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Green Completion as a mitigation for BTEX exposure in Gas flaring: Nigeria case study (Exposure assessment and Cost model)

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In partial fulfillment of the requirements for the degree of Doctor of Philosophy in Occupational Safety and Health

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Keywords; BTEX, Gas flaring, Green Completion, Benzene, IELCR, NMVOC, Exposure Assessment.

ABSTRACT

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Akintunde Stephen Akinyemi

Gas flaring is an essential part of the oil and gas industry safety and waste management procedures; however, it presents a potential exposure to BTEX compounds, a group of Non-Methane Volatile Organic Compounds (NMVOC), within up to a 10-mile radius of the flare point.

The physical and the psychological cost of the journey to work, make employees live close to the workplace.

This study examined the perceived exposure of oil and gas industry workers to possible carcinogenic emissions outside the workplace. It looked at the outcomes of the exposure to BTEX through gas flaring drawing on archival data and using Nigeria as a case study. The methodology included a trend analysis, a meta-analysis, and an exposure assessment to develop an incremental excess lifetime cancer (IELCR) risk of the case study population. I developed a cost model for all outcomes, and the sustainability of a green completion strategy for the mitigation of the BTEX exposure through gas flaring is explored.

The results showed that the Green completion policy can be employed to reduce the exposure of the oil and gas host communities to BTEX in gas flaring by at least 80% while yielding a Net impact benefit greater than 1 on a 6-year return on investment period.

DEDICATION

To the loving memories of my dad, Chief Joseph Daramola Akinyemi and my wife Twin, Kehinde Obamuyide, Nee Akintomide. The two most brilliant people I have met.

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Abbreviations

BTEX = Benzene Toluene Ethylbenzene and Xylene.

LMIC =Low Medium Income Countries

NHL = Non-Hodgkin Lymphoma

AML =Acute Myeloid Leukemia

VOC =Volatile Organic Compound

NMVOC =Non-Methane Volatile Organic Compound

NOx =Oxide of Nitrogen

CO =Carbon Monoxide

SOx =Oxides of Sulfur

PM =Particulate Matter

GDP =Gross Domestic product

WHO =World Health Organization

APG =Associated Petroleum Gas

PAH =Poly Aromatic hydrocarbon

GGFR =Global Gas Flaring Reduction Partnership

GWh =Giga Watts Hour

Bcm =Billion cubic meters

MSCF =Million Square Cubic Foot

IEA =International Energy Agency

DRE =Destruction and Removal Efficiency

PDO/PIO = Plan for Development and Operation /Plan for Installation and Operation of facilities for the transport and utilization of petroleum.

US EPA =United States Environmental Protection Agency

IARC =International Agency for Research on Cancer

LD_{50} =Lethal Dose for 50%

CNS =Central Nervous System

MRL =Minimal Risk Level

ATSDR =Agency for Toxic Substance and Disease Registry

OPEC =Organization of Petroleum Exporting Countries

UNEP = United Nations Environmental Program

GNI =Gross national Income

BMI =Body mass Index

DNA =Deoxyribonucleic Acid

IHME =Institute for Health Metrics Evaluation

IELCR =Incremental Excess Lifetime Cancer Risk

CDI =Chronic daily Intake

C = average concentration of contaminant at exposure (mg/m3)

CR = contact rate (m3/day)

EF =exposure frequency (in days per year)

ED = exposure duration (in years)

BW = Body weight (in kg)

AT =Period over which exposure is averaged (day)

SF =Slope factor

1.0: INTRODUCTION.

1.1 BACKGROUND OF STUDY

1.1.1 Air Pollution

Air pollution is the introduction of substances that are potentially harmful to humans, other living things, and the environment into the atmosphere. It may cause discomfort, allergies, diseases, or even death. Clean air is an essential requirement for human health and wellbeing[1]. While cases of severe episodes of air pollution witnessed in Europe and North America before the sixties are no longer commonplace, there has been an increase in chronic and acute air pollution exposure as industrialization increases[2].

Physical activities like volcanoes and sandstorms may cause air pollution; nevertheless, the most release of pollutants to the atmosphere is from anthropogenic sources. Accidental releases may lead to air pollution, but most pollutants release from human endeavors are by design: from industrial activities and other related processes, these could be to control such processes, ensure safe operations, or just for waste disposal.

Historically, the blatant disposal of waste, especially air pollutants, has resulted in many disasters. London fog of 1952 cost 3000 lives: stagnant weather conditions trapped sulfur dioxide and smoke in the city.

In the last three decades, there has been a lot of sensitizations and legislations at different levels aimed at curbing the release of untreated air pollutants, even as the world continues to witness major industrialization and urbanization age.

As the awareness of the impacts of air pollution increases, there is a global improvement in the level of air pollution. For instance, in the United States, several laws and new technologies have resulted in a sharp decrease in the emission of virtually all categories of air pollutants as shown in Figure 1.1, the trend is similar in the United Kingdom as depicted in Figure 1.2.

Emissions of air pollutants, United States

Annual emissions of various pollutants indexed to emission levels in the first year of data. Values in 1970 or 1990 are normalized to 100: values below 100 therefore indicate a decline in emissions. Volatile organic compounds (VOCs) do not include methane emissions.

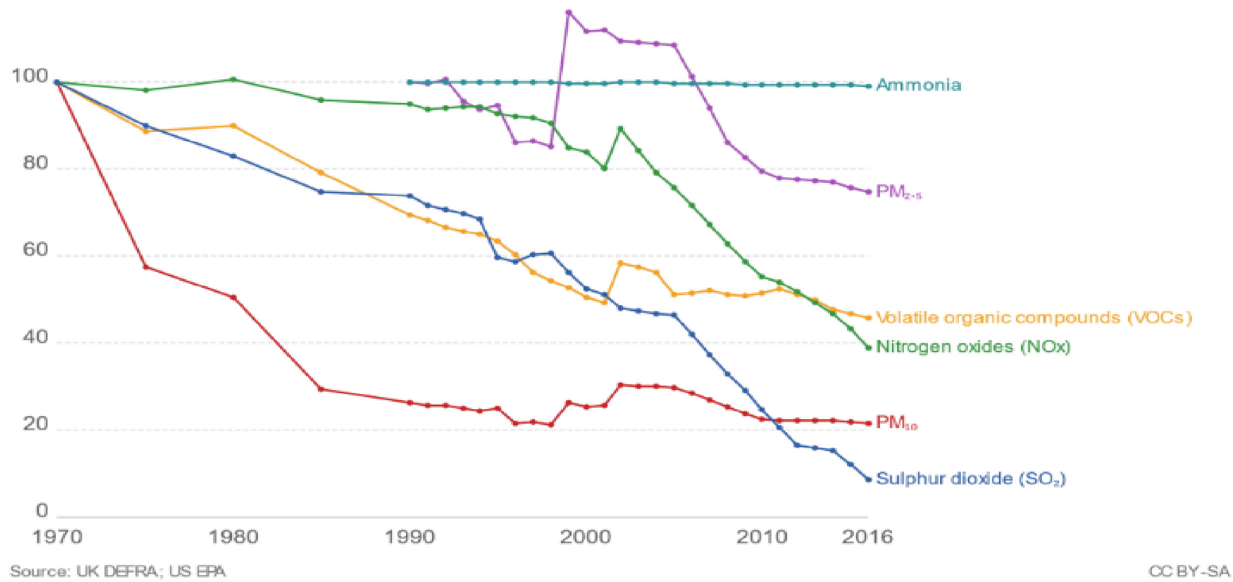


Figure 1.1: Emission of air pollutants in the USA between 1970 and 2016.

Air pollutant emissions, United Kingdom.

Annual emissions of nitrogen oxides (NOx), non-methane volatile organic compounds (VOC) and sulfur oxides (SOx)measured in tons per year. This is measured across all human-induced sources

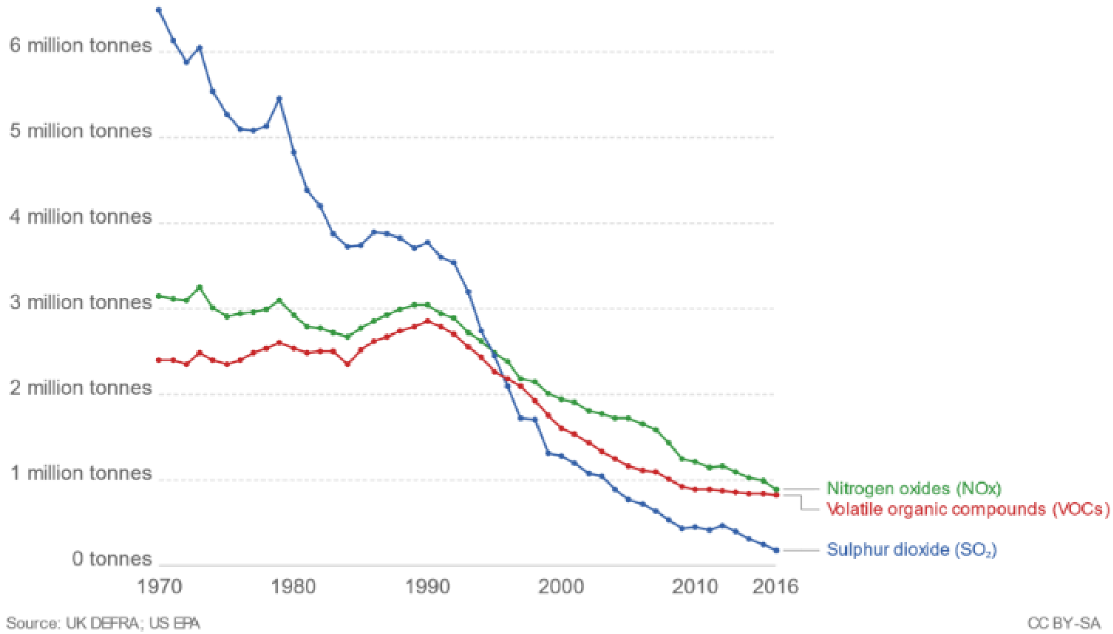


Figure 1.2: The trend of air pollutant emissions in the UK between 1970 and 2016.

1.1.2 Classification of pollutants

Pollutants come in various chemical compositions, with differing reactivity, different lengths of time of suspension in the atmosphere, the range of dispersion, and the outcome of human/animal exposure to them: however, air pollution can be classified into four according to their similarities[3].

i. Gaseous pollutants: these are oxides of sulfur (SO_x), Oxides of Carbon (CO_x), oxides of Nitrogen (NO_x), Ozone (O_3) and Volatile Organic Compounds (VOC)

ii. Persistent organic pollutants like dioxins

iii. Heavy metals: Examples include lead, mercury, etc.

iv. Particulate Matter: Coarse, Fine particles and Ultrafine particles

For the scope of this research, the focus is on gaseous pollutants and Particulate Matter; these are collectively called criteria pollutants. The limit of this focus is because the products of gas flaring are gaseous for the most part, and the standards of measuring air pollution are usually in the amount of particulate matter in the atmosphere.

1.1.2.1 Gaseous Pollutants:

These are a range of pollutants found both indoors and outdoors. They are produced from a variety of sources like burning fossil fuels, cigarette smoking, smog, etc. The group consists mainly of oxides of sulfur (SO_x), oxides of Carbon (CO), oxides of Nitrogen (NO_x), Ozone (O_3), and Volatile Organic Compounds (VOC).

1.1.2.1a Oxides of Sulfur:

The advent of the Industrial Revolution marked a critical transition point in SO_2 emissions as a result of large-scale use of Sulfur-containing fuels in industrial processes. Global SO_2 emission per capita trend in the top 10 gas flaring countries is as shown in figure 1.3 below

Sulfur Dioxide (SO_2) emissions per capita

In tons per capita per year

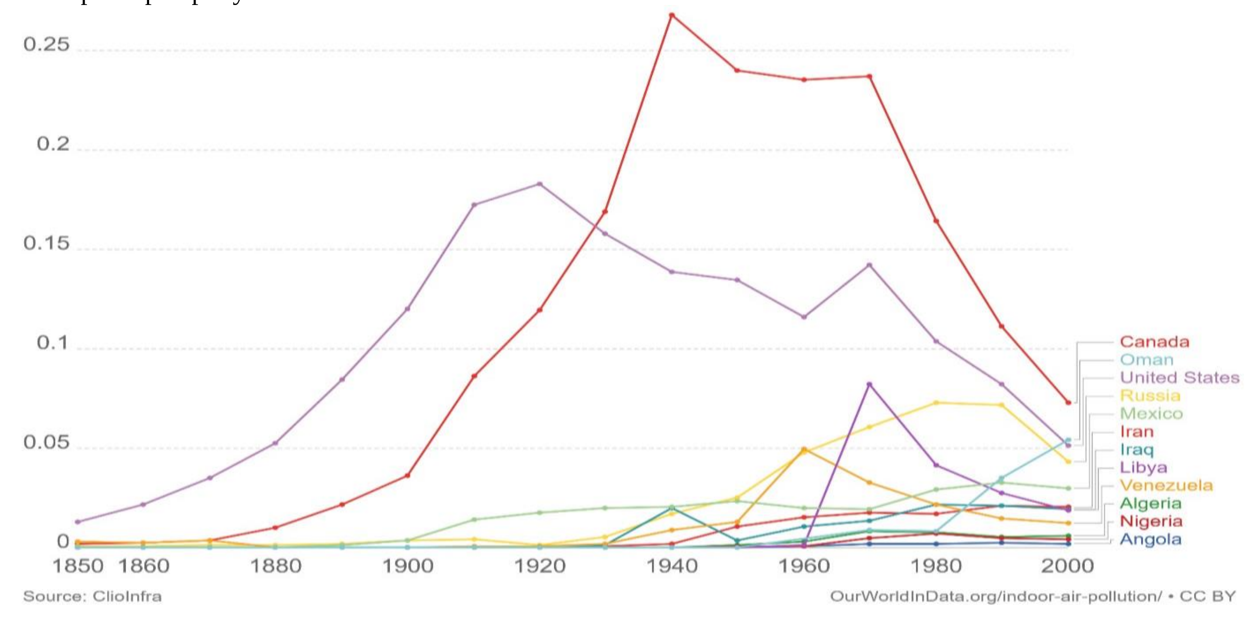


Figure 1.3: The trend of SO_2 emission per capita in the top 10 gas flaring countries.

