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ESTIMATION OF POTENTIAL HEALTH IMPACT OF ELECTRICITY GENERATION USING SIMPACTS MODEL

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Abstract

The global drive towards affordable, reliable and sustainable electricity generation without carbon emissions is a crucial goal for modern industrial society. To this end, the development of baseload power plants, including hydroelectric, coal, gas-fired and nuclear power plants, has been pivotal in driving global industrialization due to their continuous operation and low cost per unit of electricity. Despite their advantages and the critical role they play in socioeconomic development, studies have shown that atmospheric emissions from especially fossil fired technologies can pose significant health risks that cannot be ignored. Therefore, it is crucial to assess the environmental and human health implications of these technologies. The study evaluates the health impacts of emissions from coal, gas and nuclear power plants on the local population near the site of operation. The study used the Simplified Approach for Estimating Impacts of Electricity Generation (SIMPACTS) model to estimate the atmospheric emissions impact of electricity generation technologies on human health during regular operation. The comparative study shows that coal power plants have the potential to cause health-related cases associated with PM10 (619 cases per year), sulphates (9,612 cases per year), and nitrate (1,333 cases per year). While the estimated gas power plant cases were lower than those of coal, they also had the potential to cause some adverse health impacts. In contrast, nuclear power plants do not emit particulate matter, sulphates and nitrates but instead, releases some radionuclides under regulations. The assessment showed that the collective dose from the nuclear power plant was estimated at 0.441 man-Sv/year, well below the International Commission on Radiological Protection (ICRP) recommended guideline value. The study provides valuable insights into the health impacts of baseload power plants on the local population near the site of operation. The assessment carried out in this study will inform policy in selecting the best alternative power plant and address climate action targets SDG 13.

Keywords
energy sector emissions, radionuclides, fossil fuels, nuclear, sustainable development, Ghana

Introduction

Electricity is key to the ability of modern societies to function. As such, an increase in industrial consumption of electricity is recognized as an instantaneous indicator of a country's economic growth (Abokyi et al., 2018). Electricity consumption directly reflects economic development (Lin and Liu, 2016; Mawejje and Mawejje, 2016; Wolde-Rufael, 2004). This essential role of industrial electricity consumption in economic growth and development is attributable to the considerable empirical research and policy interest received over the past years (Payne, 2010; Zhang et al., 2017). Globally, electricity demand is projected to increase more than proportionately, and this has informed the various economies of the world today to work hard to expand their electricity generation mix. The case is not different for Ghana, where the government sustained efforts to address the growing demand for electricity within the country. The response to this consideration is the country's quest to adopt a mix of generation options, including hydro, fossil fuels and in recent times, renewables. So far, the interest in renewables, specifically solar is on the rise due to their capability for the grid and off-grid connections (Ghana Energy Commission, 2020; GoG - Ministry of Energy, 2019). However, a number of challenges are associated with the renewable energy penetration in Ghana (Nyasapoh et al., 2022a). Furthermore, the solid national drive for industrialization to achieve high socioeconomic growth, and developing baseload power plants such as coal, gas-fired and nuclear power plants are also being considered. The consideration of the baseload generation sources is mainly to augment the existing hydroelectric and also boost the national electricity capacity (Nyasapoh et al., 2023). This is because these power plants are designed to operate continuously, supply electricity on demand and have low cost per unit of electricity. Undoubtedly, the consideration of nuclear and coal as baseload power technologies is an attempt to ensure affordable, reliable and sustainable electricity generation mix for Ghana (GNPPO & IAEA, 2019; Shenzhen Energy & VRA, 2015). Hence, guaranteeing sustainable energy security for industrialization, socioeconomic development, and international environmental obligations (Debrah et al., 2020; GoG - Ministry of Energy, 2019). Thus, coal is globally recognised asone of the most economical and competitive power generation technologies (Shenzhen Energy & VRA, 2015). Nuclear on the other hand is perceived to have the added advantage of greater security for electricity generation and clean with no greenhouse gas (GHG) emissions (GNPPO & IAEA, 2019).

Generally, every technology has its own risk. Thus, Smith et al. (2013) indicated that energy's effects on human health are not limited to injury to individuals through direct physical or mechanical means but indirect processes such as global and local emissions of pollutants (Markandya, 2012; Smith et al., 2013). The combustion of fossil fuels, including Coal and gas, is considered harmful to the environment. They contribute significantly to atmospheric pollution, including greenhouse gases, while presenting great risks to human health. The total greenhouse gas (GHG) emissions of Ghana in 2016 was approximately 42.15 million tonnes $MtCO_{2e}$, out of which, electricity contributes 16% of the energy sector emissions of 15.02 $MtCO_{2e}$ (EPA-Ghana, 2020). These effects are not limited to individuals working directly at the power stations and the external populace due to the emission of pollutants from the power plant into the atmosphere (Bickel and Friendrich, 2004; Markandya, 2012; Perman et al., 2003; US-EIA, 2019). The emissions from power plants differ from one technology to another, and so do their associated adverse health impacts. Despite the consideration of coal and nuclear to ensure the security of electricity generation in Ghana, there are serious environmental and human health concerns associated with the two energy sources (GoG - Ministry of Energy, 2019; Ministry of Energy, 2010). The electricity generation from coal produces emissions into the atmosphere causing societal harm (Burt et al., 2013; Chien et al., 2023). Nuclear power is faced with societal concerns of spent fuel or waste management and the possible release of radionuclides into the atmosphere that can have serious environmental impacts (Khunsrimek et al., 2023).

