Environmental Impact of Energy Resources

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ABSTRACT

Energy production has several direct environmental challenges which include climate change, air pollution, water pollution, land contamination, thermal/heat pollution, and solid waste disposal. Energy related air pollution is a major environmental challenge facing urban areas. Fuel combustion leads directly to emissions and potential environmental harm, while use of electricity does not lead directly to environmental impacts, but its production from fuels leads to emits significant quantities of greenhouse gas emissions and other environmental impacts. However, if electricity is produced from renewable and low carbon sources like wind turbines , solar photovoltaic cells and nuclear has limited direct emissions compared to fossil fuels. Assessment of environmental impacts of energy carriers considers processes from resource extraction, its conversion into secondary energy carriers, consumption, and waste disposal or recycling. The cradle-to-grave approach captures all steps between extracting materials and fuels from the environment until and their returned to the environment. The attainment of decarburization targets and keeping global warming below 2°C threshold requires well-informed energy policy design. Low-carbon electricity supply for all needed to attain the 2°C-compatible energy system, will entail electrification of most of our economy. Life cycle assessment facilitates evaluation of a product over its life cycle, and across various environmental indicators. Energy resources and technologies for power generation are a mix of renewable and nonrenewable e.g. coal, natural gas, hydropower, nuclear power, concentrated solar power (CSP), photovoltaics, and wind power. Life cycle assessment is a tool used to evaluate the environmental impact of energy sources. One major limitation of the standard life cycle assessment methodology is that it ignores the impact of the impact of greenhouse gases. Life-cycle impacts decrease substantially when current fossil fuel technologies diminish in the energy mix, particularly coal. Natural gas use may play an important role during the transition while installation of new fossil options without CO_2 capture should be avoided to minimize emissions. The endogenous integration of life-cycle indicators into energy models adds value to both life cycle assessment and energy systems modelling in their support in energy decision as well as policymaking for sustainable energy transition.

Key Words: Greenhouse gas emissions; life cycle assessment; greenhouse gas emissions; energy sources.

1. Introduction

Globally, countries are devising low carbon energy and electricity policies as a result of the double constraint of depleting fossil resources and climate change from greenhouse gas emissions. The Intergovernmental Panel on Climate Change (IPCC) identified electrification of the global economy combined with the rapid decarbonization of the grid as a key option to reduce greenhouse gas (GHG) emissions and keep global warming under 1.5°C or 2°C. The energy related activities ranging from extraction, conversion, intermediate and final use, are responsible for three quarters of greenhouse gas emissions with most of it coming from combustion of oil. gas, and coal in power generation(García-Gusano et al., 2016). It is important to note that the physical bounds of planet earth are finite with growing need for resources leading to environmental and social concerns. These issues include high level greenhouse gas emissions, climate change, water scarcity, pollution, human health, and land use. Coping measures should focus on reducing consumption of nonrenewable resources and verification of their suitability in terms of sustainability. This is linked to the energy transformation processes taking place under these circumstances. By combining Energy Systems Modelling (ESM) and Life Cycle Assessment (LCA) methodologies produces research field for both analysts and energy planners(García-Gusano et al., 2016; Junne et al., 2021). A key step forward involves the endogenous integration of life-cycle indicators into energy system management (ESM) which is based robust optimization procedures(García-Gusano et al., 2016).

Lifecycle analysis of a fuel or energy resource, often called the fuel cycle or well-to-wheel analysis, is applied to determine overall greenhouse gas (GHG) impacts for all stages of production, transport and use hence direct and indirect emissions are captured(EPA, 2022). Life cycle assessment is an important tool for evaluation of the environmental impact of energy resources and other products. The main limitation of standard life cycle assessment methods is that they ignore time aspect of the emissions (Sproul et al., 2019). Through Life cycle assessments (LCAs) potential impacts of technologies and processes across a detailed set of environmental categories are computed.(Junne et al., 2021).

Greenhouse gas emissions are important indicators of the environmental impacts of power generation. Lifecycle emissions are established by computing the global-warming potential of energy resources through the life-cycle assessment. The values of life cycle emissions are presented in units of global warming potential per unit power produced. The scale applies the global warming potential unit, unit of electrical power, the carbon dioxide equivalent (CO_2e), and, the kilowatt hour (kWh). The assessments cover the full life of the energy resource, from material, fuel mining, construction to operation and maintenance and waste management. A lifecycle analysis of power generation technologies, accounts for resource use i.e. minerals, metals, land use, ozone depletion, fuel use, consumption of water; particulate matter; photochemical ozone formation; toxicity; cancer causing risks; ionizing radiation; human toxicity ; eutrophication i.e. terrestrial, freshwater and marine, eco-toxicity on freshwater; acidification; and climate change (United Nations Economic Commission For Europe, 2021).

Life cycle assessment (LCA) refers to the holistic approach applied in evaluation of the environmental impacts of energy sources and other products as well as systems. In the energy sector, life cycle analysis (LCA) helps in fostering development of energy technologies in a sustainable manner (Paredes et al., 2019). LCA remains a powerful tool used in evaluation of the environmental performance of energy sources, products, processes, and production systems. LCA studies on power generation can focus on the evaluation and calculation of single types or multiple types of power to identify environmental advantages of specific power types or provide the basis for policy and energy conservation measures. Studies show that greenhouse gas emissions intensity of various technologies greatly varies between regions and sources (Zhu et al., 2022).