Globally, the trend of SO_2 emission shows a continuous decrease in Europe and the Americas, while increasing in Asia and Africa.

SO_2 emissions, by world region (in million tonnes)

Annual sulfur dioxide (SO2) emissions in million tonnes

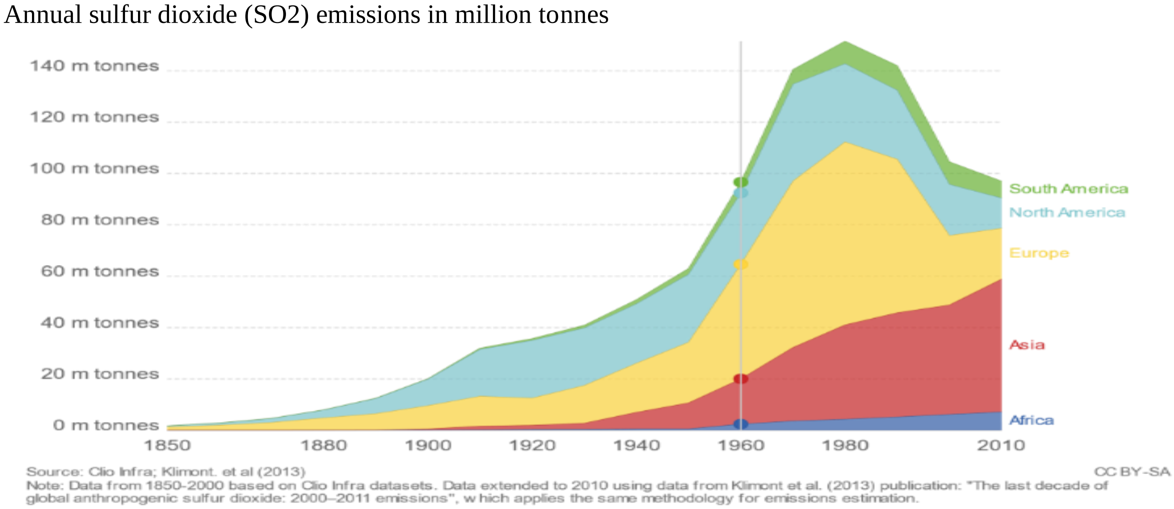


Figure 1.4: Global SO_2 emission trend by region.

1.1.2.1b Oxides of Nitrogen:

These are gases consisting of Nitrogen and oxygen, the type with most toxicity are nitric oxide and nitrogen dioxide. Nitrogen oxides react with other compounds to form smog and pose adverse respiratory outcomes.

1.1.2.1c Carbon Monoxide:

Carbon monoxide is often regarded as an essential gaseous pollutant when considering the total amount in the air. Odorless, colorless, without any form of an alert trigger before the poisoning, exposure could result in headaches, dizziness, nausea, and breathing difficulty. Poisoning is determined by the dose and duration of exposure. Another oxide of carbon of great importance is carbon dioxide: together with nitrous oxide, methane, etc. are called greenhouse gases, they are essential for sustaining a comfortable temperature on earth. Excessive greenhouse gases are responsible for increasing temperatures worldwide, the phenomena called global warming.

1.1.2.1d Ozone:

Ground-level ozone or smog is the product of the reaction between nitrogen oxides and volatile organic compounds in the presence of sunlight. It reduces visibility, could trap poisonous gases close to the earth's surface resulting in hazardous instances. Health effects of smog exposure include shortness of breath, wheezing, coughing, etc., severe cases could result in lung cancer, asthma-related symptoms, etc.

1.1.2.1e Volatile Organic Compounds:

VOCs are mainly hydrocarbon compounds heavier than ethane. Examples are the BTEX compounds. They are mostly released into the atmosphere from automobile sources and industrial processes. Exposure to VOCs has proven to result in respiratory discomforts, endocrine disruptions, and cancer.

1.1.2.2Particulate Matters:

PMs are matters suspended in the air, either substantial or liquid[4]. They include smoke, soot, fumes, and various bye products of combustion; these come mostly from factories, power plants, refineries, vehicular emissions, and construction activities. PM can also come from natural sources like windblown dust, mists, pollen, etc. The composition varies as determined by the source, but majorly, PM comprises of transition metals, ions, organic compounds, minerals, reactive gases, and biological materials[5]. Different types of PM are identified using their size distribution into an ultrafine, fine, and coarse PM. Since samplers cannot differentiate sizes precisely, PM is delineated by 50% cut off point at a specific aerodynamic diameter, e.g., 0.1, 2.5, and 10 µm.

Exposure to PM, especially the fine PM, has been associated with increased morbidity and mortality[5].

Several reports and investigations have shown that the size of the PM and their surface area determine their potential damage to human health. In general, the smaller the size, the higher the toxicity. While several air pollutants can have negative health impacts, there is a special concern for the smaller particles with a diameter of less than 2.5µm because these can penetrate the lungs, impacting respiratory health.

Figure 5 below shows the death rate from PM air pollution compared with the PM2.5 concentration for different countries.

Death rate from particulate matter air pollution vs PM2.5 concentration.
Age-standardized death rate from particulate matter (PM2.5) exposure per 100,000 people versus the average mean annual exposure to particulate matter smaller than 2.5 microns (PM2.5) measured in micrograms per cubic meter.

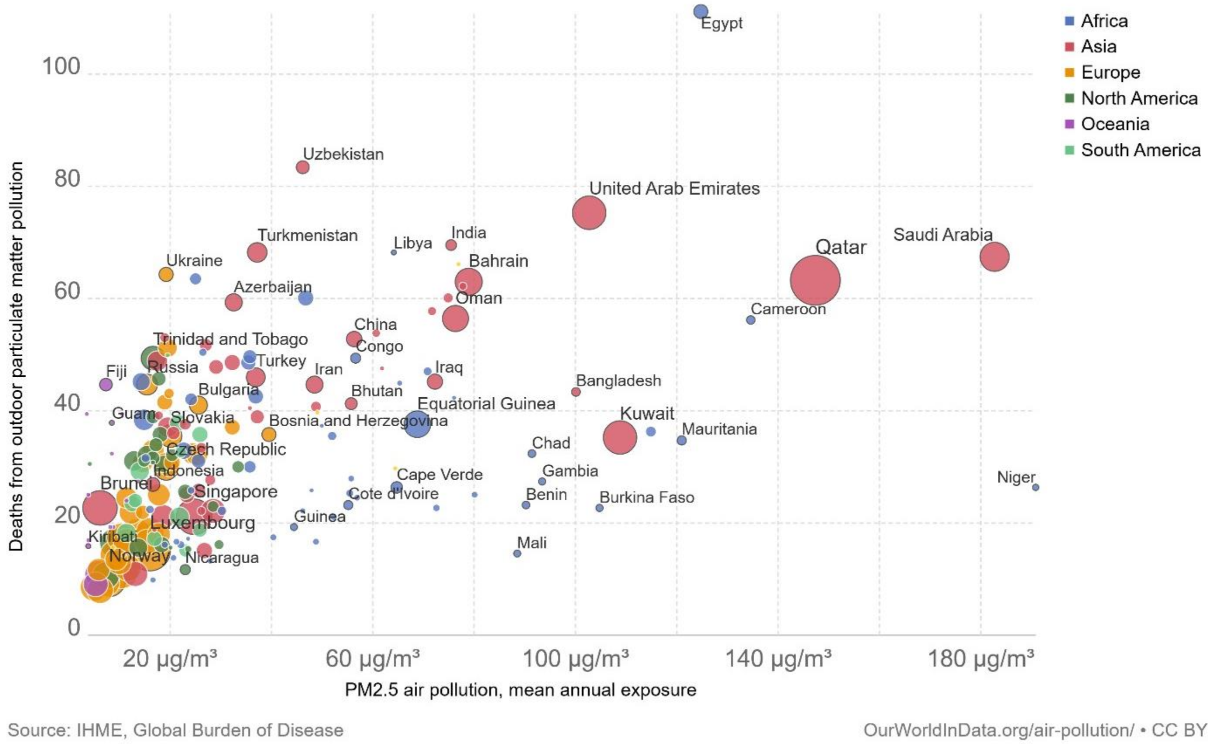


Figure 1.5: PM2.5 mean annual exposure versus Death from its exposure.

Generally, air pollution is a burden on human health; this is a key driver in dealing with the issue. The likelihood of death from exposure to PM2.5 increases with the concentration according to figure 1.5, however, there are a few outliers: Countries like Qatar and Saudi Arabia have a higher mean annual exposure but lower death rate than others like Ukraine and Turkmenistan. The factors might be the difference in GDP per capita, as high GDP per capita means greater access to healthcare and other advantages of better socioeconomic indices. Figure 1.6 below shows the negative correlation between GDP per capita and death rates from ambient PM air pollution.

Richer nations recorded lower death rates from the same concentration of exposure compared with the less prosperous ones.

Death rates from ambient particulate air pollution vs. GDP per capita, 2017.

Deaths attributed to exposure to outdoor particulate air pollution, measured as the number of premature deaths per 100,000 people versus gross domestic product (GDP) per capita, measured in 2011 international-$. Death rates are age standardized, so correct for differences in age structures between populations.

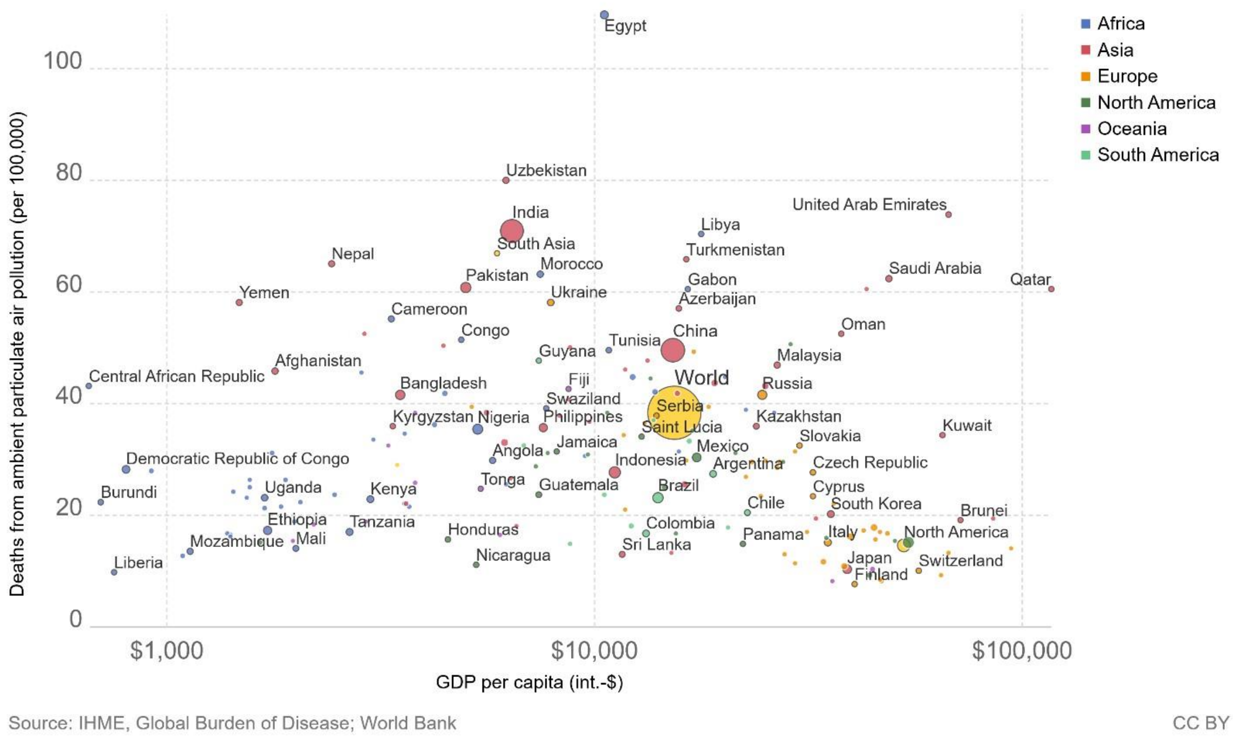


Figure 1.6: Comparing the death rate from ambient PM and GDP per capita.

1.1.2.2a Coarse PM:

PM_{10} These are inhalable particles that are less than 10 µm but greater than 2.5 µm in diameter, also referred to as PM_{10}. They are mostly dust, sand, and non-exhaust vehicle emissions. They can also have fungi and endotoxins attached to them. PM_{10} may not enter the circulatory system directly, but the toxins and the soluble compounds they carry can leach into the fluids in the lining of the airways[5].

1.1.2.2b Fine PM

These are particulate matters that are less than 2.5 µm in diameter, also called $PM_{2.5}$. Fine PM is of utmost concern in addressing air pollution because they are capable of being suspended in the air for a relatively long time and can, therefore, penetrate a deeper deposition in the lungs, causing serious damages. $PM_{2.5}$ is sometimes difficult to sample because it can be transported over long distances[5], allowing mixture with precursor gases, making it difficult to identify sources producing the primary particles. Some analysis has attributed as much as 3% of mortality from cardiopulmonary disease, about 5% of mortality from cancer of the trachea, bronchus, and lung, and about 1% of death from acute respiratory infections in under five-year-old worldwide to $PM_{2.5}$: This is about a million premature deaths and as much as 6.4 million years of lost life.