Different authors have discussed several adverse health impacts due to cardiopulmonary diseases, lung cancers and others like respiratory diseases (Demin, 2002; Penney et al., 2009; Treyer et al., 2014). Some works conducted on coal and nuclear power plants by researchers in Europe, Asia, and the United States of America have given examples of the impacts of energy generation systems on human health during normal operating conditions or under accident scenarios. Key to these findings was the fact that though these plants contribute significantly to socioeconomic development globally, they also present a significant health risk to humans through atmospheric emission that cannot be downplayed (Caiazzo et al., 2013; Hirschberg et al., 2008, 2016; Hong and Dong, 2000; Levy et al., 2009; Markandya and Wilkinson, 2007; Rashad and Hammad, 2000). The study by Nyasapoh et al. (2022b) on the emssions of fossil power plants for Ghana revealed that adopting clean energy technologies key to realise low external health risk from electricity generation. Therefore, these concerns about energy sources, mainly fossil fuels and nuclear require the assessment of the potential impact of the technologies atmospheric emissions on the environment and the health of people who reside near the generation technologies (Demin, 2002; Menzel et al., 2011; Perera, 2018; Rashad and Hammad, 2000).

Atmospheric dispersion modelling has been used over the years by researchers to predict the environmental and health impact of atmospheric emissions from various sources and air quality studies. Abiye et al. (2016) used AERMOD, an atmospheric dispersion model to estimate the dispersion of pollutants such as SO_x and NO_x released into the atmosphere. Other models have also been used to assess both the sources of pollution and the diffusion of pollutants ranging from chemical to radionuclides in the atmosphere (Abiye et al., 2016; Aliyu et al., 2015; Cretu et al., 2010; Morino and Ohara, 2016; Udiyani et al., 2018). In addition, the versatility and capability of such atmospheric dispersion modelling have attracted their use in studying the impact of electricity generation emissions on the health of humans in various countries (Gao et al., 2017; Kurokawa, 2013; Levy et al., 2002).

As Ghana seeks to diversify its energy portfolio to meet its growing energy demand while also meeting its climate action target and SDG 7, it is imperative that data on all aspects of energy generation are made available to aid decision-making. To this end, the health and environmental impact of all potential technologies that are most often than not downplayed are highlighted. Data on such studies are limited in Ghana. The aim of this study is to assess the potential health impacts of atmospheric emissions from proposed power generation technologies, including coal-fired thermal plants, gas-fired thermal plants, and a nuclear power plant, on the local population near the proposed site in Ghana. The study adopted the Simplified Approach for Estimating Environmental Impacts from Electricity Generation (SIMPACTS) model for the atmospheric emissions impact assessment. Thus, the study intends to give thorough information on the health hazards connected with the proposed power generation methods to enable policymakers and stakeholders in Ghana to make well-informed decisions on energy generation and public health.

Materials and Methods

Scope of the study site

The site in this study is a proposed site for a power generation plant for Ghana, considering electricity generation technologies such as Coal, thermal(oil/gas), and nuclear power plants. The site is located at Dangme East in the Volta region with coordinates latitude 5.971667 and longitude 0.371667. Dangme East is 10.77 km north of Aveyime, 9.80 km south of Battor, and 49.56 km west of Sogakope (Figure 1). Significant towns within this district include Big Ada, Ada Kasseh and Ada Foah (Ghana Statistical Service, 2012). The estimated terrain elevation above sea level is 45 meters. According to the 2010 population census, the population of the district stands at 71, 671.The site was selected because of its proximity to the river as a water body that will be ideal for any type of thermal power (i.e. gas, coal and nuclear) generation, the site's seismic stability, and the population density of the location. The exact location for the study is to allow for a more concrete and even comparison of the emissions and radionuclides on human health.