Overall global warming potentials shows that biomass receives credit for avoiding biomass decay into carbon dioxide and methane thus giving biomass a negative net CO_2 equivalent life cycle emission profile. However, this applies if the residue biomass is left to decay. A zero or net negative CO_2 zero can be achieved by a combination of various power generation. The amounts of life cycle CO_2 equivalents for the various sources of electricity be added up and the total used as an objective for minimization within feasibility constraint.

The Intergovernmental Panel on Climate Change harmonized the carbon dioxide equivalent (CO_2e) findings of the major electricity generating sources in use worldwide in 2014. by analyzing hundreds of individual scientific papers that assessed each energy source. The reports have identified coal as the worst emitter, followed by natural gas, with solar, wind and nuclear as low carbon fuels. Although biomass, hydropower, geothermal and ocean power are regarded as low-carbon fuels, any poor design and other factors lead to higher emissions from the power plants.

Advances in technology and improved efficiencies have the overall effect of reducing the CO_2 emissions over time, hence the need to continuously update the values. As an example, the life cycle emissions for solar, wind and nuclear have been in declining trend over time e.g. nuclear Generation II reactor's CO_2e values are more than those of Generation III reactors. Figure 1 below summarizes the global warming potential for selected energy sources.

1.1. Problem Statement

The transition to renewable energy sources and "green" technologies for power generation and storage should mitigate the climate change from greenhouse gas emissions. The main sustainability challenge for the transition is the dependency on critical materials, processes and other resources that have significant environmental impacts. Beyond the global warming concerns, we have serious sustainability concerns like loss of biodiversity, water scarcity , environmental pollution, and energy security that should equally be addressed during the transition (Ciacci & Passarini, 2020; M. J. B. Kabeyi & A. O. Olanrewaju, 2020).

The issues of energy and environment are seriously interconnected and need comprehensive analysis and understanding of resource management strategies and their consequences. As an example vital water resources depletion and contamination is related to possible shortages in power generation, distribution and use while at the same time the supply of water needs energy(Ciacci & Passarini, 2020). There is therefore need for a system perspective to locate, locate and quantify the impact of human activities and processes on the environment. The Life cycle assessment (LCA) is one of the most inclusive analytical techniques to analyze sustainability tradeoffs and benefits resulting from complex energy and environmental systems(Ciacci & Passarini, 2020; Kabeyi & Olanweraju, 2022).

It is vital to understand the environmental impact, and pros and cons of all types of renewable and nonrenewable energy for comparison to coal and gas for proper planning of the energy transition. (Keith, 2018). It remains a challenge to all countries to provide incentives for long-term, high-capital investment in energy markets that are deregulated and driven by short-term price signals(M. J. B. Kabeyi & O. A. Olanrewaju, 2022b; Kabeyi & Olanweraju, 2022; M J B Kabeyi & A O Oludolapo, 2020). The power sector presents the greatest cost-effective potential for reducing greenhouse gas emissions compared to other sectors like heat and transport, there is growing demand for cost-optimized strategies to reduce emissions and global warming to below 2 ◦C by ensuring near zero emissions by the electricity power sector through careful selection of generation technologies [1]. This may not be realized by applying just the energy system optimization models (ESOMs) since they often just consider direct, on-site carbon dioxide emissions in their assessment of cost-optimized design of energy infrastructure components for power development.

1.2. Rationale Of the Study

Greenhouse gas emissions from fossil fuel combustion are leading sources of climate change (CC). This has forced countries to develop policies new policies on emissions and national energy security aimed increasing the use of renewable energies like ocean energy. The use of these technologies is however not exempt from potential environmental impacts throughout their life cycle(Paredes et al., 2019). LCAs continue to face challenges like variability of several energy sources. The power grid comprises diversified generation technologies and energy leading to varying regional energy mixes while demand and supply is dynamic with significant impact on LCA results. LCAs for power sector should better characterize spatial and temporal characteristics for accuracy (Jordaan et al., 2021). The demand for clean power has become part of the national and international dialogue among lenders, lawmakers, and utilities, hence the need for very accurate and comprehensive data on greenhouse gas emissions by various sources of energy for use by policy makers, energy planners and investors (NREL, 2021).

Analyzing the environmental impact of processes in power generation makes it possible to put in place effective measures for control of energy consumption and emissions by power plants. Therefore life cycle assessment (LCA) method is applied to analyze the environmental impact of various power generation methods(Wang et al., 2018). As the most effective tool in environmental management, LCA is used to comprehensively and scientifically analyze the environmental impact from cradle to grave and identify opportunities for mitigating environmental impact from emissions and other pollutants(Wang et al., 2018).

2. Life Cycle Analysis (LCA) In Energy and Power Generation

A life-cycle inventory is used to quantify energy and material requirements, emissions, solid wastes, waterborne emissions, and other releases for the entire life cycle of a product, process, or activity. An inventory analysis generates a list of quantities of pollutants released and amount of energy and material consumed by a process or system(International Energy Agency, 2020).