1.1.2.2c Ultrafine PM

Ultrafine particles are smaller than 0.1 µm in diameter; they are mostly unstable at that size, often bounding together to form $PM_{2.5}$ µm. On their own, they are capable of deep deposition.
They are small enough to penetrate the bloodstream, hence can cause heart and brain diseases[6].
$PM_{0.1}$ are mostly generated at high temperature: wood fires, cigarette smoke, industry, and cooking fumes

1.1.3 Health Effects of air pollution

The impacts of air pollution can be devastating on human health, damaging to the ecosystems, triggering droughts, and severe famine. Epidemiological studies have shown a cause and effect relationship between air pollution and illness in people and, sometimes, increased mortality rate. The popular Harvard Six cities study investigated the respiratory health effects of respirable particles and Sulphur oxides in the 70s through to the 80s. It showed that after adjustment for individual risk factors, life expectancy was estimated to be reduced by approximately two years in the dirtiest city compared to the cleanest[6]. Another study by The American Cancer Society involving a sample of 500,000 US adults replicated the same result[7]. Several other studies echoed these findings.

According to the WHO statistics, air pollution causes an estimated seven million premature deaths every year globally, both directly and indirectly, of this figure, 4.3 million deaths were from ambient outdoor pollution.[8]

Figure1.7 below shows the global trend of the number of deaths per 100,000 persons due to air pollution distributed between three causes: Ozone, Ambient particulate matter, and indoor solid fuels.

While there has been a global decrease in the total number of deaths from the three sources considered jointly: death from the Ambient particulate matter has remained the same. It is plausible to assume that the increasing rate of urbanization and industrialization is responsible.

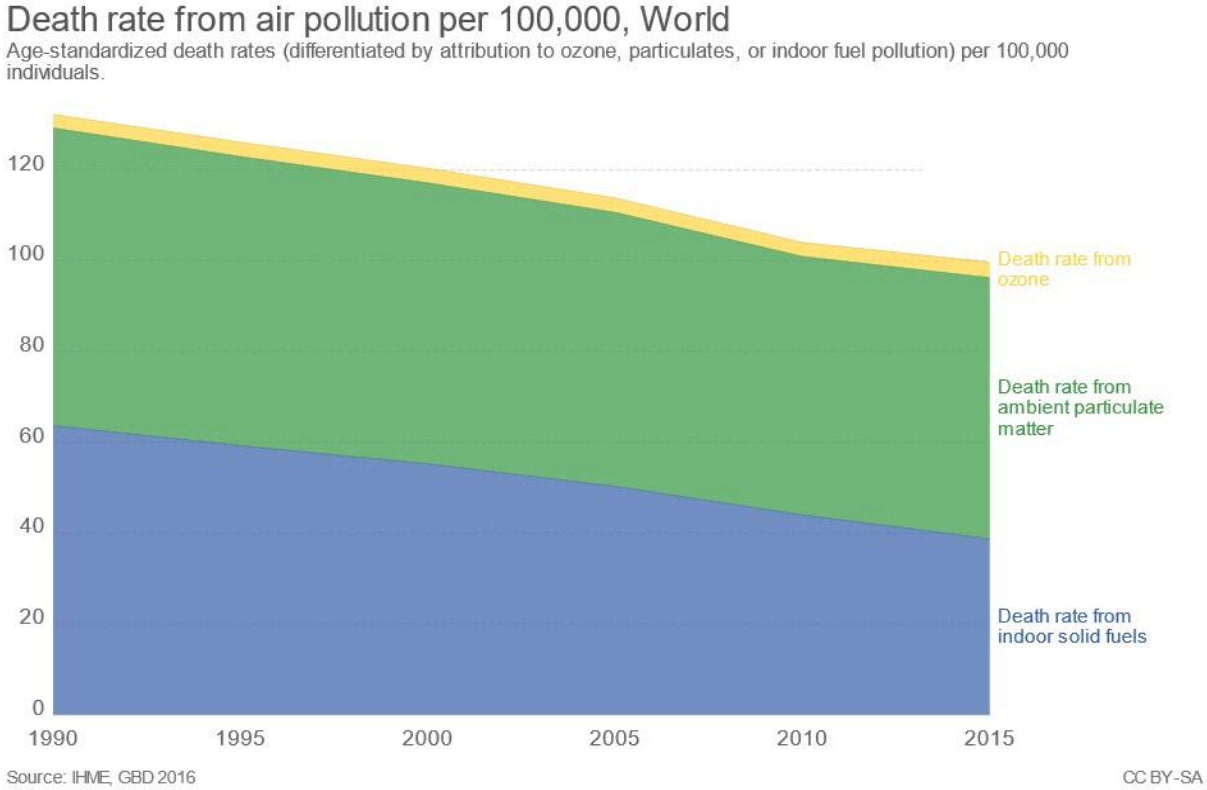


Fig 1.7. The worldwide Death rate from Air pollution per 100,000 persons. [2]

Figure 1.8 below takes a closer look at deaths from outdoor air pollution around the world. Most deaths are in the region with a higher number of exposures due to higher population density.

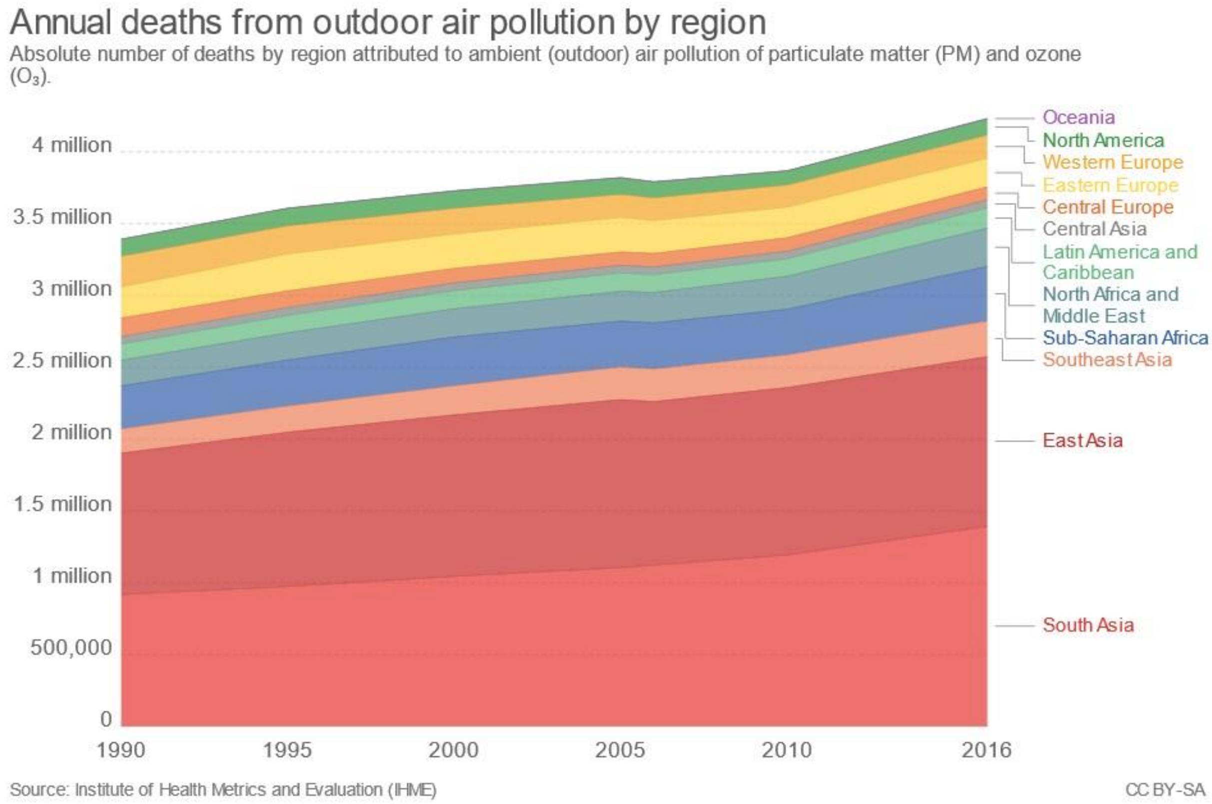


Fig 1.8. Worldwide Annual deaths from outdoor air pollution by region. [2]

1.1.4 Air Pollution from Gas flaring

Crude oil deposits often contain some natural gas known as associated petroleum gas (APG)or solution gas. The gas is dissolved in the oil under pressure in underground reservoirs, when the crude oil is brought to the surface, because of the reduced pressure: the gas is released[8].

The release could be by direct venting or through a process called flaring.

Gas Flaring is the open-air disposal of associated natural gas by incineration. This process is designed to dispose of associated gas and release emissions into the atmosphere during oil and gas exploration. It is an important safety measure to control fire hazards and gas poisoning during drilling operations and at natural gas facilities. Safe disposal of gas is also required during equipment failures, power outages, and other emergencies.

Gas flaring has always been a part of crude oil exploration and refining. Still, it potentially wastes valuable resources and produces emissions that affect human health, livestock, and environment[9]. Carbon dioxide and methane are some of the major emissions in gas flaring, contributing significantly to global warming, methane has twenty-three (23) times as much global warming potential (per ton) as carbon dioxide[9].

Particulate Matter (PM), Polycyclic Aromatic Hydrocarbons (PAH) and Volatile Organic Compounds (VOC) are some of the other products of gas flaring, especially when operated under less efficient conditions[9].

The global warming potentials of Gas flaring makes it a global problem: The World Bank figures show 147 billion cubic meters (bcm) of gas was flared in 2015 a substantial increase on 145 bcm from the previous year and 141 bcm from 2013(GGFR).

Russia is the world's largest gas flaring country, flaring about 21 bcm annually, followed by Iraq, Iran, USA, and Venezuela flaring 16, 12, 12, and 9 bcm, respectively (GGFR). According to the Nigerian government data, monitored via the country`s gas flare tracking satellite, the country flared 240.2 million mscf in the year 2018, resulting in 12.8 million tons of CO_2 with the gas valued at 840.5 million USD and a power generation potential of 24 thousand GWh. As a policy, the companies responsible were fined 480.3M USD (gasflaretracker.ng).

1.2 RESEARCH SCOPE.

Workers often live as close as possible to their work place[10,11] In his work titled 'the journey to work patterns in human geography", Kevin O'Connor emphasized the premium consideration of what he called geography of residences of the employed populations[12]. Wachs et al. 1993, Wang 2000 and Peng 1997 argued for co-location of employment and population as viable for reducing commuting time.

Kain.1962 posited that the cost of residential provided services: retailing, medical facilities, schools, etc., may be considered invariant as the cost of trips to work both in time and money are often large and significant; hence, the journey to work (JTW) influences the location of residences due to work places[13].

While it might be rational to think the consideration for time and distances to work matters in large cities as a lot of studies opined, Goldstein et al. 1964, propounded that the same principles apply to the suburbs. Their findings showed that most people in the suburbs and the outlying areas live reasonably close to their place of work[14].

A great deal of effort goes into protecting workers at work from harmful emissions, yet gas flaring releases these emissions to the non- work environment. Workers who live close to such workplaces are ultimately exposed to the same emissions off work; hence, a non-occupational exposure from gas flaring is a subject of interest in occupational safety and health.

Methane forms 70-90% of the emissions from gas flaring[15]. However, there is a significant emission of non-methane volatile organic compounds NMVOC called BTEX standing for Benzene, Toluene, Ethylene, and Xylene. BTEX are some of the most prominent environmental groups of pollutants often found in discharges and petroleum products[16]. BTEX is proven to contribute to the formation of ground-level ozone and photochemical smog: these damage plants and materials as well as pose human health concerns. The route of contamination with these compounds include air, water, and soil.

This study investigates the non-occupational exposures to BTEX as a result of gas flaring to provide a sustainable proposal for managing it. Data from Nigeria, one of the largest gas flaring nations in the world, is used to establish the cost of non-occupational exposure to BTEX as a low middle-income country (LMIC). This research investigated Green completions strategy capacity to eliminate BTEX exposure while solving the country`s other major challenge, power.

The country currently generates 3358 MW of electricity while requiring at least, 12,000MW, representing a shortfall of 65.7%.

Summarily, the scope of this research covers five stages of activity: Hazard identification, toxicity assessment, exposure assessment, risk characterization, and mitigation action. The interrelationship between these five stages is as depicted in fig 1.1 below.

Hazard identification involves isolating the hazard of concern.

Toxicity assessment investigates how bad the hazard is. The exposure assessment stage will determine how much of the risk is there in the case study; we investigate the population involved and the level of exposure. The combination of the outcomes of toxicity assessment and exposure assessment will help in Risk characterization, answering the questions of “what's the risk?”. The level of the risk determines the Action to recommended.

In all, the dollar value of the final stage is determined, and a comparative analysis was done to determine profitability.

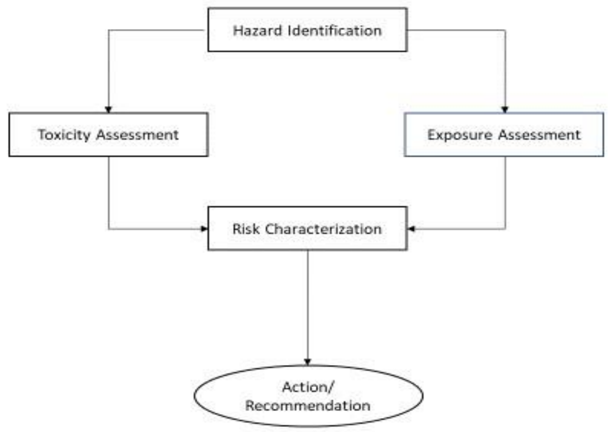


Figure 1.9 The summary of the research scope.