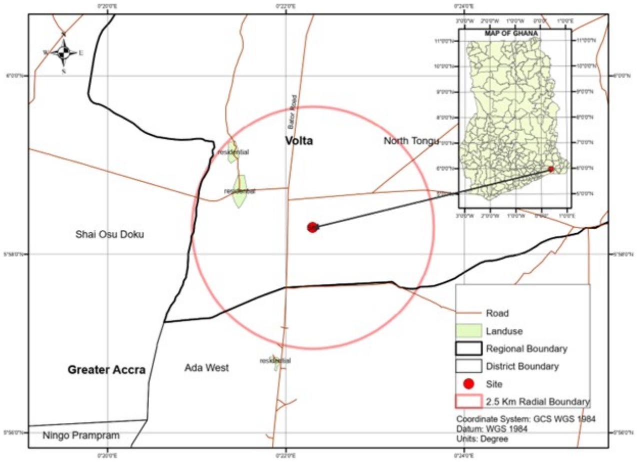

Figure 1. Geographical location of the Site

SIMPACTS Model

SIMPACTS is a program developed by the International Atomic Energy Agency (IAEA) with basis in CALPUFF model. SIMPACTS model analyses the impacts of emissions of various power plant technologies during regular operation and inundation caused by the construction of hydropower plants on human health, agriculture and the environment. The process of SIMPACTS modelling is characterized first by the computation of the ground concentration of the pollutants for each of the technologies using CALPUFF modelling system and several other global databases that have been integrated into the SIMPACTS model. When the pollutant concentration from the power plant is computed, then the physical impacts are quantified using exposure-response. The methodological approaches of the SIMPACTS model consist of the sources of CALPUFF air dispersion model, ExternE, which is the external costs of energy, IAEA Safety Report Series no.19 and the International Commission of Radiological Protection (ICRP) 103. The physical environmental impacts of power plants are quantified in SIMPACTS using a data-driven bottom-up impact assessment approach based on the impact pathways analysis (Bickel and Friendrich, 2004; Corrigall, 2004; Scire et al., 2000).

CALPUFF air dispersion model Methodology

The CALPUFF model for dispersion considers the transport of pollutants as a distributed parameter system governed by a transport equation and particular initial and boundary conditions. Notably, the form and structure of dispersion models depend on its application, type of pollutant to be considered and simulation scale. The CALPUFF model assumes and models the advection of puffs of materials released from point sources (Scire et al., 2000). The basic equation for the CALPUFF model is as shown below:

$$C = \frac{Q}{2\pi\sigma_x\sigma_y} g exp\left[-d_a^2/\left(2\sigma_x^2\right)\right] exp\left[-d_c^2/\left(2\sigma_y^2\right)\right] \quad (1)$$

$$g = \frac{2}{2\pi^{1/2}\sigma_z} \sum_{n=-\infty}^{\infty} exp\left[-\left(H_e+2nh\right)^2/\left(2\sigma_z^2\right)\right] \quad (2)$$

where C is the ground concentration; Q is the pollutant mass; σ is the standard deviation of the Gaussian distribution; d is the distance from the puff centre to the receptor; "g" is the vertical term of the gaussian equation; H is the effective height above the ground of the puff centre; h is the mixed layer height.

The basic point source plume rise relationship is based on the Briggs equations (Briggs, 1985). The Plume rise due to buoyancy and momentum during neutral and unstable condition is given by

$$z_n = \left[3F_m \times / \left(\beta_j^2 u_s^2\right) + 3Fx^2 / \left(2\beta_1^2 u_s^3\right)\right]^{\frac{1}{3}} \quad (3)$$

where F_m is the momentum flux; F is the buoyancy flux; us is the stack height wind speed; x is the downward distance; β_1 is the neutral entrainment parameter;β_j is the jet entrainment coefficient.

All physical quantities are assumed to be uniform within this cross-section and align with the conservation of mass, momentum and energy. The Mass conservation law can be expressed in the entrainment hypothesis, which accounts for the ambient air's entrainment flowing both parallel and across the plume centreline (Hoult and Weil, 1972). The mass conservation equation is given as

$$\frac{d}{ds}\left(\rho U_{sc} r^2\right) = 2r\alpha\rho_a|U_{sc} - U_a cos\varphi| + 2r\beta\rho_a|U_a sin\varphi| \quad (4)$$

The Momentum equation in the wind direction is given by

$$\frac{d}{ds}\left(\rho U_{sc} r^2 (u - U_a)\right) = r^2 \rho w \frac{dUa}{dz} \quad (5)$$

The Energy Equation can be written as

$$\frac{d}{ds}\left(\rho U_{sc} r^2 (T - T_a)\right) = \rho \frac{d\eta a}{dz} w r^2 + \frac{Q}{C_p} r^2 \quad (6)$$

Health impacts Methodology

One of the critical essences of the model is to estimate the health impact of the dispersed pollutants emitted from these electricity generation technologies. To evaluate this, the unit health impacts are quantified using Exposure Response Functions (ERF) which relate the pollutant concentration to the effect on a receptor.

