 1,105 MWh |
|---|---|---|
| Abiotic Depletion | 0.056E-08 | 5.925E-08 |
| Acidification | 0.001E-08 | 0.153E-08 |
| Eutrophication | 0.857E-08 | 1.892E-08 |
| Global warming (GWP100) | 0.052E-08 | 5.834E-08 |
| Ozone Layer Depletion | 88.062E-08 | 7.422E-08 |
| Human Toxicity | 0.018E-08 | 0.134E-08 |
| Fresh Water Aquatic Ecotoxicity | 0.001E-08 | 0.843E-08 |
| Marine Aquatic Ecotoxicity | 0.006E-08 | 0.030E-08 |
| Terrestrial Ecotoxicity | 0.014E-08 | 7.862E-08 |
| Photochemical Oxidation | 0.016E-08 | 2.476E-08 |

Table 4-3. Normalized results of impact categories from most significant to least significant for producing electricity from coal

| Impact Category | Normalized Results |
|---|---|
| Marine Aquatic Ecotoxicity | 5.94237E-05 |
| Acidification | 1.26575E-05 |
| Fresh Water Aquatic Ecotoxicity | 1.14035E-05 |
| Abiotic Depletion | 5.6153E-06 |
| Global Warming (GWP100) | 5.18275E-06 |
| Human Toxicity | 1.8165E-06 |
| Photochemical Oxidation | 1.66155E-06 |
| Terrestrial Ecotoxicity | 1.43252E-06 |
| Eutrophication | 8.56978E-07 |
| Ozone Layer Depletion | 8.80624E-09 |

Table 4-4. Normalized results of impact categories from most significant to least significant for producing electricity from nuclear power

| Impact Category | Normalized Results |
|---|---|
| Marine Aquatic Ecotoxicity | 3.00959E-06 |
| Fresh Water Aquatic Ecotoxicity | 8.43059E-07 |
| Acidification | 1.53209E-07 |
| Human Toxicity | 1.33835E-07 |
| Terrestrial Ecotoxicity | 7.86204E-08 |
| Ozone Layer Depletion | 7.42249E-08 |
| Abiotic Depletion | 5.92519E-08 |
| Global Warming (GWP100) | 5.83372E-08 |
| Photochemical Oxidation | 2.47606E-08 |
| Eutrophication | 1.89218E-08 |

Table 4-5. Characterized results for producing 965 MWh from coal versus nuclear power

| Impact Category | Unit | Coal, 965 MWh | Nuclear, 965 MWh |
|---|---|---|---|
| Abiotic Depletion | kg Sb eq | 8382.67 | 88.45 |
| Acidification | kg $SO_2$ eq | 7418.65 | 89.79 |
| Eutrophication | kg $PO_4$ eq | 376.08 | 8.30 |
| Global Warming (GWP100) | kg $CO_2$ eq | 1142957.88 | 12865.17 |
| Ozone Layer Depletion | kg CFC-11 eq | 0.01 | 0.06 |
| Human Toxicity | kg 1,4-DB eq | 298186.92 | 21969.64 |
| Fresh Water Aquatic Ecotoxicity | kg 1,4-DB eq | 74877.78 | 5535.68 |
| Marine Aquatic Ecotoxicity | kg 1,4-DB eq | 165270383.97 | 8370330.65 |
| Terrestrial Ecotoxicity | kg 1,4-DB eq | 1147.73 | 62.99 |
| Photochemical Oxidation | kg $C_2H_4$ | 264.30 | 3.93 |

Table 4-6. Normalized results for producing 965 MWh from coal versus nuclear power

| Impact Category | Coal, 965 MWh | Nuclear, 965 MWh |
|---|---|---|
| Abiotic Depletion | 0.049E-08 | 5.174E-08 |
| Acidification | 0.001E-08 | 0.134E-08 |
| Eutrophication | 0.748E-08 | 1.652E-08 |
| Global Warming (GWP100) | 0.045E-08 | 5.095E-08 |
| Ozone Layer Depletion | 76.905E-08 | 6.482E-08 |
| Human Toxicity | 0.016E-08 | 0.117E-08 |
| Fresh Water Aquatic Ecotoxicity | 0.010E-08 | 0.736E-08 |
| Marine Aquatic Ecotoxicity | 0.005E-08 | 0.026E-08 |
| Terrestrial Ecotoxicity | 0.013E-08 | 6.866E-08 |
| Photochemical Oxidation | 0.015E-08 | 2.162E-08 |

# CHAPTER 5
# DISCUSSION

## What Was Learned?

This Life Cycle Assessment (LCA) study achieved its goal of determining the environmental differences that can be anticipated between utilizing coal versus nuclear power. A planner involved with the decision making of this project could use this information to make more informed and scientific decisions about which energy source should be pursued. From a planning perspective this case study is pertinent to generally knowing about the differences between the energy sources' areas of environmental concern and pollution sources. The information gained from the case study is important for the Progress Energy case but what is more important to the larger scale of urban and regional planning is the LCA methodology used in my study and Environmental Impact Statements (EISs).