1.3 RESEARCH QUESTIONS

This study will answer the following questions:

(i). What are the impacts of gas flaring on the exploration host communities viz a viz environment, economy, health, and safety?

(ii). Can the policy of green completion be transferred to the Nigerian system?

(iii). Can green completion eliminate the hazards posed by BTEX exposure via gas flaring?

(iv). Is it economically viable to solve the country`s power crisis using green completion?

(v) What is the cost-benefit of using green completion to mitigate BTEX exposure through gas flaring?

1.4 AIM

This study aims to present a framework that eliminates gas flaring and, consequently, BTEX exposure in oil and gas producing environment using green completion. While providing a solution to the electricity supply shortage from the same. Using Nigeria as a case study.

1.5 OBJECTIVES:

The following are the objectives of this research:

1. To review the literature on gas flaring, BTEX exposure and its effects on human health
2. To determine the health outcomes of BTEX exposure
3. To evaluate the economic cost of BTEX exposure
4. To determine the financial import of green completion
5. To develop a framework for mitigating BTEX exposure through gas flaring.

Figure 1.9 Highlights the typical daily interaction between the host communities and Gas flaring in the Niger Delta regions of Nigeria.

Source: Michael Kembar, 2005

Figure 1.10 A Daily interaction between residents and Gas flaring in the Niger Delta.

1.6 RESEARCH HYPOTHESIS.

1. Green completion policy can be shown to be a method to reduce the exposure of the oil and gas host communities to BTEX through gas flaring by at least 80%.
2. The Green completion will yield a Net impact benefit greater than 1 when considering a 6year return on investment period from introduction of the technology into the energy drilling operations.

1.7 RESEARCH DESIGN.

This research is in three parts:

(i) The study: an extensive review of the literature covering the details of gas flaring, the breakdown of its composition, BTEX and its effects on human health, the elements of green completion, Nigeria and her socio-politico-economic factors affecting management policies,

(ii) Methodology: engaging data from the archives, figures from the World Bank, Nigerian health, power, and the petroleum ministries, the oil and gas industry data bank and literature reviews to ascertain the prevailing conditions, cost of management of illnesses, the design and potential revenues from green completion.

(iii) The data gathered is used to perform cost modeling and to develop a framework for the management of BTEX exposure through gas flaring and a profitable supply of electricity.

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews previous literature on the oil and gas industry and the practice of gas flaring. It also examines researches focused on BTEX and the outcomes of ambient exposures to the compound. Current practices and policies of governments in High income, Middle income, and Low-Middle Income Countries as regards managing gas flaring and the success or otherwise is addressed. The case study of Nigeria as a low-Middle income gas flaring country is critically examined.

2.2 GAS FLARING.

Flaring is a high-temperature oxidation process used to burn combustible components, mostly hydrocarbons, of waste gases from industrial operations[17]

Flaring is associated with a wide range of activities in energy development operations; these activities include[18]:

- Oil and gas well drilling
- Oil and gas well completion or well servicing
- Gas well testing to estimate reserves and determine the productivity
- Routine oil production producing solution gas
- Planned non-routine depressurizing of processing equipment and gas pipelines for maintenance

- Unplanned non-routine de-pressuring of a process equipment and gas pipeline due to process interruption or emergency
- Oilfield waste management facilities.
- Other stages of crude oil refining operations.

Like crude oil, natural gas, and water mix come out of a well, the pressure typically ranges from a few hundred Psi to as much as 7500psi[18]. The combination is separated midstream, and associated gases are piped off to the flare stack.

Methane (CH_4) is the main component of hydrocarbon. Its combustion yields water and carbon dioxide. $CH_4 + O_2 -> CO_2 + H_2O$.

Several stages of crude oil exploration require gas flaring for safe operations. Still, the massive injurious gas flaring that threatens human and environmental health is the large-scale “waste” gas flaring: usually, because it is more economically convenient to do so.

The release of CO_2, a known greenhouse gas, contributes significantly to global warming; hence gas flaring is a significant air pollution concern globally. The effect of air pollution is emphatic on human health, ecosystems, food production, etc.

The World Health Organization (WHO) highlighted air pollution as the most significant environmental risk to human health, with an estimated seven million premature deaths every year.

4.3 million from ambient outdoor pollution, and 2.6 from households.

(http://ghdx.healthdata.org/gbd-results-tool).

World bank data, 2016, shows that the total global gas flaring for that year was an estimated 149 billion cubic meters (bcm), an increase of 2billion m^3 from the previous year[19]. The setback resulted from the increase in flaring: 4 bcm in Iran, three bcm in Russia, and one bcm in Iraq. According to the same release, gas flaring reduced in the united states to 9 bcm, a reduction of 2bcm[20] in the same period. In the rest of the world, it has also moderately declined despite oil production levels remaining unchanged.

Energy production is essential to economic prosperity, and fossil fuels are central to energy production; hence, gas flaring may be around for a long time yet.

As a result of a global effort in finding alternatives to gas flaring, there has been a marginal reduction in flaring levels over the last two decades. New oil and gas development projects are beginning to have credible flare management as a part of the overall project; hence, the negative correlation of the trend of crude oil production and gas flared curves worldwide. However, most installations are the old production sites that continue to burn associated petroleum gas. Figure 2.1 shows the global reduction in gas flaring despite increasing oil and gas exploration activities between 1996 and 2017[21].

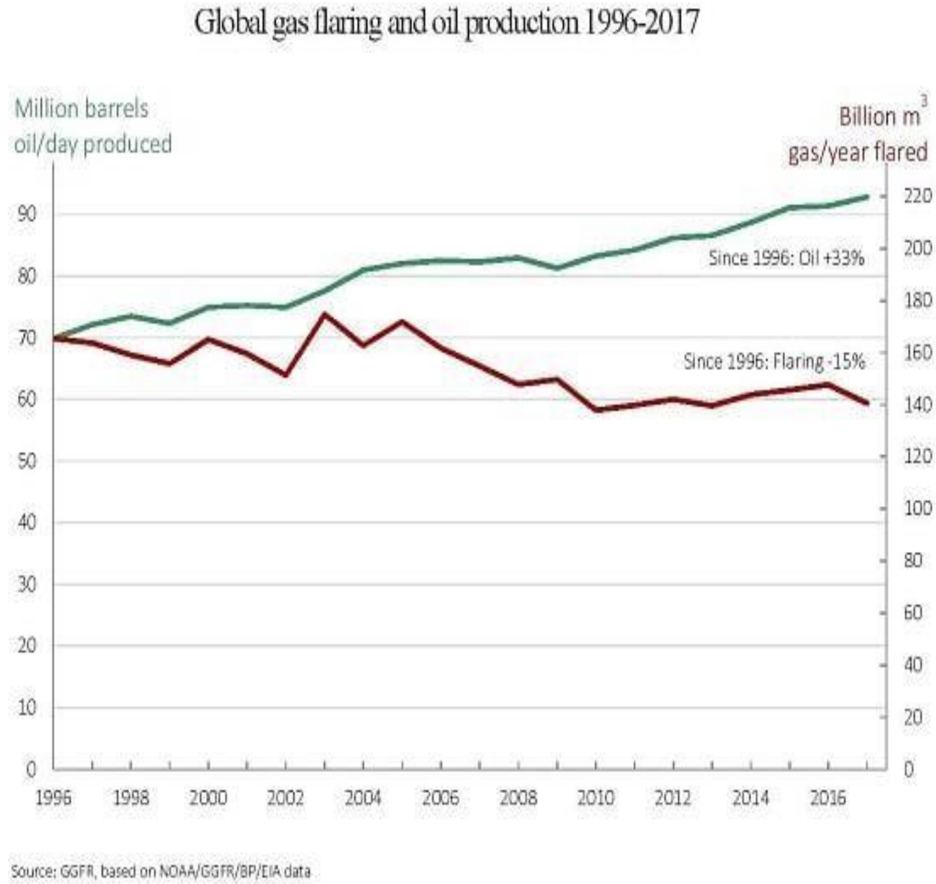


Figure 2.1: Global gas flaring and oil production from 1996 – 2017.

Crude oil production has gone up by 33% from 1996 levels, while gas flaring has reduced by 15% over the same period, quoting the US National Oceanic and Atmospheric Administration (NOAA) figures. From figure 2.1 above, the rate of reduction of flaring slowed down between the years 2010 and 2015; however, the downward trend seemed to have resumed by the year 2016.

2.2.1 Global Gas flaring trend.

As of 2018, Russia remains the world`s largest flaring country, flaring about 21 bcm annually, Iraq 16 bcm, Iran 12bcm, the United States 12bcm, and Venezuela 9bcm, respectively. Most bother nations are making progress in flare reduction, among the large gas flaring countries, Nigeria, the country of this research interest reduced flaring by about 8 percent between 2014 and 2018, coinciding with a period when the country`s crude production level dropped. Below is the latest ranking of the top thirty gas flaring Nations, the figure also compared flaring in each country from 2014 to 2018.

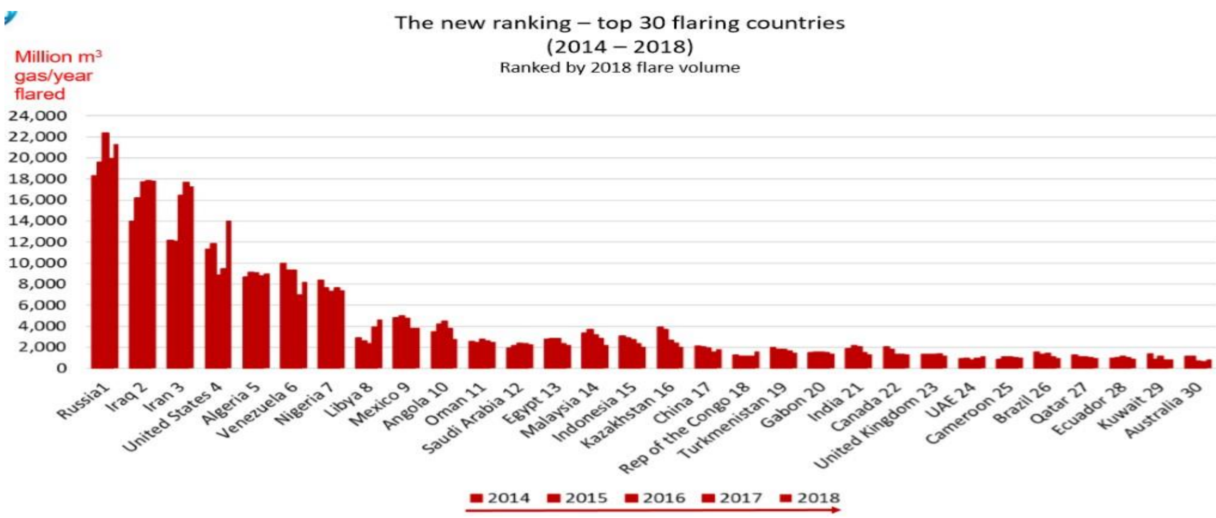


Figure 2.2 Top 30 gas flaring countries, 2013 -2018[8].

Source: NOAA/ GGFR

There has been a global effort, championed by the world bank`s Gas Flaring Reduction initiative (GGFR), the International Energy Agency (IEA), to mitigate gas flaring. There are also efforts to monitor gas flaring real-time via satellite, making recent estimates accurate, and therefore giving a solid base for policy formulation. The Russian Federation and Nigeria, flaring 25% and 10% of global estimates, respectively, have the largest satellite observed emissions in the world[8].

The estimated global gas flared annually is 150 billion cubic meters with a dollar value of between 15 to 20 billion USD, a colossal waste with the attendant 260 to 400 million metric tons of greenhouse gases released to the atmosphere[19]. The question that comes to mind readily is, “Why?”

There are five seemingly "plausible business reasons” why the waste has been overlooked for so long[19]:

a) Associated gas is not typically as pure as pipeline or utility gas, and the latter usually has above 90% methane content, which makes for efficient utility. In comparison, APG typically has between 60 to 80% methane content.

b) The amount of gas available from a barrel of oil is determined by gas to oil ratio (GOR), this value differs from site to site and often dramatic changes in the same field from time to time.

c) Associated gas usually contains heavier volatile hydrocarbons: these can condense and have higher heat value. APG is, therefore, considered a “wet gas.”

d) The gas sometimes contains water vapor, hydrogen sulfide, nitrogen, and other compounds and impurities; these make handling and transportation difficult and limit high volume use.

e) The largest volume of flaring occurs in remote areas; difficult investment climes and small volumes of gas often do not justify the expense of gathering.

2.2.2 What is in the flared gas.

When done with 100% efficiency, gas flaring should produce Carbon dioxide (CO_2) and water. However, studies have found that in operation, most flares operate at a wide range of Destruction and Removal Efficiency (DRE), often between 60% to 80%[22]. The efficiency of a flare depends on various factors like wind speed, stack exhaust velocity, heating value, etc. The resulting incomplete combustion, depending on the composition of the associated gas, emits unburned crude oil components like methane and non-methane Volatile organic compounds, oxides of sulfur, oxides of nitrogen, and particulate matters.

Speciation profiles are needed to know the percentage composition of flared gas: A Texas commission on environmental quality sponsored flare study gave the composition of the flared gas as shown in the table below[22],[23],[24].