The main reference for the ERFs in the ExternE study by the European Commission. Various epidemiological studies are reviewed, and parameters of ERFs are suggested for their application to European studies (Bickel and Friendrich, 2004). Hence, the slope erf is obtained as a product of increased risk ratio (IRR) (% change in risk per μg/m^3), incidence rate (annual cases per receptor at risk, e.g., adults, child, elderly, etc.), and a fraction of population at risk. In the absence of country-specific studies, Increased Risk Ratio (IRR) in SIMPACTS are assumed constant throughout the world. The values are thus pre-specified to the values in the ExternE study. The calculation of mortality and morbidity impacts is as represented in equation 7.

$$erf_{i,k} = IRR_{i,k} \cdot IR_k \cdot f_k^{pop} \quad (7)$$

where $erf_{i,k}$ *is unit health impact for health impact type k and chemical species type i (cases per year per person per* $\mu g/m^3$*);* $IRR_{i,k}$ *is the increased risk ratio for health impact type k and chemical species type i (% per* $\mu g/m^3$*);* IR_k *is the incidence rate for health impacts/disease k (case per person per year);* f_k^{pop} *is the fraction of the population affected by the health endpoint in question for health impact type k, e.g., a fraction of adults within the exposed population.*

The health impacts due to air pollution are expressed in the impact assessment function, given as the product of population density, unit health impacts, and incremental change in ground-level ambient air concentration due to emission, integrated over the affected area represented in equation 8.

$$I = \int \rho(r)\cdot erf.C(r,t,Q)dA \tag{8}$$

where;I is the health impact (cases per year); ρ*is the population density (person per* km^2*); r is the source-receptor position vector with polar coordinates (r,* θ*); with r being the radial distance from the source (m) and* θ *being the anticlockwise angle from the* 0^o *ray (radian); (r,* θ*) describe the position at the ground level as the origin of the coordinate system is fixed to the emission source; erf is unit health impacts (cases per year per person per* $\mu g/m^3$*);C is the increase in ground-level ambient air concentration (*$\mu g/m^3$*); t is the time (s); Q is the emission rate (ton/year); dA is an infinitesimal area element.*

The compliance of the discrete calculation approach of the SIMPACT model in equation 8 is discretized as shown in equation 9.

$$I_{i,k} = G^2\cdot\sum_{x=1}^{NX}\sum_{y=1}^{NY}\rho_{x,y}\cdot erfi,k\cdot C_{i,x,y} \tag{9}$$

where $I_{i,k}$ *is the health impact for health impact type k and species type i (cases per year); G is the grid size for each exposure area Axy within the impact domain (km);* $\rho_{x,y}$ *is the population density within the exposure area Axy (person per* km^2*);* $erf_{i,k}$ *is unit health impact for health impact type k and species type i (cases per year per person per* $\mu g/m^3$*);* $C_{i,x,y}$ *increases ground-level ambient air concentration within the exposure area Axy (*μ*g per* m^3*).*

Statistics Computation and data analysis

This study employs statistical computation and data analysis which is processed in Excel to produce graphs and pie charts that aid reader comprehension and facilitate discussion of the findings. The input to the Excel computation is the output generated through the SIMPACTS model. By using established methods and models in the SIMPACTS model, the study generates reliable estimates of the health risks associated with different power generation technologies. The use of Excel to visualize the data makes the findings more accessible and understandable for readers, facilitating broader dissemination and application of the results.

Input Data

To assess the impact of potential pollutant discharges, power plants considered include a 500MW Thermal Power Plant that uses gas as fuel, a 700MW lignite coal power plant that utilizes Coal as fuel, and a 1000MW generic pressurized water nuclear reactor that utilizes uranium as fuel.

The study's input data comprised the emission and dispersion of Stack Characteristics (units) of power plants. Constant emission cycle was assumed for all the power plants under consideration. The domain variables that include the 'terrain elevation' and 'land use' derived from the model based on the site's coordinates were presented. The terrain elevation of the domain results was used to compute the population density for the catchment area and used as input data for the receptor and impacts section of the SIMPACTS model. The power plant data and emissions rates of power plants were also presented.

Results and Discussion

Results

Total Health Impacts from fossil fuel power plants

The model was run for each proposed plant based on the site-specific characteristics and the power plants considered in this study. The health impacts were estimated separately for each technology. Table 1 shows the results for the two fossil-fuelled technologies concerning the different health impacts, namely mortality, respiratory and other health-related impacts (restricted activity days and Cardiac hospital admissions), respectively.