2.1. The Life Cycle Inventory (LCI)

The Life Cycle Inventory (LCI) is the phase of a life cycle assessment (LCA) which involves data compilation whose objective is to quantify resources used and the related emissions for each process in an energy system. A Life Cycle Inventory can be summarized in a statistical package, a spreadsheet, or dedicated LCA software like openLCA, SimaPro and Gabi. Quite often, the life cycle inventory (LCI) is designed to accommodate or facilitate a sensitivity analysis in the Life Cycle Impact Assessment (LCIA) stage(Nieuwlaar, 2013). Results are segregated by specific process, life-cycle stage, media i.e., air, water, and land, or any combination thereof.

Multiple sources of data can be used to develop an LCI e.g.: academic literature, primary data, LCI databases and expert opinions which the sources used being determined by the specificity required by the assessment. Production reports and interviews can provide crucial data and information for the LCI. (Curran, 2008; Nieuwlaar, 2013).

At the LCI phase, all relevant data are collected and organized to form a basis for evaluation of comparative environmental impacts or possible improvements. There is no predefined list of data quality goals exists for all projects and the number and nature of data goals depend on the level of accuracy needed to inform the decision makers in the process(Curran, 2008).

The level of required detail depends on the size of the system and the purpose of the analysis e.g., for a large system with several industries, some details may not be important or significant contributors and can therefore be omitted with little or no effect to the accuracy or application of the results. For a study with a specific focus, e.g., comparing generation technologies, it is important to capture all inputs even in very small quantities. Life-cycle inventory analyses can enable comparison of technologies or products and considering environmental factors in material selection. Inventory analyses can be applied in policymaking, by governments to develop regulations on resource use and environmental emissions(Curran, 2008).

2.2. Lifecycle assessment for Renewable Energy sources

The lifecycle analysis for renewable fuel standard (RFS) captures the emissions related to feedstock production and transportation, fuel processing and supply/distribution, and use of the finished fuel. The best fuel pathways to meet the GHG reduction thresholds is determined by comparing the sum of all lifecycle emissions for renewable sources energy and direct emissions from the baseline petroleum fuel. (EPA, 2022). Figure 1 is an illustration of processes and inputs involved in production and consumption of fuels. It is noted that the inputs in form of materials and energy start at the farm level or mines and transportation to the processing facility are accounted for. In the processing facility, more materials and energy are used to make the final product or fuel which must be delivered to the market or consumers in processes where more energy is consumed. Related products or coproducts may also be produced and processed for delivery to the market.

2.2.1. Feedstock Production and Transportation

Analysis of feedstock production takes into consideration the domestic and international agricultural/forestry sector-wide impacts of biofuels. Impacts determined by modeling the market impacts more use of energy sources based on relevant scenarios(EPA, 2022). Under energy feedstock production and transportation, the analysis considers.

i.) The sector impacts like increases or decreases in feedstock and livestock production.
ii.) Impacts from use of fuel co-products in e.g., use of distillers' grains as livestock feed.
iii.) Emissions from land use changes, like cultivating of new land for feedstock.

Feedstock analyses are usually country neutral which implies the point-of-origin or different is not important. Average impacts of using a certain amount of a feedstock in production e.g., for biofuel is captured as opposed to an alternative use. The impacts are likely to be the same regardless farm of origin for the specific feedstock used in production. The analysis also captures emissions that are associated with transporting the feedstock the fuel processing or use facility(EPA, 2022).

2.2.2. Fuel Production and Distribution

The analysis for fuel production stage involves emissions associated with a specific type of fuel production technology, which captures all energy and material inputs consumed in the production process and the impacts of any co-products. Analyzed include material, energy inputs used for processing, handling, and storage of feedstock, intermediate products and co-products, and the resulting fuel. Emissions are computed using emissions factors for processing energy like natural gas, coal and electric power consumed during fuel production. Upstream emissions are associated with transport, extraction, and distribution of energy, on an average basis. Also included in the analysis are upstream emissions associated with significant material inputs used for fuel processing e.g. methanol for biodiesel production. All activities not clearly related to the fuel lifecycle like offset projects or emissions related to physical and organizational infrastructure like facility construction, employees commuting to the facility are not included. However, emissions associated with distributing of finished fuel to the consumer are included in the analysis(EPA, 2022).

2.2.3. Co-products

Co-products are used in modeling of the sector energy. For some co-product's emission evaluation considers emissions impacts of the most likely application and products displaced in the market. Analysis of co-product a applies globally hence any GHG emissions associated with co-product are captured. The main challenge is to distinguish between different fuel producers based on slight modifications in their co-products and application. However, the variations may not have a significant impact on the emissions analysis, since average impacts on the overall market tends to be similar(EPA, 2022).

2.2.4. Use of the Finished Fuel

This refers to emissions at the actual point of fuel use during combustion. The tailpipe combustion emissions include Sulphur dioxide, carbon dioxide, methane, and nitrous oxide. It is important to consider the complete life cycle of a power plant and energy source when comparing their environmental impacts because different options have impacts and benefits occurring at different times e.g., production, construction or use phases. This is because environmental impacts and benefits may occur at different phases of the life cycle(Cartelle Barros et al., 2022). This makes life cycle assessment very useful for quantitatively and qualitatively identification and describing, the various requirements for energy and materials, as well as emissions and waste released to the environment (Cartelle Barros et al., 2022).