Compound	**Weight%**
Methane	69.5
Ethane	11.2
propane	8.56
Butane	5.71
Pentane	2.85
Hexane	0.412
Benzene	0.088
Toluene	0.078
2,2,4,-trimethylpentane	0.116
Ethylbenzene	0.005
Isomers of Xylene	0.022
Isomers of Hexane	1.480

Source:[22]**,**[16]**.**

Table 2.1 Percentage composition by weight of the gas to be flared

	DRE RANGE			
	>0.98	0.95 - 0.98	0.8 - 0.95	< 0.8
Compound	**Weight (%)**			
Formaldehyde	3.910	2.710	2.220	1.250
Methanol	0.169	0.126	0.136	0.119
Acetaldehyde	2600	1.720	1.320	0.678
Acetylene	5.290	4.100	3.910	2.150
Ethylene	2.600	1.860	1.620	0.916
Methane	59.30	62.20	63.100	65.90
Ethane	9.570	10.00	10.20	10.60
Propane	7.320	7.660	7.770	8.130
Butane	4.880	5.110	5.180	5.420
Pentane	2.440	2.550	2.590	2.710
Hexane	0.352	0.369	0.374	0.391
Benzene	0.075	0.079	0.080	0.083
Toluene	0.067	0.070	0.071	0.074
2,2,4 trimethylpentane	0.099	0.104	0.106	0.110
Ethylbenzene	0.004	0.004	0.005	0.005
Isomers of xylene	0.019	0.020	0.020	0.021
Isomers of hexane	1.260	1.320	1.340	1.400

Table 2.2. Percentage component after flaring at different efficiencies (Source[16,22])

The optimal result was obtained at above 95% efficiency getting as much as a 14% reduction in the benzene content of the flared gas. As earlier identified, the commonest operation efficiency is between 60% and 80%. This research shows only 5% efficiency is obtainable when The DRE is less than 95%. This observation holds for all the BTEX compounds.

2.2.3 The Products of Gas Flaring and their Health Effects.

Crude oil and natural gas usually contain a mixture of hydrocarbons and other substances, which can form a variety of chemical compounds during combustion. Several scientific studies in the 1990s indicated that under certain circumstances, flares did not burn natural gas as efficiently as previously believed[25]. In essence, this was specifically the case with low gas flow rates and high winds. The incomplete combustion of hydrocarbons can lead to the formation of carbon monoxide (CO), atmospheric Nitrogen is also oxidized during combustion to form oxides of nitrogen, known collectively as NOx. Oxides of nitrogen such as nitric oxide (NO) and nitrogen dioxide (NO_2) contribute to ground-level ozone (a component of smog), and acid deposition[26] Flaring is, therefore, a source of several substances that can affect human health, livestock and the environment. The CO_2 and nitrous oxide (N_2O) emitted from flares and incinerators are greenhouse gases that contribute to global warming. In addition to NOx, CO_2, and CO, emissions from flaring can include unburned hydrocarbons, particulate matter, polycyclic aromatic hydrocarbons (PAH) and volatile organic compounds (VOC)[15]. VOCs include a wide variety of hydrocarbon compounds heavier than ethane. VOCs combine with oxides of nitrogen in the presence of sunlight to create ground-level ozone and smog. One of the VOCs is benzene, which is classified as toxic and is a known cancer-causing compound (citation). The particulate matter affects the respiratory health of humans and animals and is yet another component of smog. If the natural gas contains H_2S, emissions include sulfur dioxide (SO_2), carbon disulfide (CS_2), and carbonyl sulfide (COS)[15.] Oxides of nitrogen, such as nitric oxide (NO) and nitrogen dioxide (NO_2), contribute to ground-level ozone[9] (a component of smog) and acid deposition[27]. With efficiencies that could be as low as 66 per cent[16]under actual field conditions, flares could be releasing a range of pollutants with potentially harmful effects on human and animal health, crops, forests, soil, and water resources[25].

These realities inform the growing concern among people living near natural gas and oil production facilities about the emissions, odors, bright lights, and noise associated with flaring.

2.2.4 Local effects of Gas Flaring products

Gas flaring is a global concern with an immense, often severe local impacts, especially when exposure is chronic. Apart from the release of a large volume of CO_2 resulting in global warming, the process generates particulate emissions(soot), sometimes vent methane and many harmful products. Assessment projects have shown that, depending on the local ecological and metrological factors, larger Nitrogen oxides (NOx) are found within one to three kilometers (0.6 to 1.9 mile) radius of the flare, carbon monoxide, sulfur dioxide, and the present hydrocarbon products of incomplete combustion are found between five to fifteen-kilometer radius (3 to 10 mile)[19],[28].

2.2.5 Model Gas flare management.

There are countries with large volumes of oil and gas exploration activities that are not featuring among the top gas flaring nations: examples of such countries are Norway and Canada.

Norway has about 2 million bpd production and 99.3 billion cubic meters of gas using [29] and Canada world's fifth-largest producer of oil and natural gas, has an average production of 3.5 million bpd, and 13.7 billion cubic feet of natural gas according to the Natural Resources Canada.

Energy markets factbook, 2014[30]. These countries have managed their associated petroleum gas with success and are, therefore, discussed below as possible examples of policy approaches to be considered in addressing gas flaring.

2.2.5.1 Gas Flaring Management in Norway

Norway is the world`s 7th largest crude oil exporter and notably, the 2nd largest exporter of natural gas[29]. Although its oil fields are offshore, the Norwegian management of its flared gas could be a good model for the others. Crude production from the Norwegian continental shelf has increased six-fold since 1981, while the flaring volume as a percentage of oil production has substantially decreased[29]. It is noteworthy that Norway flares less than 1% of the total annual associated gas production from her 60 oil fields.

Figure 2.3 shows an overview of Norway's crude production and annual flaring volume over the last two decades

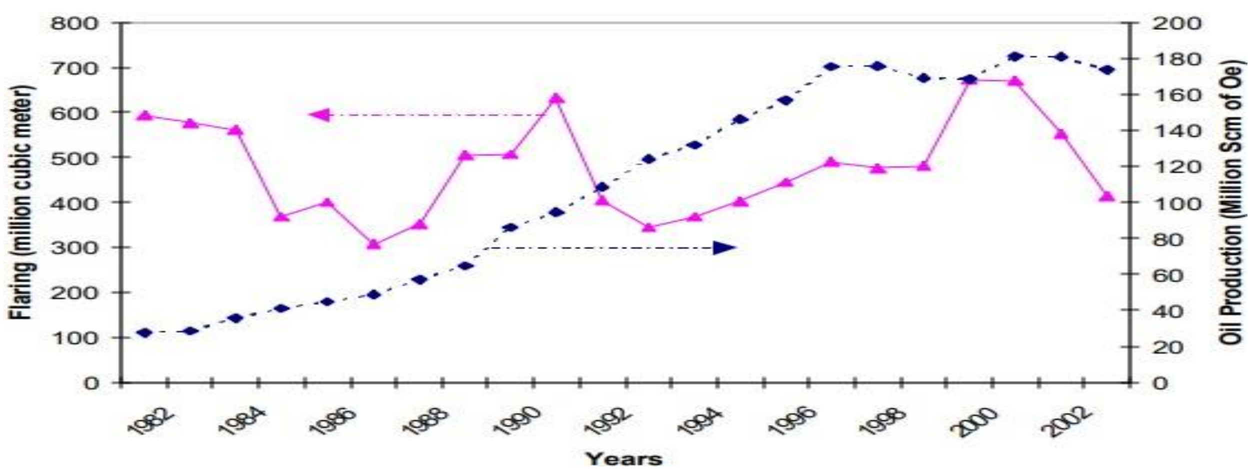


Figure2.3: An overview of Norway's crude production and annual flaring volume over the last two decades[31] *Source: GGFR*

Figure 2.3 shows[31] the progress the country made starting high rate of flaring incidence in 1981 and a steady increase in production never translating to an increase in flaring, occasional spikes were results of new fields coming on, and the figure shows immediate decline after each spike.

The country has combined administrative measures in tax codes and technology to control environmental pollution from the oil and gas industry, which constitutes 44% of its industry.

According to the Norwegian oil and gas ministry release[32], *"All plans for development and operation of oil and gas fields (PDOs/PIOs) must contain a good and efficient energy solution, including an analysis of possible power supply from shore." "The authorities and the oil companies maintain a strong focus on research and technological development to find good technical solutions that can contribute to reducing harmful emissions. Considerable efforts are devoted to the development of environmental expertise and technology, and the Norwegian petroleum Industry Is At the forefront when It comes to utilizing both environmentally and climate friendly solutions. This has yielded results, and many of the solutions used In Norway have become export commodities,"* the document emphasized.

2.2.5.1.1 Norway`s Technical management of emissions

Storage of CO_2: In 1996, Norway became the first country in the world to store large amounts of CO_2 in a geological formation under the seabed[32]. CO_2 is injected and stored in depleted oil and gas reservoirs. About 700,000 tons of CO_2 is stored each year.

Power Generation: As a power policy, Norway also employs combined cycle power plants in managing its associated gas release. Combined cycle power is a solution in which exhaust gas from the gas turbine is used to produce steam, which in turn is used to drive a steam turbine for additional power generation and effective control of emissions[32].

Conservation: the industry is open to several energy conservation measures as a policy. The measures include modifications to power-intensive equipment and optimization of processes.

2.2.5.1.2 Norway`s Administrative management of emissions

There is a CO_2 Tax Act and the Greenhouse Gas Emission Trading Act: these are the key administrative Instruments for reducing emissions. There is also a PDO/PIO emission /discharge permits and production licenses that regulate gas flaring[32].

2.2.5.2 Gas flaring management in Canada

Canada is the world`s 5th largest producer of oil and natural gas, with an average daily production of 3.5 million barrels per day and 13.7 billion cubic feet of natural gas[30].

The country, despite her huge oil and gas exploration activities, has managed to keep the volume and effects of its gas flaring relatively low. From figure 2 above, Canada ranked 22nd among the top gas flaring nations, but when compared on an intensity basis, among the top 30 gas flaring nations, Canada ranks in the bottom three[30]

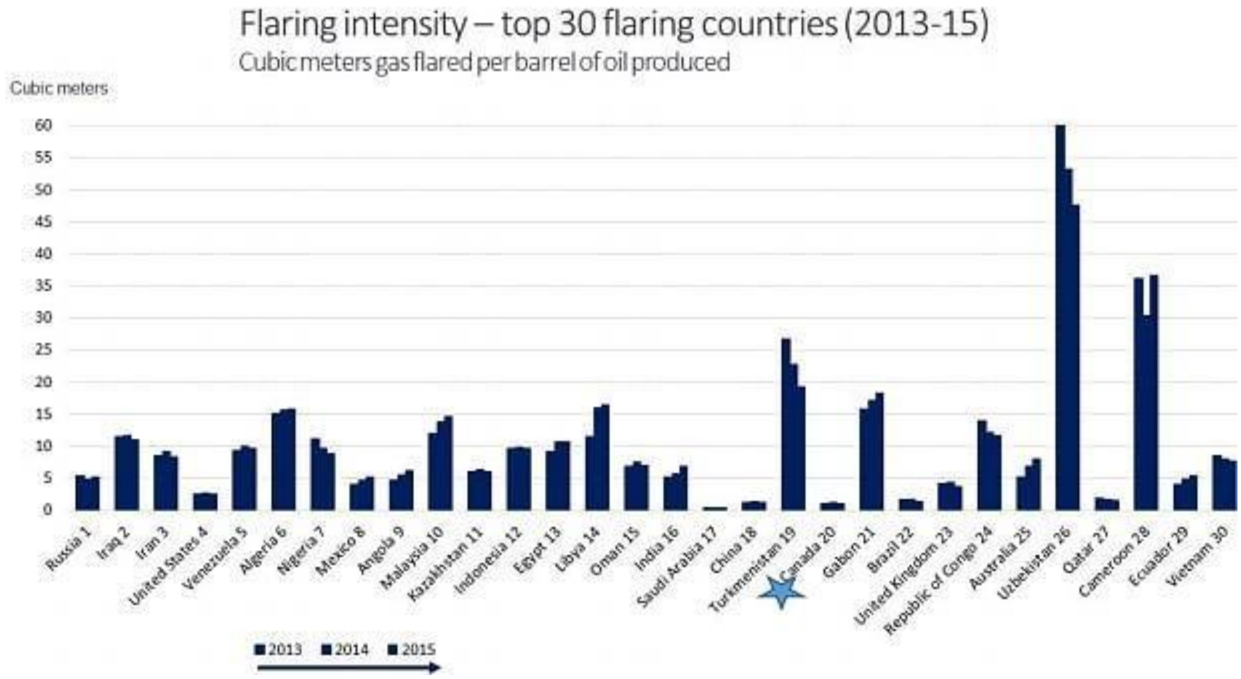


Figure 2.4[19] showing Canada in the 20th position among the top Gas flaring countries.

2.2.5.2.1 Canadian National regulations on gas flaring

All oil and gas activities are regulated at both national and provincial levels. The federal regulations are from the Canada oil and gas operations act. The Canada oil and gas regulations suggest that no operator shall flare or vent gas unless it receives special approval to do so, or if it's otherwise necessary to do so because of an emergency. The regulation further saddles the operators with the responsibility for the reports of flow rates and flow volumes. Appendix 1 shows a copy of the operational regulations for the oil and gas industry on gas flaring in Canada. The country also conducts a regular baseline assessment of its existing domestic policy initiatives and instruments as regards gas flaring. Central to its efforts is the Zero Routine Flaring (ZRF) by 2030, the world bank initiative on gas flaring, with the focus on conserving the flared gas. Conservation in this regard is defined as the recovery of the gas for use as fuel for production facilities, to sell, to inject for enhanced recovery from oil or condensate pools, or to generate power, among other uses.

2.2.5.2.2 Canadian Provincial Action on gas flaring.

Alberta, Saskatchewan, and British Columbia provinces have a major share of oil and gas facilities in Canada; therefore, they have the most comprehensive laws on flaring, venting, and incineration. The regulations in these three provinces are closely related. The regulations in Alberta particularly provide a high level of detail in flaring and venting reduction guidelines, which date back to 1996. To guide regulation development and to facilitate clustering, the Province compiles collected emission data into an annual Upstream Petroleum Industry Flaring and Venting Report. According to the Canadian oil industry reports, BC and Saskatchewan originally developed their policies to align with those of Alberta[30].