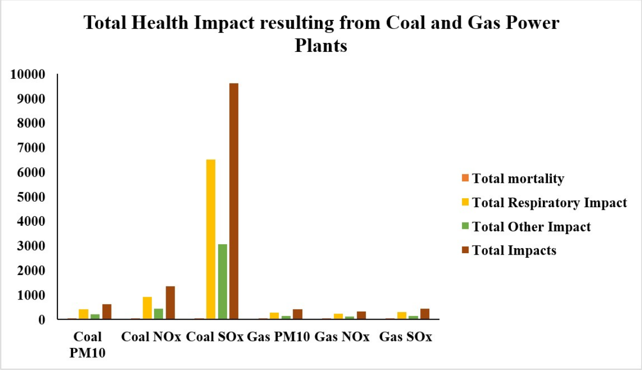

Figure 2. Total health impact resulting from coal and gas power plants

A total of approximately 12,716 cases of health-related cases were recorded per annum for the two fossil-fuelled technologies studied for this work. Estimated health-related cases per annum for Coal fuelled technology recorded was significantly higher (11,565) and often about 10 times more than cases estimated for Gas fuelled technology (1,510) (Table 3.1). For the three pollutants used in these estimations, PM10 (619 cases), SO_x (9612 cases) and NO_x (1333 cases) were all significantly higher for Coal fuelled technology than for gas-fuelled technology (PM10 - 405 cases; SO_x - 428 cases; NO_x - 317 cases), (Figure 2; Table 1). Furthermore, the three health-related impacts estimated, respiratory-related impact recorded significantly higher total cases per annum (8,600 cases) than mortality (62 cases) and other impacts (4,053 cases) respectively (Figure 2; Table 1).

Table 1. Title?

Mortality	Coal			Gas		
Impact / Pollutant	PM10	NO_x	SO_x	PM10	NO_x	SO_x
Chronic Mortality (Entire Population)	3.04	6.65	46.55	1.99	1.59	2.07
Infant Mortality (Children Under 12 Months)	0.0010	0.0030	0.0210	0.0009	0.0007	0.0009
Acute Mortality (Entire Population)	0.022	0.048	0.335	0.014	0.011	0.015
Total Mortality	3.06	6.71	46.90	2.00	1.60	2.09
Respiratory Impact						
Bronchodilator Usage (asthmatic adults, 20+)	23.91	52.40	366.54	15.64	12.48	16.33
Bronchodilator Usage (asthmatic children, 5-14)	2.78	5.96	161.28	1.82	1.42	7.19
Lower Respiratory Symptom (adults with chronic respiratory symptoms)	233.42	503.12	3578.86	152.67	119.85	159.48
Lower Respiratory Symptom (children, 5-14)	156.11	342.20	2393.59	102.11	81.52	106.66
Respiratory Hospital Admissions (entire population)	0.032	0.070	0.489	0.034	0.028	0.035
Chronic Bronchitis (adults, 27+)	0.138	0.303	2.12	0.090	0.072	0.094
Total Respiratory Impact	416.38	904.05	6502.88	272.36	215.37	289.80
Other Impacts						
Restricted Activity Days (working adults, 15-64)	179.40	379.67	2750.58	117.34	90.45	122.57
Restricted Activity Days (non-working adults, 15-64)	20.32	43.01	311.60	13.29	10.25	13.89
Cardiac Hospital Admissions (entire population)	0.032	0.070	0.489	0.021	0.017	0.022
Total Other Impact	199.75	422.76	3062.67	130.65	100.71	136.48
Total Impacts	619.19	1333.51	9612.45	405.01	317.68	428.37

Pollutants contribution to estimated health impacts

Generally, SO_x (10,040 cases) contributed the most to all health impacts and was significantly higher than contributions from NO_x (1,651 cases) and PM10 (937 cases) for both Gas and Coal Power plant technologies (Table 1). The dominant health impact recorded for Coal powered technology were Lower Respiratory symptoms in both adult (3579 cases), and children (2394 cases) and restricted activity days for adult (2750 cases), respectively, and associated with emissions of SO_x. Similarly, for Gas fuelled power plants, Lower Respiratory Symptom in both adult (120 cases), and children (82 cases) and restricted activity days for adults (90 cases) associated with SO_x emissions were the highest recorded health impacts. In addition, the dominant health impact associated with NO_x emissions and PM10 were also Lower Respiratory symptoms for adult (503 and 233 Coal powered plant; 120 and 153 Gas powered plant) and children (342 and 156 Coal powered plant; 82 and 102 Gas powered plant) as well as restricted activity days (380 and 179 Coal powered plant; 90 and 117 Gas powered plant). The two power plant technologies' two least recorded health impacts were infant mortality and acute cardiac admissions, respectively. The two impacts accounted for less than 0.01% of the total health impact resulting from emissions of SO_x, NO_x and PM10 from the two technologies (Table 1).

Generally, in all cases, the health impact associated with SO_x, NO_x and PM10 emissions from Coal fuelled plants were significantly higher than the same compounds emitted from Gas fuelled power plants. Respiratory effects related to emissions of SO_x from Coal (6503 cases) was substantially higher than cases recorded for mortality (47 cases) and other health-related impacts (3063 cases) respectively (Table 1).

Health Impacts/Effects from Nuclear Power Plant

The modelling of nuclear power technology covered human activities such as water intake for drinking, irrigation, fishing, and beach activities. The total health impact covered all possible side effects of radionuclide releases from nuclear technology. Table 2 shows the estimated health impacts of regulated radionuclide releases into the atmosphere over one year that can cause a specific hereditary effect, expected occurrence of cancer (fatal and non-fatal). The total health impact of emissions to the atmosphere was 0.079 cases/year. In addition, it is worth noting that nuclear power plants do not release particulate matter or other pollutants as estimated for gas and coal technologies. The total health impact of liquid effluent relative to the entire population was estimated at 0.018 cases/year.