2.3. Life Cycle Impact Assessment Method

A life cycle impact assessment provides a more meaningful basis for comparisons e.g. we may know that know that 8500 tons of carbon dioxide (CO_2) and 5000 tons of f methane are released to the atmosphere both being potentially harmful greenhouse gases, it is through a life-cycle impact assessment (LCIA) that we can determine has a greater impact. In terms of smog formation? Or which is worse than the other? Or what are the potential impacts on global warming? The LCIA uses science-based characterization factors, to determine the impacts of each emission to the environmental (Curran, 2008).

Life cycle impact assessment (LCIA) is part of life cycle assessment (LCA) whose objective is to evaluate and understand the magnitude and significance of environmental impacts for a product system across its life cycle(Zhu et al., 2022). Life cycle impact assessment involves characterization of impacts and selection of impact assessment categories based on their contribution to the normalized and weighted analysis results. There are two basic approaches that can be used to characterize environmental impacts, namely.

i.) The midpoint approach and midpoint indicators recommended by the EC Environment Footprint Guidelines [12, 13] or
ii.) The endpoint approach and endpoint indicators.

These e approaches are different in terms of objectives and robustness, a comprehensive LCA may display the results using both. midpoint and endpoint approach and the endpoint and endpoint indicators approach but the conclusions remain the same. The term "impact" is generally used as the shorthand for "potential impact", as it is defined in the ISO standards. Therefore, in the lifecycle assessment (LCA), "impact" associated terms like "impact assessment" or "impact category" is associated with the potential detrimental effects that a substance or a stress can leave on the environment, resources or human health or resources. Therefore, only potential environmental impacts are regarded as real impacts influenced by factors usually not included in the study. "The LCIA does not have to quantify any actual, specific impacts associated with a product, process, or activity, but seeks to establish a linkage between a system and potential impacts(UNECE, 2022)

3. Environmental Impact of Renewable Resources

Power generation from solar, wind, and hydropower ranks high in terms of sustainability with respect to emissions. Geothermal requires combined production of heat and electricity to be as competitive as wind, solar and hydro. Significant amounts of fossil fuels are used in harvesting and processing biomass fuels making biomass electricity generation worse than noncombustible renewables(M. J. B. Kabeyi & O. A. Olanrewaju, 2023a; Kabeyi & Olanweraju, 2022). Photovoltaic cell manufacture requires high energy and material input making solar photovoltaic to have relatively high life cycle emissions, with SO_2, being in the order of magnitude as the emissions from fossil fuel sources. Lifecycle emissions for solar photovoltaic can be reduced by recycling of materials (Nitsch et al., 2004).

The main source of environmental impact for renewable energy technologies is as a result of emissions from upstream processes, like equipment or component manufacture and transportation. It is recommended that the evaluation of emerging technologies be based on conditions that represent conditions at the time of their entry to the market, as opposed to the environmental load from replacement technologies(M. J. B. Kabeyi & O. Olanrewaju, 2023; M. J. B. Kabeyi & O. A. Olanrewaju, 2022a).

The various environmental impacts \ impacts from energy generation are health effects, loss in yield of crops, damage of materials, and other external costs. A proper or right price requires a surcharge on the energy price which accounts for environmental damages from power generation activities and processes. The challenge remains ho to quantify the environmental impacts and the subsequent monetary valuation of the externalities. Internalization of the environmental damage costs helps improve the competitiveness of renewable energy sources (Nitsch et al., 2004).

4. Developing Temporally Resolved LCA Data

There are two primary phases in the lifecycle of a n energy technology, namely the construction phase which often takes place within the first year of the lifetime and the second phase which is operation and maintenance which occurs in the entire lifespan after construction. These two phases can be used to define the temporal emissions of a technology(Sproul et al., 2019). To apply the DGWI and obtain a monetized impact of emissions, a temporally resolved Life cycle assessment emissions of conventional electricity-generation technologies like coal, wind, nuclear and solar is used. Another important component is the temporally resolved LCA emissions for post combustion carbon capture and sequestration (CCS) in coal and natural gas systems.

4.1. Operational life cycle emissions

Operational emissions of CH_4 and N_2O are often negligible for conventional PV, CSP, nuclear, and wind with less than 6 g of CO_2-eq per kWh in all case scenarios analyzed. (Sproul et al., 2019). Table 1 shows the construction related emissions of conventional energy sources.

Table 1. Life Cycle Emissions: Construction (Sproul et al., 2019)

	Technology	CO_2(g/kWh)	NH_3 (g/kWh)	N_2O(g/kWh)	Total (combined)	Rank
1	Coal	41	0.04	0.001	41.041	3
2	Coal with CCS (90%)	56	0.06	0.002	56.062	4
3	Natural gas	23	0.03	0.001	23.031	1
4	Natural gas with CCS (90%)	30	0.04	0.001	30.041	2
5	PV	949	5.58	0.015	954.595	8
6	CSP	606	1.53	0.0175	607.5475	7
7	Nuclear	89	0.18	0.001	89.181	5
8	Wind	97	0.32	0.008	97.328	6

From table 1, it is noted that the conventional power sources have different construction related emissions with natural gas having the lowest construction related emissions followed by coal, nuclear, wind and solar respectively. Solar photovoltaic has the highest construction related greenhouse gas emissions while the fossil fuel power plants have lowest construction related emissions. Coal with CCS at 90% has higher construction emissions than conventional coal. The same applies to natural gas where natural gas with CCS technology has more construction emissions compared to conventional natural gas power plants.