For the Atlantic provinces like Newfoundland and Labrador and Nova Scotia, regulations are focused on offshore flaring and venting. Quebec and Ontario have much less oil and gas exploration activities. Hence, they do not have regulations for the industry.

Since the regulations from the Alberta province is reckoned to be the source document for most of the Canadian regulations, it is important to take a closer look at the document

2.2.5.2.2i Alberta Provincial Regulations

According to Alberta Energy Regulator (AER), the agency established in 2013 under the Canadian Responsible Energy Development Act (REDA) to ensure the safe, efficient, orderly and environmentally responsible development of oil, oil sands, natural gas and coal resources over their entire life cycle in Alberta, a set of regulatory requirements are developed to meet the goal set by the government of Alberta, the documents are referred to as Directive 060 and Directive 017. Excerpts from these documents are attached in Appendix 3 &4.

2.2.5.2.2ii AER Directive 017

The directive clarifies the AER requirements for measurement points used for accounting and reporting flaring. It specifies what and how volumes must be measured, what, where, and how volumes may be estimated if accounting procedures must be performed on the determined volumes and what they are, what data must be kept for audit purposes, and what resultant volumes must be reported to the AER.

Specifically, directive 017 defines flared gas as either processed gas or unprocessed gas, depending on the point at which it was removed from the system, as shown in the flow chart below.

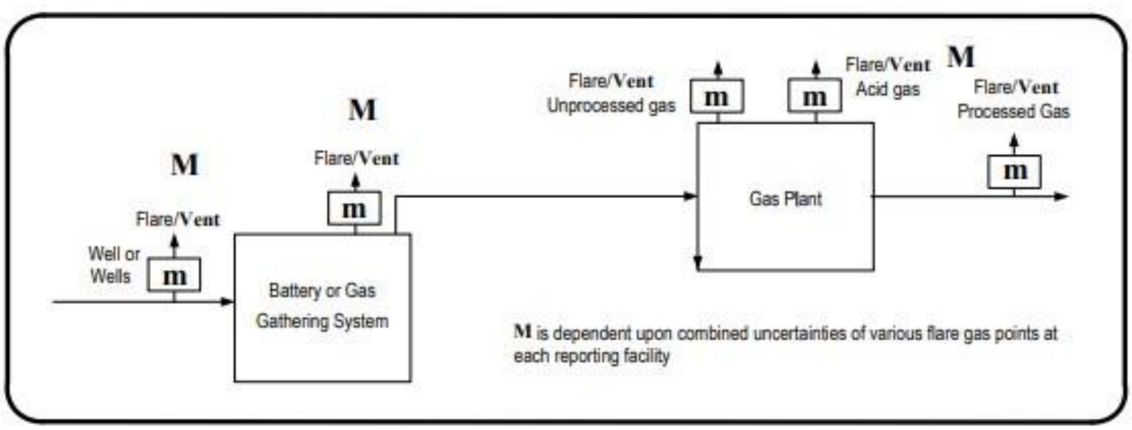


Fig 2.5 Directive017 flow chart definition for flared gas

The directive requires that all continuous and intermittent flared and vented volumes at all oil and gas production or processing facilities where annual average total flared and vented volume per facility exceeds 0.5 103 m3/d must be metered. Effective January 1, 2020, gas used for pilot, purge, sweep, blanket, and makeup gas must be reported as flared. From the same date, noncombusted gas released to the atmosphere other than fugitive emissions must be reported as vent gas. There are also provisions guiding the maximum allowable volume of estimation: the limit is set at 20% of monthly flared volume.

The equipment and procedures used to determine the measured gas volumes must be capable of meeting 5% single point measurement uncertainty. Directive 017 ensures Alberta at every point could accurately declare the volume of gas flared within the region to a reasonable degree of certainty; this accounting principle allows for detailed planning and control.

2.2.5.2.2iii AER Directive 060

This directive contains the requirements for flaring, incinerating, and venting at all upstream petroleum industry wells and facilities in the province of Alberta. It also applies to the pipeline installations conveying such gas, e.g., Compressor stations and line heaters, as determined by the Canadian pipeline Acts.

Most of the Directive 060 requirements have been developed in consultation with the Clean Air Strategic Alliance (CASA) to eliminate or reduce the potential and observed impacts of these activities and to ensure that public safety concerns and environmental impacts are addressed before beginning to flare, incinerate, or vent. Directive 060 requirements are also aligned to ensure compliance with Alberta Environment and Parks (AEP) Alberta Ambient Air Quality Objectives and Guidelines (AAAQO).

The definition of flared gas in Directive 060 covers the product of oil, bitumen, and gas well drilling, well completion or servicing, well testing for reserves estimates, planned and unplanned non-routine depressurizing of processing equipment for maintenance or emergency and oilfield waste management facilities.

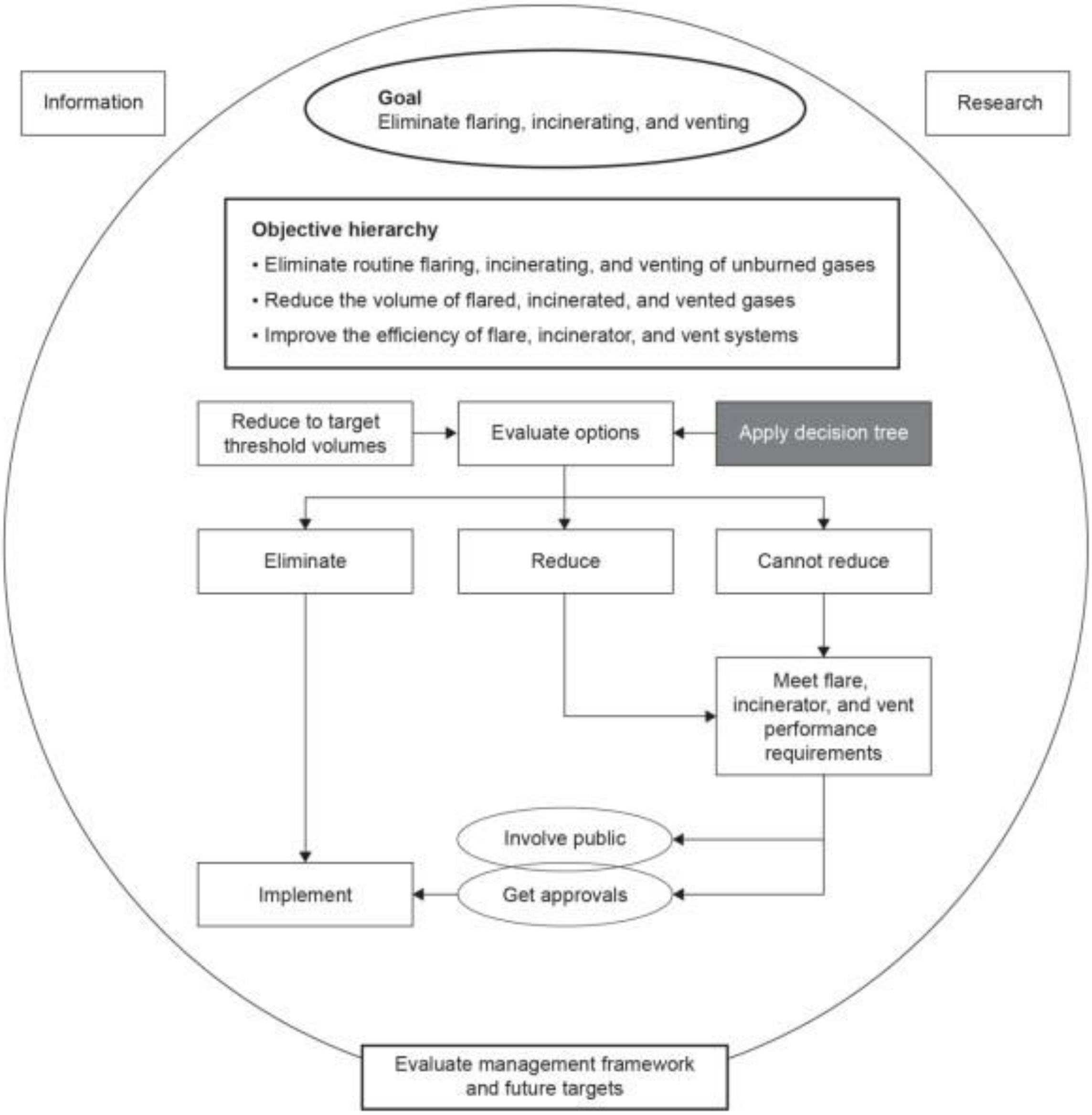
The directive adopts CASA objective hierarchy in managing gas flaring. Following the objective hierarchy, licensees, operators, and approval holders must consider the following:

• Can flaring, incineration, and venting be eliminated?

• Can flaring, incineration, and venting be reduced?

• Will flaring, incineration, and venting meet performance standards?

The CASA framework for managing Gas Flaring is as shown in the chart below.



Fig, 2.6 CASA framework for managing Gas Flaring

The directive puts a limit on the province`s gas flaring volume for a year, estimates showing excess will result in the imposition of limits on individual sites according to Section 2.1 subsection 1 and 2 of the directive as shown below:

"1) The Alberta solution gas flaring limit is 670 million cubic meters (106 m3) per year (50 percent of the revised 1996 baseline of 1340 106 m3 /year).

2) If solution gas flaring exceeds the 670 106 m3 limit in any year, the AER will impose reductions that will stipulate maximum solution gas flaring limits for individual operating sites based on analysis of the most current annual data to reduce flaring to less than 670 106 m3 /year. For example, solution gas flaring could be limited to a maximum of 500 thousand (103) m3 /year at any one site".

The AER also adopted the CASA decision tree to be used by operators or licensee to limit their gas flared per day to less than 900m3/day; they are required to demonstrate how each element of the decision tree was considered and implemented. The decision tree is as shown below.

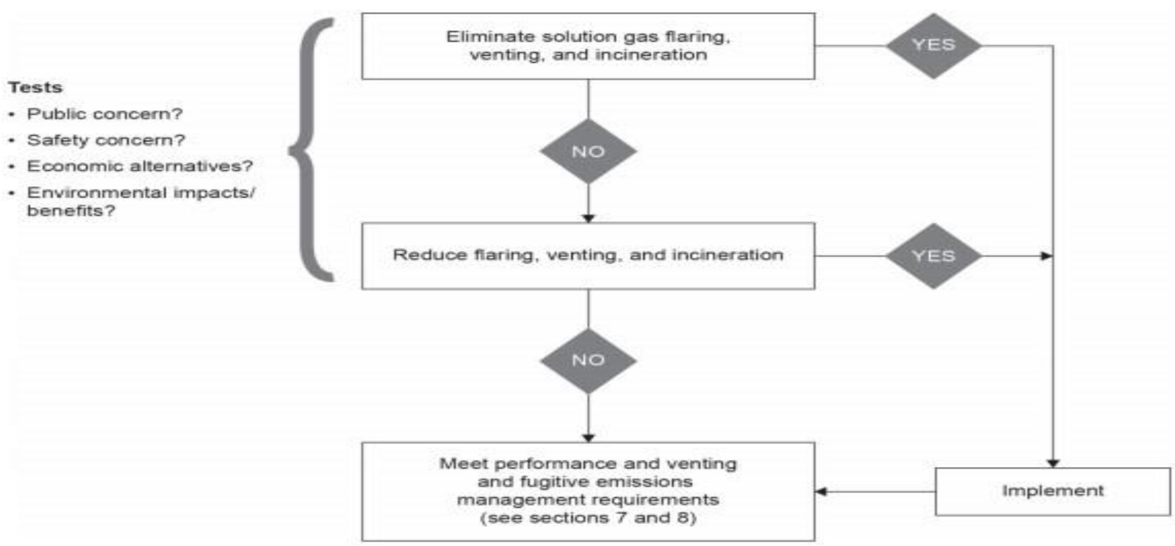


Fig. 2.7 CASA decision tree used by operators or licensee to limit their gas flared per day.

An important part of directive 60 is what it calls "Clustering." This is the practice of gathering associated gas from several locations to a point for conservation. The concept is borne out of the empirical fact that associated gas is economical to conserve in some areas if operators efficiently coordinate efforts to take advantage of combined volumes and economics of scale. Section 2.7 subsection 1 and 2 of the directive states that:

"1) Licensees or operators of existing production facilities operating within three kilometers (km) of each other or other appropriate oil and gas facilities (including pipelines) must evaluate clustering when evaluating solution gas conservation economics. The AER may suspend production in the area under consideration until the economic assessment is complete. The AER recommends that

- *all licensees and operators exchange production data and jointly consider the clustering of solution gas production or regional gas conservation systems, and*

- *the licensee or operator with the largest flare and vent volumes take the lead in coordinating the evaluation of conservation economics for the area.*

2) The licensee or operator of a multi-well oil or bitumen development must assess conservation on a project or development area basis regardless of distance. Evaluations must address all potential gas vent and flare sources associated with multi-well development.

a) The licensee or operator must incorporate provision for conservation at all stages of project development to optimize the opportunity for economic conservation of solution gas.

b) Applications under Directive 056: Energy Development Applications and Schedules for multi-well oil or bitumen developments must include a summary of the gas conservation evaluation and a description of the licensee or operator's detailed project plans.

The AER may suspend production at any facility until the economic assessment is complete".

2.2.5.2.2iv AER Directive 060 and power generation.