## Life Cycle Assessments and Environmental Impact Statements in Urban Planning

The goal of a planner is to choose the option that will provide the greatest benefits to the population with the fewest costs. To achieve this goal it is extremely important for urban planners to have as much information about potential options. It is important to know the environmental impacts of various options in order to make informed decisions that will greatly impact the future. LCAs and EISs are two environmental assessment methods that can be used as decision making tools. An EIS is the current method that is required by the federal government for assessing anticipated environmental impacts that a project may cause. A LCA is the method that was used in my study to determine the differences that may be seen within the environment between utilizing coal versus nuclear power to produce electricity at Progress Energy Florida's potential nuclear power plant in Levy County, Florida. Both EIS and LCA are valuable to the field of urban and regional planning and can lead to more informed decision making.

Both EISs and LCAs can be used by urban planners as technical environmental tools to aid in making informed decisions based on environmental impacts. There are many similar features between the two methods and there are also many differences.

Both LCAs and EISs are tools for decision making that can be used when planning for sustainable development. All three sustainability pillars (environment, society, and economy) are accounted for in an EIS. There are separate sections in an EIS that each directly relate to the implications that may be seen on the environment, society, and economy as a result of the proposed action. A LCA only directly relates to the environmental pillar of sustainability planning. However, there are two additional life cycle methodologies associated with a LCA that account for the economy and society pillars. Life Cycling Costing (LCC) is a decision making tool that can be utilized to analyze a product or process on its economic sustainability. Social Life Cycle Assessment (SLCA) is the life cycle assessment for impacts on society. SLCA is still in the development stage and is not yet ready to provide for decision making based on social sustainability. Once SLCA is done being developed it can be combined with LCA and LCC to provide life cycle assessments for all three of the sustainability pillars.

LCAs and EISs provide technical information on environmental impact categories. The impacts are broken down into environmental impact categories such as toxicity to water. These environmental impact categories are further broken down in both LCAs and EISs to provide information on what substances will likely affect the impact categories. Both LCAs and EISs can display information in visually effective ways that allow for non environmental professionals to get a general understanding of potential environmental impacts. However, both methods require the expertise of environmental professionals to analyze the supplied data to fully understand what the provided information is saying and the potential implications that may occur to the environment as a result of the proposed project. These are some of the main similarities between LCAs and EISs but there are also many differences between the two methods.

LCAs are often used in the private sector to compare different products and processes. Companies often utilize the LCA methodology due to its ability to relatively quickly and inexpensively provide lots of information on environmental impacts. The LCA methodology is an extremely useful tool to compare products and processes to determine environmental impacts, the severity of impacts, life cycle stages of concern, contributing parameters, and more. The SimaPro 7.1 software is especially useful for comparison purposes due to its ability to customize inputs and easily create graphs that compare data in effective ways. The SimaPro 7.1 software is also a great planning tool because it allows for a high amount of customization. Very basic LCAs can be done with only having one input; if more accurate site, product, or process data are needed then more inputs can be put into the programs to be more specific to a certain study. Overall LCA is an effective, relatively inexpensive, and fast decision making tool that allows for comparison studies and high levels of customization. However, downsides to the LCA methodology exist. For one, the program creates the models based on a general region and it is not site specific. Certain data can be input as additional information to create more site specific information. For instance, travel distances for products and materials can be inputted into the database to overwrite the data the program would automatically use but the overall information is generally region specific. In addition, the programs typically use database information that is based off of averages for the same product or process. This data based on averages may not always be the most accurate data for the exact region where the site of interest is located. This is an extremely important factor when considering wind and solar energy due to the fact that the amount of energy that can be produced is very site specific and hard to regionalize.

An EIS contains extensive amounts of information to assist in informed decision making. EISs are often thousands of pages, providing lots of pertinent information based specifically on the site of interest. A major difference between an EIS and LCA is their area of concern. An EIS is concerned with the specific site and the pollution that results at that site and impacts the environment. On the other hand, a LCA is concerned with all environmental impacts no matter where they occur. For example, in a LCA the impacts from mining the materials used for construction and daily operation are included in the environmental impacts. LCA takes a more holistic approach, while an EIS is more site specific. However, an EIS contains massive amounts of site specific data that are not generalized.

As previously stated, EISs contain extensive amounts of information. It is extremely useful to have large amounts of site specific information but compiling this information is extremely timely and costly. While this method is more time intensive and expensive the site specific results are critical when making large scale decisions that will likely adversely impact the environment. In addition, an EIS provides comparison studies of alternative sites and options. For example in the EIS prepared for the Levy

County Nuclear Project, detailed information was not only provided on the Levy County site. In the EIS, information was also provided on various sites around the area to determine if the proposed site was the best suited for the project. In addition, different scenarios of utilizing different energy sources were provided. Providing these comparisons allows for decision makers to not only have pertinent information on the project of question but also to consider the various other options that may be viable.

In addition to an EIS containing data it also includes the review team's analysis that considers the environmental impacts and provides their recommendations. The review team also considers the environmental impacts and determines if there are viable mitigation measures for reducing or avoiding some of or all of the adverse impacts. Environmental impacts should not be the only factor that decisions are based on.