4.2. Operational life cycle emissions

Life cycle emissions can be broadly divided into construction related emissions and the operation related emissions. Table 2 shows the operational greenhouse gases of conventional power generation technologies.

Table 2. Life Cycle Emissions: Operational Greenhouse Gas Emissions (Sproul et al., 2019)

	Technology	CO_2(g/kWh)	NH_3 (g/kWh)	N_2O(g/kWh)	Total(combined)	Rank
1	Coal	936.00	3	0.0001	939.0001	8
2	Coal with CCS (90%)	152.00	0.06	0.0001	152.0601	7
3	Natural gas	384.00	0.03	0.0001	384.0301	6
4	Natural gas with CCS (90%)	69.00	0.04	0.0001	69.0401	5
5	PV	0.10	00	0.000	0.10000	1
6	CSP	17.0	00	0.000	17.000	4
7	Nuclear	4.0	00	0.000	4.0000	3
8	Wind	0.1	00	0.000	01.000	1

From table 2, it is noted that photovoltaics and wind have the lowest life cycle emissions followed by nuclear which has got less operations lifecycle emissions than CSP Natural gas with CCS has the lowest operational emissions among fossil fuel sources with conventional coal power plants having the highest operational life cycle emissions.

4.3. Life cycle emissions based on CO_2, NH_3 and N_2O Emissions

The total life cycle emission consists of both construction and operational greenhouse gas emission. Table 3 shows total life cycle emissions and ranking for coal, natural gas solar photovoltaic and CSP, nuclear and wind.

Table 3: Total life cycle emissions for power generation technologies

	Technology	Total constructional(g/kW)	Total operational(g/kW)	Combined emissions	Rank
1	Coal	41.041	939.0001	980.0411	9
2	Coal with CCS (90%)	56.062	152.0601	208.121	4
3	Natural gas	23.031	384.0301	407.0611	6
4	Natural gas with CCS (90%)	30.041	69.0401	99.0811	3
5	PV	954.595	0.10000	954.6950	8
6	CSP	607.5475	17.000	614.000	7
7	Nuclear	89.181	4.0000	93.1810	1
8	Wind	97.328	01.000	98.3280	2
9	Geothermal			4-740 gCO2/kWh	5

From table 3, it is noted that based on total life cycle emissions, conventional coal technology remains the most polluting followed by PV and CSP respectively. Nuclear followed by wind has the lowest total lifecycle emissions which implies that nuclear is superior to the renewable sources of energy in terms of life cycle emissions. Natural gas with CCS is also superior to renewable energy sources based on CO_2, NOx and carbon dioxide emissions combined.

However, based on long term operations, power plants with less operational emissions become superior in mitigating global greenhouse gas emissions in the long run.

4.4. Operational CH_4 and N_2O Emissions Are Considered Negligible for Low Emissions Technologies.

The present value of emissions for each year can be obtained by integrating the DGWI values with temporally resolved LCA emissions for each year represented by a mass of CO_2-eq. As shown in eq 2, these present values of emissions represents emissions that are weighted based on their impacts when they are released relative to the impact of CO_2 in the present. Mean present value of emissions overall years (*n*) of a technology's lifetime can be obtained using equation 3 to generate a single emissions value, which includes temporally resolved impacts quantified in g of CO_2-eq per kWh unlike the traditional LCA method(Sproul et al., 2019).

$$\text{present value}_{\text{GHG},i} = \text{emissions}_{\text{GHG},i} \times \text{DGWI}_{\text{GHG},i}$$

(2)

$$\text{mean present value} = \frac{\sum_{i=1}^{n} \text{present value}_{\text{CO}_{2,i}} + \text{present value}_{\text{CH}_{4,i}} + \text{present value}_{\text{N}_2\text{O}_i}}{\sum_{i=1}^{n} \text{electricity generated}_i}$$

An LCOE is computed after defining all costs that are associated with generation technology resolved over the lifespan of a conversion technology. This LCOE is the minimum selling price of electricity for one to offset all production costs, that includes the impacts of emissions and therefore gives a more realistic and acceptable internal rate of return for the power plant. Integration of emission costs into the LCOE directly merges temporally resolved LCA with TEA to accommodate dynamic impacts of emissions over the time of a conversion technology. A dynamic TEA considers analysis of private costs e.g. external social costs of greenhouse gases through a mechanism like a carbon tax(Sproul et al., 2019).