Of great relevance to this research is the position of AER 060 on power generation using otherwise flared/vented gas. The Act recognizes that power generation is a means of conserving associated petroleum gas and stipulated that operators must consider power generation if distribution lines are nearby or if on-site power is required. It, however, requires the operators to seek the approval of the appropriate government agencies under the nation's Hydro and electric Energy Acts and, above a generating capacity of 1.0MW, seek approval under the Environmental Protection and Enhancement Act.

Directive 060 is extensive in the coverage of the economic options of gas flare management as seen in Appendix 3

2.2.5.3 Gas flare management in Russia

Canada and Norway have developed a clear policy on gas flaring management, and the results show in their economic and environmental successes despite the large-scale exploration.

In other countries where the policies are less clear and less detailed, the resultant effect is large scale flaring with the attendant economic losses and adverse environmental impact. One such country is Russia.

Russia is the largest gas flaring nation in the world. The Russian state issues operating licenses for exploration through its Ministry of Natural Resources. However, the prospecting licenses mandate the operators to lift, process, and market associated gas and also Use APG for reinjection and related processes, the requirement is not bound by law. The two major oil and gas producing regions –Khanty-Mansijsk and Yamalo-Nenetz, require the operators to obtain a mandatory license agreement on the APG usage rate. With the former establishing a 5% maximum gas flare annually except if the operator could provide the evidence of the threshold being unrealistic: there are reports that most operators never bother Gun with the provision because monitoring is inefficient. This contrasts the laws in Alberta, Canada, where rigorous measures are put in place to monitor meterage.

In cases where punitive measures are required to be meted out to the operator for breaching gas flaring rules, a fine equivalent to a maximum of USD 1540 annually is attached to such infringement; this makes noncompliance a cheaper option for the operators. According to PFC Energy reports for 2007, out of 213 licenses issued to operators of exploration activities the previous year, only about 26% complied with the terms.

2.2.5.3.1 Russia Flaring legislations

Despite the public awareness and an effort to make legislative provision for mitigating gas flaring in Russia, it is safe to say the lack of standardized reporting, metering, monitoring, and enforcement of appropriate laws are the bane of curbing gas flaring in Russia. The mix is the prevailing socio-economic and political atmosphere in the nation.

2.2.5.4 Gas Flaring Management in Uzbekistan

By the Gas flaring countries ranking of 2017(Fig 2.1), Uzbekistan did not even rank in the top 30 gas flaring countries in the world; however, when flaring intensity is considered, the country has the largest gas flaring intensity in the world (Fig 2.2). Flaring Intensity is the amount of gas flared per unit of oil produced. Uzbekistan flared 48 cubic meters of gas per barrel of oil produced in 2015, compared to 2 cubic meters intensity by Canada in the same year. The significance of the country here is that in the year 2013, the flaring intensity in Uzbekistan was 60 cubic meters, the country started reforms earlier, and that has helped her bring down her flaring intensity by as much as 12 cubic meters within three years. For a better perspective, Nigeria made the closest improvement in flaring intensity within the same period; she brought down her flaring intensity figures by two cubic meters.

Uzbekistan discovered oil in 1983, but exploration only commenced after its independence in

1991, the largest exploration activities take place in the Kashkadarya province where more than 90% of its APG were flared initially. Management of APG became bigger problems as its reservoir pressure began to drop, and the exploration transited to an open system of well production accumulation, and gas-lift oil production method was introduced. Uzbekistan established a company, Kokdumalakgaz, whose sole responsibility was to develop utilization projects in the province for APG. The company considered multiple solutions, including electricity generation. All available flaring in the province was classified according to their pressure: High pressure > 1.0Mpa, Medium pressure 1.0Mpa< >0.5Mpa and low Pressure 0.5 Mpa < >0.1Mpa.

The company divided its flaring control approach into three and tackled the high-pressure group of flares first. It involved further compressing the high-pressure APG and transmitting it to a dedicated treatment facility before transferring the treated gas to the gas transportation network. The first phase was implemented in 2005; it was such a huge success that the second phase started two years later, and the third phase was started in 2011. The multi-stage approach to flare management was estimated to have saved 17 million cubic meters of gas per day or 5.5 bcm yearly. It was also recognized as one of the best flaring reduction projects in the world by the world bank GGFR excellence award in the year 2012. The country has since initiated the same method in the remaining production clusters elsewhere. Her latest effort is projected to save 800 mcm of low-pressure APG.

It must be noted, however, that the production capacity of Uzbekistan is just about 100,000 barrels per day, which pales in comparison with 10 million barrels per day for Saudi Arabia or 2 million barrels per day for Nigeria.

2.3 BTEX

The ‘BTEX’ compounds standing for Benzene, Toluene, Ethylbenzene, and Xylene are organic compounds categorized as Volatile Organic Compounds (VOCs). They are present in a range of commercial products because of their wide industrial use in the production of plastic, paints, glues, solvents, and as intermediates in the production of other chemical substances[25]. BTEX exposure can occur during the manufacture or use of the substances or products containing them. BTEX compounds may also be emitted from flaring, venting, engine exhaust, and during the dehydration of natural gas[33]. The high volatility of BTEX compounds makes their emissions commonplace, and these emissions occur principally from industries and automobile transportation. Petroleum refineries and exploration sites have been identified as large emitters of a wide variety of pollutants, including BTEX[34], because of their presence in fossil fuels.

BTEX's presence in the atmosphere is air pollution. In essence, they contribute to the formation of ground-level ozone and photochemical smog, which can cause damage to plants and materials in addition to posing human health concerns. When inhaled, these organic compounds are readily absorbed by the lungs. A significant absorption may also occur through the skin upon contact[25].

Most studies looked at exposure from occupational sources, granted that the bulk of exposures to BTEX occurs at work, an estimated 638 million people in LMICs live in rural areas close to oil reserves[35]. Acute exposure is possible in occupational settings, but low dose chronic nonoccupational (ambient) exposures could be significant also.

A review of multiple studies on ambient exposure to BTEX shows a range of mean exposure, as shown in the table below[36].

BTEX		**Personal air, μg/m³**	**Indoor air, μg/m³**	**Outdoor air, μg/m³**	**Lowest effect concn, g/m³**	**RFC mg/m³**
Benzene		1.21-2.8	1.01-24.8	1.5-6.95	1.01	0.03
Toluene		14.33	6.95-325.5	7.17-26.9	6.95	5.0
Ethylbenzene		2.55	0.8-18.7	0.59-2.06	1.5	1.0
Xylenes						0.1
	ortho	2.16	0.49-5.9	0.94-4.16	1.5	
	para/meta	5.97	1.55-7.23	3.07-13.3	4.1	

Table 2.3: The Range of Mean Exposure to BTEX across reviewed studies

Reference concentration was from US EPA Integrated Risk Information System (IRIS) database

the review shows that there are health effects that are significantly associated with low-level exposures, and non-occupational exposures can be significantly higher than the regulated, safe baseline[36].

2.3.1 Benzene

Benzene is a known human carcinogen as classified by EPA and IARC, it is a hydrocarbon, existing in a colorless liquid form but evaporates very quickly, it is therefore highly flammable and slightly soluble in water. Benzene can be formed from both natural and artificial processes.

Ranking among the top 20 most used industrial chemicals by volume, benzene is used in making detergents, plastics, resin, etc.

Benzene has been described as the signature component of BTEX as it is often recommended that the cancer unit risk value for benzene forms the basis for the assessment of other components of BTEX[37], and benzene evaluation is enough to determine the possible hematotoxicity and carcinogenic hazards of BTEX exposure for lack of data on carcinogenic response to the whole mixture[37].

2.3.1.1 Health Effects of Benzene exposure.

Research has shown that there is a rapid intake of benzene in humans, averagely 50% in 2 to 3 hours. The minimal risk level MRL for Benzene estimating the daily human exposure level without the risk of adverse, non-cancer effects is as shown below:

Route	Duration	MRL	Factors	Endpoint
Inhalation	Acute	0.009ppm	300	Immune
Inhalation	Intermediate	0.006ppm	300	Immuno
Inhalation	Chronic	0.003ppm	10	Immune
Oral	Chronic	0.0005mg/kg/day	30	immuno

Source: ATSDR, 1997.

Table 2.4 The minimal risk level MRL for Benzene

Where: acute =1 to 14 days, Intermediate= 15 to 364 days and chronic = 1 year or longer.

The main targets of benzene are the nervous and hematopoietic systems[38].

A major risk factor in the outcome of exposure is the length of time. Rushton 1997 investigated the risk of leukemia in petroleum marketing and distribution workers in the UK and concluded that there was no significant increase in the overall risk. However, risk doubles for greater than ten (10) years of exposure.

2.3.1.1.1 Carcinogenicity of Benzene

The carcinogenicity of benzene is established[37], several studies have also identified the major cancer outcomes of benzene exposure as Non-Hodgkin Lymphoma[39,40,41,42,43,44]and Leukemia[45,46,35,47].

Non-Hodgkin Lymphoma: Hayes et al. revealed a relative risk of 4.7(95% CI, 1.2 to 18.1) for Non-Hodgkin lymphoma while studying the outcomes from 74,828 workers exposed to benzene from diverse industry in china. A later study returned a less emphatic RR, Sorahan et al. reported 1.00 (95% CI 0.64 to 1.49) for non-Hodgkin lymphoma among workers exposed to benzene in the United Kingdom[47]. It must be noted that both studies have a large difference in sample sizes and exposure levels. More specifically, however, Steinmaus et al., 2008, in a review, identified 21 studies for exposed refinery employee cohorts, the summary RR for the 21 studies showed 1.21 (95% CI 1.00 to 1.46: p=0.02)[42]

2.3.1.1.2 Maternal/ Neo-Natal effects

There is a widely held notion that air pollution negatively affects fetal growth; Malmqvist 2016[48] investigated these effects and listed femur length, abdominal diameter, and fetal weight as the major outcomes returning statistical significance[48]. A well-researched outcome of benzene exposure is low birth weight[36],[38],[49]. In investigating birth outcomes of maternal exposure to benzene in several US cities, Zahran, 2011, regression results show an increase by 1µg/m^3 in maternal exposure to benzene results in a reduction of birth weight by 16.5g, representing an average of 4% reduction in birth weight[38].

2.3.2 Toluene

Toluene is a sweet-smelling, aromatic hydrocarbon, similar to benzene in many factors; it has a molecular weight of 92.15 with an LD_{50} of 5mgkg$^{-1.}$ The main route of exposure is by inhalation, and it is readily absorbed by the GI tract but slowly by the skin[50]. It is more fat-soluble and less volatile than benzene, hence its use as a solvent in many industrial processes.

2.3.2.1 Health Effects of toluene exposure

Animal studies suggest toluene is more toxic than benzene, and chronic exposure could result in CNS damage, while fetal death has been recorded in exposed animal studies[51].

There were other suggestions of toxic effects of toluene on the liver and kidney, but neither is confirmed.

Route	**Duration**	**MRL**	**Factors**	**Endpoint**
Inhalation	Acute	3ppm	30	Neurological
Oral	Chronic	1ppm	30	Neurological
Oral	Acute	0.8 mg/kg/day	300	Neurological
Oral	Intermediate	0.02mg/kg/day	300	Neurological

Source: ATSDR, 1997.

Table 2.5 The minimal risk level MRL for Toluene

2.3.3 Xylene

Xylene is a mixture of three isomers, ortho-, meta, and para-xylene. M-xylene is always the dominating component. It is also a clear, colorless and flammable liquid, other two methyl groups to benzene makes it less volatile but more fat-soluble than both toluene and benzene. It is used mainly in aviation fuels, cleaning agents, plastics, and enamels.

2.3.3.1 Health Effects

Xylene is a narcotic at a high dosage. It is also proven to be more acutely toxic than both benzene and toluene. In an animal test, benzene was lethal at 2440ml/m3, whereas xylene and toluene were lethal at 1600ml/m3. Human exposure to high concentrations of xylene vapor may result in skin irritation and irritation of mucus membranes and the eyes[51].

Route	Duration	MRL	Factors	Endpoint
Inhalation	Acute	1ppm	30	Neurological
Inhalation	Intermediate	0.7ppm	30	Neurological
Inhalation	Chronic	0.1ppm	300	Neurological
Oral	Intermediate	0.02mg/kg/day	300	Neurological

Source: ATSDR, 1997.

Table 2.6 The minimal risk level MRL for Xylene

2.3.4 Ethylbenzene

Ethylbenzene has similar effects as xylene; the industrial xylene is a mixture of xylene and ethylbenzene (Exposure to xylene and ethylbenzene. Uptake, distribution and elimination in man)

Route	Duration	MRL	Factors	Endpoint
Inhalation	Developmental	0.2 ppm	100	Neurological

Source: ATSDR, 1997.

Table 2.7 The minimal risk level MRL for Ethylbenzene

2.4 Nigeria.

Nigeria is the largest country in Africa by population; the world bank put the country`s population at 190.9 million in 2017, ranking the 7th largest country in the world. Located in the Gulf of Guinea, the country`s vegetation runs from the dense rainforest in the south through the grasslands of the savanna to the edges of the arid Sahara Desert.

Nigeria's economic conditions are representative of much of sub-Saharan Africa: this means that Nigeria is an extremely emerging country by world standards. Indeed, sub-Saharan Africa is the poorest region of the world by most standards. Economic conditions have a vital role to play in people's experiences and perceptions of Nigeria.

A person or a household's socioeconomic status influences the range of opportunities and constraints that such faces. It affects nutrition levels and health, geographic mobility, educational attainment, and overall quality of life.

According to the world health organization, four categories of factors are important in determining the health indicators for any society:

1. Health Status as determined by Mortality by age and sex, mortality by cause, fertility, and morbidity.

2. Risk factors: These are Nutrition, Infections, environmental factors, Non-communicable diseases, and injuries.

3. Service coverage; This includes reproductive health, maternal, newborn, child and adolescent, immunization, HIV, TB, Malaria, neglected tropical diseases, screening and preventive care, and mental health.