Table 3 further represents the health impacts of a collective dose of man-Sv/year for ingestion and exceptional cases. The total collective dose of health impact was estimated to be 0.441 man-Sv/year, comprised of radionuclides resulting from inhalation due to regulated releases into the environment (4.067E-01 man-Sv/year). In addition, due to the regulated releases, some deposits would be made on plants and other food sources. Thus, in special cases where tritium and carbon 14 are released, there is an estimated collective dose of 0.035 man-Sv/year.

Combining the total impacts that could be accrued from nuclear technology, the total estimated collective dose from nuclear power plant is 0.441 man-Sv/year, which is lower the prescribed 1mSv/year for the public (Sinclair, 1995). Also, the estimated impact shows that less than one case of health effect can be expected from the regular operation of a nuclear power plant.

Table 2. Health Impacts from emissions to the atmosphere and liquid effluent

	Emissions to the Atmosphere	Health Effects of Liquid Effluent
Impact Type	Impact (case/year)	Effects (cases/year)
Fatal cancer	0.022	0.005
Non-fatal cancer	0.053	0.012
Specific hereditary effect	0.004	9.99E-04
Total Impacts	0.079	0.018

Table 3. Health Impacts of Collective Dose

Pathway Impacts	
Impact Type	Collective Dose (man Sv/year)
Inhalation	4.915E-04
External exposure from cloud	4.769E-06
External irradiation from deposited activity	0.406
Subtotal (ingestion)	4.067E-01
Ingestion special cases	
H-3	2.888E-10
C-14	0.035
Subtotal (special cases)	0.035
Total Collective Dose	0.441

Discussion

Anthropogenic activities have been attributed to the current state of the environment as they pollute the water we drink and, for other purposes, the air we breathe and the soil. The industrial revolution was seen as a great success in technology, society, and the provision of multiple services. However, they came at a significant cost, including producing large quantities of pollutants emitted into the atmosphere. These have a consequential adverse impact on human health and the environment. Environmental pollution at the global scale is considered an international public health issue with multiple dimensions. Social, economic, and legislative concerns and lifestyle habits are related to this significant problem. It is evident that urbanization and industrialization are unprecedented and alarming (particularly due to their negative impact) worldwide in our era. Anthropogenic air pollution is one of the most significant public health hazards worldwide, given that it accounts for about 9 million deaths per year (World Health Organization, 2019).

It is known that the majority of environmental pollutants are emitted through large-scale anthropogenic activities, including the use of industrial equipment, power-plant stations, combustion engines, and cars. Six major air pollutants, namely particle pollution, ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead, have been reported on by the World Health Organization (WHO) as emitted by these technologies (Manisalidis et al., 2020). The detrimental impact of air pollution on all compartments of the environment, including groundwater, soil, air and human health, is well studied (Caiazzo et al., 2013; Cohen et al., 2005; Rashad and Hammad, 2000; Wilson and Suh, 1997). Air pollution significantly contributes to acid rain, global warming and climate change (Wilson and Suh, 1997). Research over the years has shown that the key to fossil-fuelled power generation plants is the impact of airborne pollution. Pollutants such as SO_x, NO_x and PM have been identified as pollutants emitted from fossil-fuelled plants globally (Caiazzo et al., 2013; Hirschberg et al., 2016; Perera, 2018; Treyer et al., 2014). Coal fuelled plants, compared to gas-fuelled plants, are known to produce more of these pollutants (SO_x, NO_x and PM10) during their everyday operations. This has been attributed to the fact that Coal-fired power plants directly emit particulate matter, which comes off as soot alongside other gases that tend to react to form minute particles in the atmosphere, including SO_x and NO_x (Cohen et al., 2005). In this study, Coal presented the highest number of health impact due to SO_x and NO_x emissions accounting for over 85% of total impact estimated (Figure 3b), these impacts are either acute or chronic in nature. These compounds' high levels of emissions account for the significant contribution of impacts, especially for lower respiratory symptoms (Dubnov et al., 2007; Kumar et al., 2014; Tang et al., 2014; Yogev-Baggio et al., 2010). This is observed from the present model, as nearly 68% of the total health impact estimated were associated with respiratory diseases (Figure 3a). Of particular mention are lower respiratory infections, including conditions like bronchitis, asthma, dyspnea, bronchospasm, and even pulmonary edema when inhaled at high levels (Jorli et al., 2017). Pope III et al. (2002) notes that the population living close to power plants are more exposed to high levels of SO_2 and SO_x in general, causing them to suffer from suffocation, wheezing, coughing and loss of lung function. Jorli et al. (2017) observed a similar trend where SO_x from Coal fuelled plants was found to contributor the highest to health impact, with lower respiratory diseases presenting the highest recorded impact. In addition, several research papers have shown that though the cost of electricity generated from Coal is cheap, it contributes quite a high risk to human health and the environment (Finkelman et al., 2021; Munawer, 2018). This is mainly because the external costs of electricity generation represent the uncompensated monetary value of the associated environmental and health damages. Therefore, society will accept the excess costs from electricity production that are not reflected in market prices (Jorli et al., 2017).