4.5. Social Costs of Greenhouse Gases

It is important to compare the monetized impact of greenhouse gas emissions in the future with present monetized impacts of CO_2 emissions. The monetized impacts include social costs of greenhouse gases developed by the Interagency Working Group on Social Cost of Greenhouse Gases. Development social cost of greenhouse gases can be achieved using the IAMs (model) run under two different scenarios where the first scenario tracks the global gross domestic product (GDP) for a specific future global emissions pathway up to the year 2300 and the second scenario analyses the same pathway with one extra pulse of greenhouse gas emitted for the years under consideration. The difference in the results of two scenarios represents the monetized social damage due to a marginal greenhouse gas emission(Sproul et al., 2019).

The process is done across three separate IAMs (PAGE, DICE, and FUND) for a range of five potential socio-economic emissions scenarios with each model and scenario values being averaged to yield a single damage value which is then discounted back to a present value by application of economic discount rate. Current estimates for the social cost of greenhouse gases range from low (2.5%), middle (3%), and high (5%) economic discount rates. An extra cost is used (fourth cost) to account for abnormally higher than expected damages. This low probability high impact damages outside the 95th percentile is discounted back at 3%, to produce the low probability high impact (3%–95th) social cost. The social cost of greenhouse gases for the four identified are shown in table 2(Sproul et al., 2019).

Analysis shows that th**e** social costs increase for greenhouse gases emitted in future years. The increase is due to exponential damage functions representing scenarios where global systems become more stressed over time. By applying the growing social costs of SC–CO_2, SC–CH_4, and SC–N_2O values, it is possible to derive a dynamic global warming impact (DGWI) that can be used to compare the monetized impacts of greenhouse gas emissions for today's environmental and economic conditions. This approach weights the value of emissions on the basis of the monetized impact at a given time which is analogous to the present value of money(Sproul et al., 2019).

4.6. Deriving the Dynamic Global Warming Impact

By leveraging the social cost of greenhouse gases, a Dynamic Global Warming Impact (DGWI) is developed to compare the monetized impact of a marginal emission released in a future year, to the monetized impact of a marginal CO_2 emission released in a reference year. The difference obtained is a representation of the change in monetized impact of emissions as a result of dynamic greenhouse gas concentrations and socio-economic damage caused. Equation 1 shows how the DGWI is derived as a ratio of the social cost of a particular greenhouse gas (GHG) in a future year (*i*) to the social cost of CO_2 in the present year e.g. 2020(Sproul et al., 2019). Equation1.

$$\text{dynamic global warming impact}_{GHG,i} = \frac{\text{social cost}_{GHG,i}}{\text{social cost}_{CO_2,2020}}$$

The DGWI values can be derived for all emissions like CO2, CH_4, and N_2O using SC–CO_2, SC–CH_4, and SC–N_2O, respectively. The DGWI makes a comparison of monetized damage of a given gaseous emission to another and accounts for the time when the emission occurs. Therefore, the DGWI converts individual gases to a CO_2 equivalent, like it is in the case of GWP. The same range of DGWI values are produced as the range of discount rates applied to social costs. Therefore equation e.g., 1 is applied on the four standard discount rates for each year analyzed. The computation includes comparison of social cost based on a specific discount rate compared to the present social cost of CO_2 on the same discount rate. The 3% discount rate is the central value of social cost estimates and is often used in the literature as baseline for analysis in many studies(Sproul et al., 2019).

5. RESULTS AND DISCUSSIONS

All types of energy have some environmental impacts, although fossil fuels sources like coal, oil and natural gas have more impact compared to renewable energy sources. The various impacts associated energy production and consumption include water and air pollution, damage to public health, habitat loss and wildlife loss, water use, land use, and global climate change like warming(M. J. B. Kabeyi & O. A. Olanrewaju, 2020; Moses Jeremiah B Kabeyi & Akanni O Oludolapo, 2020).

The intensity and type of environmental impacts varies with technology used, location, energy resource, among other factors. It is important to understand both future and current environmental issues related to each energy resource so that necessary steps are put in place to effectively avoid or minimize expected impacts.

5.1. Environmental Impact of Various Renewable Sources

The renewable energy sources are largely clean with fewer negative impacts to the environment. Table 4 is a summary of the function and environmental impacts of various renewable sources of energy.

Table 4:

	Resource	Impacts
1	Hydropower	Hydropower can have massive hydroelectric dams and small run-of-the-river plants. Dams with storage require huge tracks of land which often leads to forced relocation of people from their settlements. Small and medium power plants including pumped storage hydro are continuously developed globally.
2	Solar	Solar provides a tremendous resource for clean power production. Environmental impacts of solar are land use and habitat loss, use of water use, and the use of hazardous materials solar equipment manufacture to the extend which depends on technology and method applied
3	Geothermal	Geothermal resources for power generation are located near “hot spots” where hot molten rock is close to the earth’s crust and produces hot water. Enhanced geothermal systems (or hot dry rock geothermal), can also be used by drilling into the earth’s surface to reach deeper geothermal resources, to enable broader access to geothermal energy, Geothermal power plants differ in technology and carbon footprint e.g., dry steam, flash, or binary and the type of cooling technology e.g., water or air. The Environmental impacts based on the conversion and cooling technology adopted
4	Wind	Wind power is one of the cleanest and most sustainable ways to produce with no toxic pollution or global warming emissions. Wind energy is abundant, inexhaustible, and affordable, making it a viable

		and large-scale alternative to fossil sources of energy. Environmental challenges related to wind power generation death and injury to migratory birds, wildlife and habitat.
5	Biomass	Biomass power plants are quite like fossil fuel power plants mainly due to the involvement of combustion to generate heat for steam and power generation. For biomass power plants, the feedstock can be sustainably produced while fossil fuels are non-renewable. Biomass sources for power generation include. crops residues, energy crops, like switchgrass, animal manure, forest products and waste, and urban waste. The method of biomass production and preparation affects the land use and life-cycle global warming emissions impacts of producing power from biomass.
6	Hydrokinetics	Hydrokinetic energy, which includes tidal, and wave power and many encompasses energy technologies, that are still at experimental level or early stages of deployment. The impact of largescale deployment has not been observed yet, but potential and impacts can be projected.