Overall, LCAs and EISs are both extremely valuable decision making tools. They have many similarities and differences which makes each of them more useful in different situations. They both are technical tools that provide information on environmental impacts and they can be used to compare different scenarios. An EIS addresses all of the sustainability pillars and LCA can be combined with LCC and SLCA to also address all of the pillars. A LCA considers all environmental impacts, no matter where they occur, from all stages of construction, operation, and closure. An EIS also considers all stages but is focused on the specific site of question. LCAs are quick and inexpensive while EISs are timely and expensive. However, an EIS provides more information and is more site specific which is necessary to make large scale decisions.

Many differences exist between LCAs and EISs but the differences are what make them more valuable in different situations.

LCAs are extremely valuable decision making tools in planning when quick information is needed on a product's or process' environmental impacts. LCA is also great for comparisons of different scenarios based on environmental impacts. For this case study of comparing the differences in environmental impacts of producing electricity of coal versus nuclear power in Levy County, Florida the LCA methodology is useful as a preliminary tool to gather information about environmental impacts that can be anticipated. For a large scale project such as the Levy Nuclear Plant, a LCA is a good starting place but a full scale EIS should be completed in order to gain more in depth, detailed, and site specific information that can be used for decision making purposes. All of the environmental, social, and economic implications of a project need to be considered in order to make a decision based on sustainable development. LCAs and EISs are important tools that can assist in the decision making process of sustainable development but it is important to note that they should not solely be relied on. It is important to have experts analyze as much information as possible in order to provide for proper decision making. Overall, LCAs and EISs are viable planning tools that have and continue to assist in informed decision making for sustainable development into the future.

## Other Options

It should be noted that although it is honorable to pursue more environmentally friendly energy sources, this should not necessarily be the focus on how to reduce pollution from electricity production. Continuously providing more electricity to meet demand does not tackle the main issue of over consumption of resources and wasteful energy habits. Education on energy conservation should be a focus in order to meet future energy demand. The most environmentally friendly form of producing electricity is not having to produce it at all. If consumers are educated on the importance of reducing and how to reduce energy consumption then future demand of energy may not increase and may actually decrease, even with rising populations.

# CHAPTER 6
# CONCLUSIONS

Over consumption of resources and rising pollution levels has led to the awareness of needing to develop in a more sustainable way. The three pillars that must be met in order to develop sustainably are the environment, economy, and society. Life Cycle Assessments (LCAs) and Environmental Impact Statements (EISs) are tools that can aid urban planners in the decision making process. These tools provide environmental impact data that can be used for comparison purposes in order to aid in decisions that will result in more sustainable development.

To reduce greenhouse gas (GHG) emissions Progress Energy Florida is in the process of permitting two nuclear power units each producing 1,105 megawatt hours (MWh), to produce a total of 2,210 MWh. In order to obtain previous permits, Progress Energy agreed to retire their two oldest coal-fired power plants at their Crystal River site. This will reduce their energy production by 965 MWh. Environmental impacts occur as a result of electricity production and LCAs were completed to approximate the differences that can be anticipated between the two energy sources. Two LCA studies were conducted in SimaPro 7.1 using the Centre of Environmental Science (CML) methodology and another LCA was completed in GaBi 4.4 Software System and Database (GaBi 4.4) using the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) methodology. These studies were completed to determine if switching from coal to nuclear power will be more environmentally friendly, as intended. It was found that overall nuclear power produces less severe environmental impacts, with the exception of some impacts to water and ozone layer depletion.

The usefulness of LCAs and EISs was learned. They are both technical, environmental tools that have many similarities and differences. They can provide information for more informed decision making. LCAs are great for data on environmental impacts that will result everywhere. EISs are more site specific and contain more information but they are more timely and costly. For projects like the Levy Nuclear Plant, it is crucial to have as much information as possible to make informed decisions. In that case an EIS, which is more comprehensive than an LCA, is important. Overall, LCAs and EISs are great tools for decision making.

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# BIOGRAPHICAL SKETCH

Amy Elizabeth Long was born in Stuart, Florida. The middle child of three, she grew up mostly in Jensen Beach, Florida, graduating from Jensen Beach High School in 2006. Growing up in a beach town, Amy cherished being in the outdoors and began learning the importance of preserving the environment. She earned her B.S. in Sustainability and Built Environment from the University of Florida (UF) in 2010. While pursuing her bachelor's degree, Amy became interested in how to actively plan for sustainable development. This interest led her to continue her studies at UF and pursue a Master of Arts in Urban and Regional Planning.

While attending the University of Florida, Amy has been afforded many wonderful opportunities including competing in the 2010 Solar Decathlon Europe competition. As a member of the UF's Team Re-Focus she traveled to Madrid, Spain where the team competed in the international collegiate competition aimed at promoting research and development of efficient, solar powered houses. In January 2011, Amy began interning at SCS Engineers. Upon completion of her M.A. program, SCS Engineers offered Amy a full-time position working as an environmental consultant in their Tampa, Florida office.