Several epidemiological studies have been performed on the health effects of PM. A positive correlation was shown between both short-term and long-term exposures of PM and acute nasopharyngitis (Zhang et al., 2019). Furthermore, long-term exposure to PM for years has been found to cause cardiovascular diseases and infant mortality. Moreover, respiratory

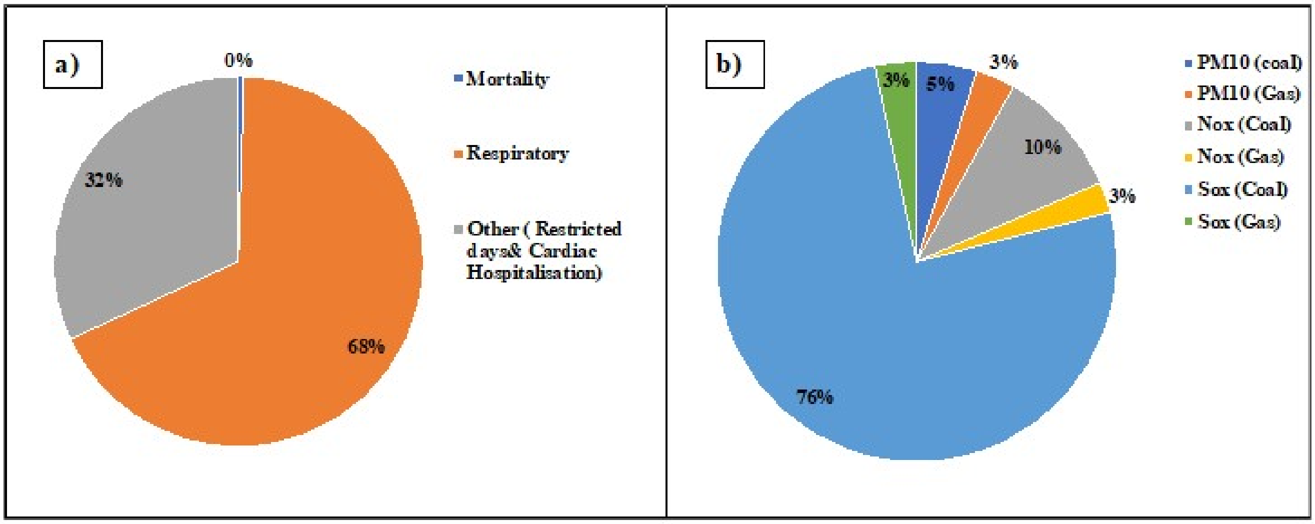

Figure 3. Contributions from each impact

diseases and their effect on the immune system are long-term chronic effects (NHDoES, 2019). Therefore, it is worthy to note that people with asthma, pneumonia, diabetes and respiratory and cardiovascular diseases are especially susceptible and vulnerable to the effects of PM (Abdolahnejad et al., 2017; EPA-USA, 2018; Marzouni et al., 2017; NHDoES, 2019). PM2.5, followed by PM10, are strongly linked with different respiratory system diseases (Bruckmann et al., 2004), as their size permits them to travel into deeper spaces (Boschi, 1999). The chemical and physical properties of the particles determine their toxicity. The components of PM10 and PM2.5 can be organic (polycyclic aromatic hydrocarbons, dioxins, benzene, 1-3 butadiene) or inorganic (carbon, chlorides, nitrates, sulfates, metals) in nature (Cheung et al., 2011). Finally, another factor is the residence time of PM10, and PM2.5 particles in the atmosphere, which is about a day, this permits their stable suspension in the atmosphere and even their transfer and spread to distant destinations where people and the environment may be exposed to the same magnitude of pollution (Wilson and Suh, 1997). They can change the nutrient balance in watery ecosystems, damage forests and crops, and acidify water bodies.

Comparatively, the two fossil-fuelled power plants present more health impacts on the populace due to the emission of SO$_x$, NO$_x$ and PM10 from the combustion of the fuels. In contrast, no such emissions were observed for nuclear power plants. The emission from the nuclear plants were mainly minute amounts of radiation. Thus, nuclear presents a cleaner generation option as it does not emit these key environmental pollutants. Sustainable development Goal 7 (SDG 7) urges to a member state to ensure the provision of clean, affordable, reliable and sustainable energy for all.