From table 4, it is noted that although renewable energy sources are regarded as environmentally friendly, they have negative impacts especially with respect to upstream and downstream activities e.g. equipment production, disposal and recycling.

5.2. Summary of Environmental Impacts by Source

The environmental challenges emerging from the production and use of energy sources are well acknowledged today and includes global climate change, acidification of ecosystems, exposure to nuclear radiations, nuclear accident risks and public health effects from air pollution. Renewables offer significant promise in the reduction of environmental impacts of energy use because the technologies largely rely on natural energy and material flow cycles(M. Kabeyi & O. Olanrewaju, 2022; M. J. B. Kabeyi & O. A. Olanrewaju, 2023b) The conversion process in noncombustible renewable sources of energy like wind , solar and hydro is , practically emission free, but their life cycle has emissions related to the production of equipment and related operations(M. J. B. Kabeyi & O. Olanrewaju, 2023). Energy sources can be compared based on factors like process energy demand, equivalent greenhouse gas emissions, acidification, and resource extraction for both upstream and downstream activities. (M. Kabeyi & O. Olanrewaju, 2022; Nitsch et al., 2004). These characteristics for difference energy sources are presented in figure 1.

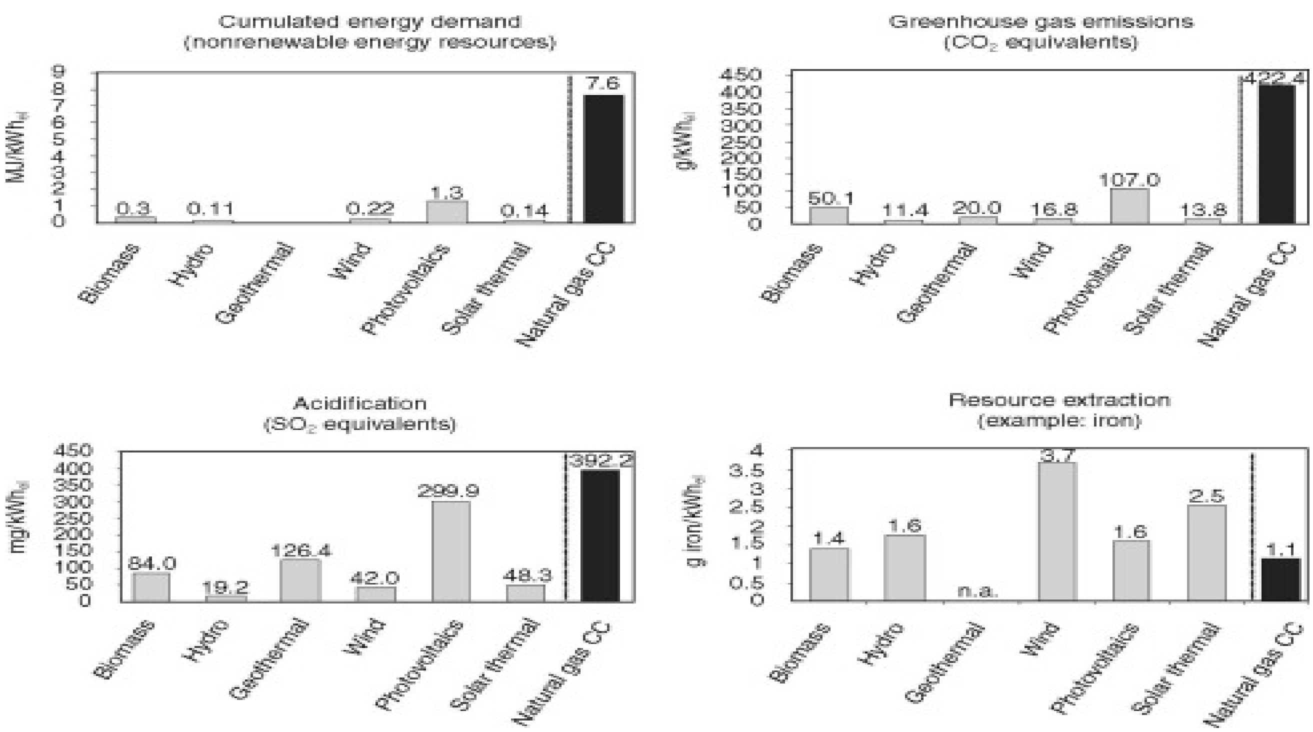

Figure 1: Environmental impacts of renewable energy sources as compared with Natural gas.

From figure 1, it is noted that natural gas has highest acidification factor followed by photovoltaics, and geothermal while hydro has the lowest. Based on natural gas has the highest value followed by photovoltaic while solar thermal and hydro have the lowest. Based on CO_2 equivalent or greenhouse gas emissions, natural gas has highest followed by solar photovoltaics, while hydro, solar thermal have the lowest.

Power from wind, solar and hydropower, is regarded as the most sustainable resources due to low greenhouse gas emissions and being renewable. The critical drawback of renewable energy is higher demand for nonenergy resources compared to fossil fuel options as shown in figure 1 above which shows that wind has highest resource extraction followed by solar while natural gas has a lower value than solar, wind, hydro and biomass. This could however be mitigated by material recycling (Nitsch et al., 2004).

5.3. Life Cycle Emissions of Renewable Energy Sources

Studies show that the average greenhouse gas emissions for renewable energy derived electricity production are 34 and 50 g CO_2-eq./kWh for wind and solar PV, respectively, 20–80 g CO2-eq./kWh for concentrated solar power, and 40–80 g CO2-eq./kWh for geothermal(Uihlein, 2016).

Table 4: Life cycle emissions and ranking for various conversion technologies.

	Energy	**Conversion**	**gCO_2eq/kWh**	**Rank**
1	Hard Coal	PC without CCS	1000	22
		IGCC, without CCS	850	21
		SC without CCS	950	20
		PC with CCS	370	18
		IGCC with CCS	280	16
		SC, with CCS	330	17
2	Natural gas	NGCC, without CCS	430	16
		NGCC, with CCS	130	14
3	Hydro	660 MW	150	15
		330 MW	11	2
4	Nuclear		5.1	1
5	CSP	Tower	22	9
		Trough	42	13
6	PV	poly-Si, ground-mounted	37	10
		poly-Si, roof-mounted	37	10
		CdTe, ground-mounted	12	4
		CdTe, roof-mounted	15	8
		CIGS, ground-mounted	11	2

		CIGS, roof-mounted	14	7
7	Wind	Onshore	12	4
		Offshore, concrete foundation	14	7
		Offshore, steel foundation	13	6
8	Geothermal	Conventional	38	12
9	Bagasse cogeneration plants		624	19

From table 4, the PC without CCS has the highest life cycle emissions followed by IGCC, without CCS. The technologies and energy sources with lowest life cycle emissions based on the analysis is nuclear followed by medium scale hydro and ground mounted PV CIGS, ground-mounted then onshore wind technology.

Life cycle CO_2 equivalent which includes albedo effect for common electricity generation technologies arranged in decreasing order based on the median (gCO_2eq/kWh) values. Wind onshore technology has the least average life cycle emissions followed by nuclear and offshore wind conversion systems. Coal PC without CCS has the highest lifecycle emissions. The production of sugarcane which produces bagasse fuel transfers about 241 kg of CO2 eq /ton of sugar produced. Each hectare of sugar cane transfers about 2,406 kg of CO_2 equivalent per year(Baker & Lahre, 1977).

6. Conclusion

The attainment of decarburization targets and keeping global warming below 2°C threshold requires well-informed energy policy design. Low-carbon electricity supply for all needed to attain the 2°C-compatible energy system, will entail electrification of most of our economy. Life cycle assessment facilitates evaluation of a product over its life cycle, and across various environmental indicators. Technologies assessed include coal, natural gas, hydropower, nuclear power, concentrated solar power (CSP), photovoltaics, and wind power. Life cycle assessment is a tool used to evaluate the environmental impact of energy sources. One major limitation of the standard life cycle assessment methodology is that it ignores the impact of the impact of greenhouse gases. Life-cycle impacts decrease substantially when current fossil fuel technologies diminish in the energy mix, particularly coal. Natural gas use may play an important role during the transition while installation of new fossil options without CO_2 capture should be avoided to minimize emissions. The endogenous integration of life-cycle indicators into energy models adds value to both life cycle assessment and energy systems modelling in their support in energy decision as well as policymaking for sustainable energy transition.

Total life cycle GHG emissions from nuclear power and renewable energy resources are lower and generally less variable than those of fossil fuels. The cradle to grave, coal-fired electricity produces about 20 times more GHGs per kilowatt-hour than solar, wind, and nuclear electricity based on median estimates for each technology. Renewable energy and low carbon energy sources play an important development of sustainable electricity system. The study demonstrates that renewable power has a great advantage over thermal power, among which traditional hydropower has the lowest GHG intensity. Solar PV power generation has a lower GHG intensity in high-radiation areas such as, wind power has more advantages in coastal areas and some areas with rich wind resources.

The deployment of wind turbines and solar contribute to the climate impact of power generation. A significant reduction in life cycle GHG emissions is realized by deployment of wind offshore, CSP and nuclear power. Additionally, nuclear is a reliable base-load power plant with capacity factor greater than 0.9 but can easily cause considerable cost increases by up to 63% higher than possible minimum cost solution. Hydrogen can play a leading role in life cycle peak load supply as life cycle emissions of the power system continue to diminish. Although renewable energy sources have some environmental impacts, they compare favorably to fossil fuel sources and therefore they remain key to the energy transition.

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