Furthermore, the Paris Agreement on climate action places an obligation on signatories to ensure the reduction in greenhouse gas production to limit the global temperature increase in this century to 2 degrees Celsius above preindustrial levels, while pursuing the means to limit the rise to 1.5 degrees. Table 3.4 shows the various emission for Coal, natural gas and nuclear-fuelled power plants. The trend seen is consistent with that seen in the results from the model as discussed earlier in this section. Comparing the nuclear, Coal and gas technologies, it is observed that except for ionizing radiation, both gas and Coal present a higher level of human toxicity and particulate matter formation than nuclear technologies (Figure 4).

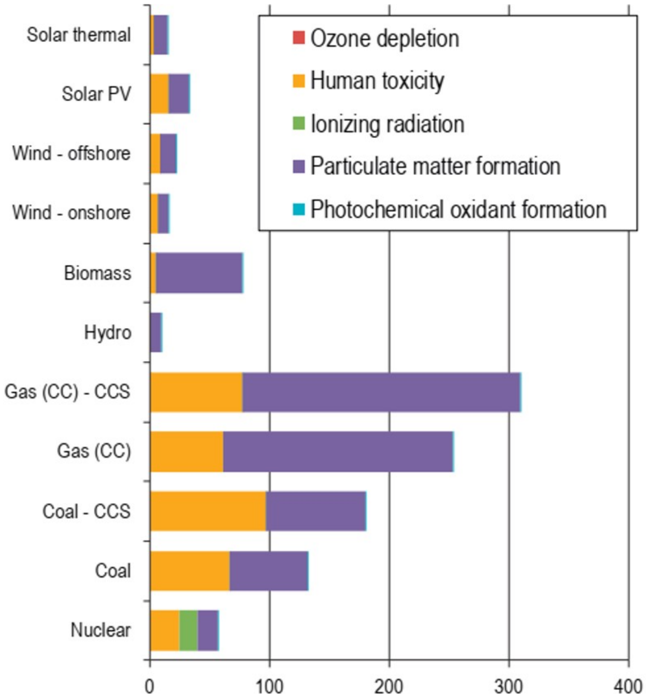

Figure 4. Impact of different technology options on human health measured in disability-adjusted life years (DALYs) (Boschi, 1999)

On the contrary, during the normal operation of nuclear power plants, the collective dose to the public from both liquid and atmospheric effluent is lower than the world's average dose rate of naturally occurring sources (background) radiation which is 2.4 mGy/year. Thus suggesting that the doses received by the populace from a nuclear power plant does not add substantially to the doses received from natural (background) radiations and lower than the regulatory requirement (Mitchel, 2007; UNSCEAR, 2020).

Table 4. Taxonomy of fuel chain discharges (Bernow et al., 1995)

	Coal	Gas	Nuclear
Outdoor Air			
Particulates	x	x	
SO_x	x	x	
NO_x	x	x	
Toxic Metals	x	x	
Co	x	x	
Greenhouse gas/CO2	x	x	
CFCs	x		
Steam	x	x	X
Radioactive	x		X
Secondary Outdoor Air			
Acid Aerosols	x	x	
Acid Deposition	x	x	
Ozone, (HCs, VOCs)	x	x	
Surface Water			
Chemicals	x	x	X
Thermal	x	x	X
Impinge/entrain	x	x	X
Radioactive	x		X
Impoundment			
Consumption	x	x	X
Solid Waste			
Transport	x		X
Volume/ Land Use	x		X
Hazardous/ PCBs Toxics in Ash	x		
Radioactive High			X
Radioactive Low	x		X

Conclusion

The study examined the potential health impacts of coal, gas, and nuclear power plants at the hypothetical location using the SIMPACTS model. The aim was to assess the effects of the power plants on human health to provide essential data to support decision-makers in selecting power plants, particularly for countries seeking to expand their energy resource to boast industrialization drives like Ghana and other developing countries. The study found that coal technology presented the greatest risk to human health with the generation of high levels of nitrogen oxides (NO_X), sulfur oxides (SO_x), and particulate matter (PM). Gas and coal fuelled power plants presented similar pollutant releases, but coal technology had a higher impact on human health. In contrast, the nuclear power plant had significantly lower atmospheric and liquid effluence cases per year compared to the coal and gas power plants. The study estimated a total of 0.079 cases per year from atmospheric dispersion and 0.018 cases per year from liquid effluence for the nuclear power plant, while the combined impacts of all three technologies resulted in a total of 12,716 health-related cases, including mortality, respiratory-related cases, and other health-related effects. The findings of this study have important implications for policymakers, public health officials, and other relevant stakeholders. It highlights the need to carefully consider the potential health impacts of power plants when selecting energy resources, particularly in developing countries seeking to expand their energy supply. It is recommended that policymakers prioritize technologies that minimize the risk of human health impacts and ensure clean, reliable, affordable, and sustainable energy supply. As nuclear technology has been identified as a critical technology to meet climate action goals, it could be a viable option for ensuring clean, reliable, affordable, and sustainable energy supply in developing countries like Ghana. The study emphasizes the importance of incorporating health impact assessments into energy planning and decision-making processes to ensure that power plants are selected in a manner that promotes sustainable development and public health.

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