Health systems vis-à-vis Quality and safety of care, Access, Health workforce, Health information, health financing, and health security[52]. Available data from Global Health Observatory show that: For a population of about 185 million people, and a gross national income per capita of $5000, Nigeria`s total expenditure on health per capita is 217 USD, total expenditure on health as a percentage of GDP is 3.7%[52]

2.4.1 The Niger Delta

Since this project examines gas flaring, which only occurs in the southern Niger delta region of Nigeria, the economic realities of the average Niger-Delta resident are important.

The Niger Delta covers an area of about 70,000km2(27000 sq. mi), at about 30 million in population, with 500km shoreline on the Atlantic Ocean.

The topography and geographical attributes of the Niger delta mean the people are largely dependent on fishing and farming for day to day survival.

The Niger Delta produces 98 percent of the nation's oil and gas; its people survive with no electricity or clean running water. Seeing a doctor can mean traveling for hours by boat through the creeks. Occasionally, oil has been spilled into those creeks, and fishing communities disrupted, dislocated, or plunged into violent conflict with one another on compensation payments

A factor that is important while considering the effect of flaring is the population density of the countries. Nigeria has a population density of 204.21people per square kilometer, more than any of the top ten gas flaring nations. The population density of the Niger Delta region is higher than the country average

The Delta region has a steadily growing population estimated at more than 30 million people in 2005 and accounts for more than 23% of Nigeria's total population. The population density is also among the highest in the world, with 265 people per square kilometer, per the Niger Delta Development Commission.

The predominant settlement type in the Niger Delta is small and scattered hamlets. Most settlements comprise largely rural communities in dispersed village settlements. The typical community consists of compounds, which are closely spaced groups of small buildings housing 50 to 500 people, most of whom are farmers or fisherfolk.

The Niger Delta region of Nigeria has about 606 oil fields with 355 situated onshore; 251 situated offshore with 5,284 drilled oil wells and 7,000km of oil and gas pipelines[53]. As at October 2015, satellites images from Nigeria gas flare tracker shows hundreds of flaring sites concentrated in the Niger Delta region of the country making Nigeria one of the highest emitters of greenhouse gases in the world

Figure 2.8: An Aerial view of Niger delta showing significant oil pollution.

Source: GGFG

2.4.2 The Nigerian Oil and Gas Industry

The Oil and Gas industry in Nigeria is the backbone of the national economy. In essence, it contributes about 92% of the government's foreign exchange earnings in 2017, according to OPEC reports. The industry is the largest employer of labor in the country, an estimated 25 million of the 185 million Nigerians are directly and otherwise involved in business activities linked to the different stages of oil and gas exploration, refining, storage, and distribution processes.

Nigeria has the largest natural gas reserve in Africa, has the second-largest oil reserve in Africa and is the African continents, primary oil producer. 98% of Nigeria`s oil and gas exploration activities take place in the Niger Delta region in the southernmost part of the country.

2.4.3 Gas Flaring in Nigeria.

Nigeria is one of the highest gas flaring nations in the world. A study on the effects of gas flaring on building in the oil-producing rural communities in Nigeria Akwa-Ibom state[54] published in the African Research Review journal estimated that as much as 1000 flaring points litter the Niger delta region of Nigeria.

Satellite images from the Nigeria Ministry of Environment gas flaring monitor website, http://gasflaretracker.ng/ monitored on the 2nd of November 2018 shows there are 222 active gas flaring points in the country as at that day, 198 of which were located in the Niger Delta region of the country.

A communique from a two-day seminar organized by the government of Nigeria, the international gas union, the world bank and Global Gas Flaring Reduction (GGFR), held in Washington DC, 10 March 2017 shows that the country reduced flaring over the previous decade by just about 2 billion cubic meters.

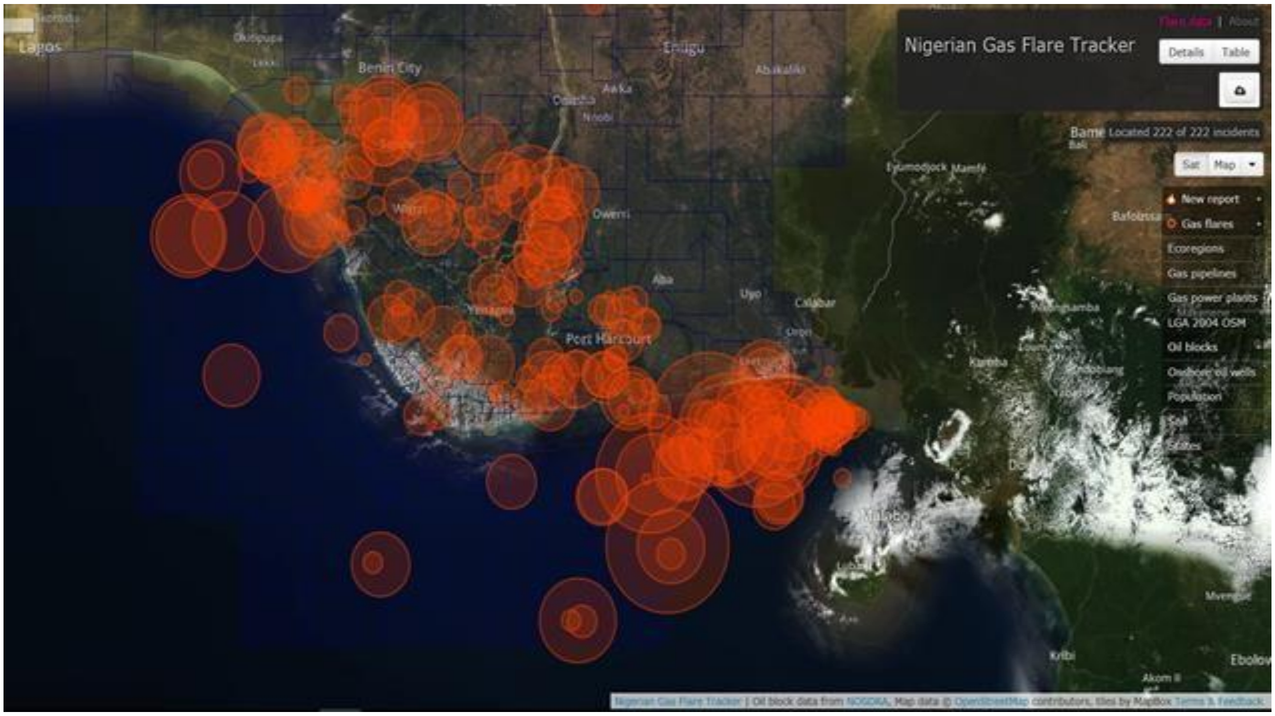


Figure 2.9: Satellite images from the Nigerian Gas flare tracker showing 202 incidents.

Source: www.gasflaretracker.ng

2.4.4 Previous studies on Gas flaring in Nigeria.

Several studies have been carried out on the gas flaring in Nigeria, with a diverse approach. Like its impact on micro-climate and vegetation[17],[55] soil, on-air and water quality[56],[57], on human health[58],[53] and the national economy[59],[55]. Other studies associated gas flaring with increasing poverty among rural women[60], climate change[61], and an increase in political activism in the Niger Delta Region[61]. Although these studies differed in their findings and conclusions, some produced very astonishing results. For example, a study in Bayelsa State in 2005 found that gas flaring caused 49 pre-mature deaths, 120,000 asthma attacks, and eight additional cases of cancer[61]. Specific data about the level of pollution and exposure of the residents in the region where flaring is prevalent is limited.

Limited research has been done to establish the level of air pollution in the immediate localities of the flaring sites.

The tracking satellite output of gas flare points also monitors the population within the immediate vicinity of such flare points.

2.4.5 Existing Regulatory laws in Nigeria

Available information from the UN environment programs (UNEP) shows that Nigeria Air pollution is regulated by three major pieces of the regulation issued by the National Environmental Standards and Regulation Enforcement Agency, these are

- The National Guidelines and standards for environmental pollution control in Nigeria.
- National Environmental Protection (pollution abatement in industries and facilities generating wastes) Regulation 1991.
- The Management of Solid and Hazardous Wastes Regulations 1991, which gave a comprehensive list of dangerous and hazardous wastes.

While all the necessary laws appear to be in place, enforcement and implementation is almost non-existence, factors like economic realities of the society, socio-political issues also prevent the effectiveness of the available laws[62]

The government put in place a ten-year plan to end all gas flaring activities by the end of 2008. The fact that eight years after the expiration of the plan, the country still flare almost the same amount of gas speaks volume of the attitude of the authorities to the implementation of any gas flaring plan.

Various legislative measures to curb gas flaring in Nigeria have been in place since 1969.

Since 1984 it has been illegal to flare gas in Nigeria without the written permission of the Minister of Petroleum Resources[62]

The current penalties for gas flaring in Nigeria officially stand at $1.50 per 1000 standard cubic feet.

3.0 Chapter Three

3.1 Research Assumptions.

Assumptions in research are defined as things, states, or conditions considered or accepted as true, plausible, or logical by researchers or their peers even if such has not been scientifically established. Assumptions may be things that are somewhat out of the researcher's control without which the study becomes irrelevant or non-applicable; according to Leedy 2010, "assumptions are so basic that, without them, the research problem itself could not exist"[63]. In research, assumptions are the foundations on which theories and models are built, and they may also be required for the test of hypothesis.

The assumptions address the theoretical and empirical basis for the expected outcomes of the exposure of interest. They underline the specific conditions necessary for the application of the economic costing, valuation, and recommendations to follow; they also form a valid basis for the cost-profit analysis and layout the general background to the whole study. For progress, there must be a justification for the assumptions from the literature.

The basis for the investigation and making proposals is rooted in the validity of these assumptions.

The aim is to critically examine the assumptions behind this dissertation and find a credible basis for employing such assumptions.

The assumptions were categorized according to the area of impact: Air pollution, The outcomes of exposure, i.e., low birth weight and cancers, and the green completion.

Conclusions from this exercise will guide in generating the figures needed for the required policy proposals.

3.2.1 Assumptions on Air Pollution.

Air pollution is a function of the concentration of pollutants in the immediate environment and the time of exposure of identified individuals to such pollutants in that microenvironment. The source of the pollutants in this study is limited to the non-occupational environment, which may indicate a chronic, low dose but long-term exposure of people who do not work directly with the compounds involved. (i.e., 0.003ppm, at more than 365 days).

The study assumes the significance of the relationship between air pollution and the burden of disease in Nigeria, that gas flaring is a significant source of air pollution in the environment, and a sizeable population in the country is exposed and therefore are at some level of risk that must be controlled.

Is air pollution a considerable challenge in Nigeria? Does the effect of air pollution as it concerns gas flaring merit the investigation? These are some of the questions the assumption on air pollution is expected to answer.

3.2.1.1 Air pollution is responsible for up to 5% burden of disease (BOD) in Nigeria[64,65,66,67]

While most literature and studies measure air pollution by the amount of PM in the atmosphere, the presence of pm traceable to gas flaring like soot or black carbon is an indicator of possible exposure to other less prominent bye products of flaring.

According to a study to estimate and monitor a 25-year trend of the global burden of disease attributable to air pollution,[68]: the exposure to air pollution increases morbidity and mortality. The report further noted that air pollution is a leading contributor to Global Burden Disease, and it ranked air pollution as the fifth in the list of risk factors for mortality in 2015: causing between

3.7 million and 4.8 million deaths worldwide.

Correia et al[69] researched the effect of air pollution on life expectancy in the US over seven years in selected counties; their report showed that air pollution control leads to improvement in life expectancy. A decrease of 10µg/m in the concentration of PM 2.5 leads to an increase in mean life expectancy by 0.35 years. Several other studies (Zeger et al. 2008, Samet et al. 2000, Laden et al. 2006) had higher results of between 0.42 to 1.51 years increase in life expectancy[69],[70].

A WHO release titled "Ambient Air pollution: A global assessment of exposure and burden of

Disease" stated that the global population exposure model and the annual mean concentration of $PM_{2.5}$ is important in estimating the burden of disease attributable to ambient air pollution[66].

Worldwide, ambient air pollution contributes to 7.6% of all deaths in 2016[67]

The world bank data from 2015, as presented in "The little green book," a compilation of the world development indicators[65] shows that air pollution is increasing worldwide, and it has become the main environmental threat to health. The compilation showed that the average exposure while worsening in places like Asia and the Pacific has remained dangerously high for decades in sub-Saharan Africa: estimating 17 µg/cu.m as the mean annual exposure to $PM_{2.5}$ pollution while indicating that up to 72% of the population is exposed. Air pollution damage being 1.1% of the gross national income GNI[3] in the same area as per the same source.

In the same vein, considering the Low-Medium Income Countries (LMIC) worldwide, the mean annual exposure to $P.M_{2.5}$ is 34 $\mu g/m^3$. At the same time, Air pollution damage as a function of national accounting aggregates is 0.5% of the Gross National Income (GNI).

For Nigeria, with a population of 180 million, a land area of 911000sq km and a GDP of 521B$, the mean annual exposure to $P.M_{2.5}$ is 27 $\mu g/m^3$, the percentage of the population exposed is 94%, and the percentage of the GNI funding the Air pollution damage is 1.0%[65]. Figure 3.2 shows the death rates from air pollution exposure in Nigeria. While the death rate from indoor/ household pollution has consistently reduced over the period considered, the death rates from outdoor particulate pollution has remained largely unchanged as well as the outdoor ozone pollution. The death rate from outdoor pollution and the rate decline of gas flaring in Nigeria over the same period is a similar curve.

Death rates from air pollution, Nigeria.

Age-standardized death rates from outdoor ozone, particulates and indoor fuel pollution per 100,000 individuals.

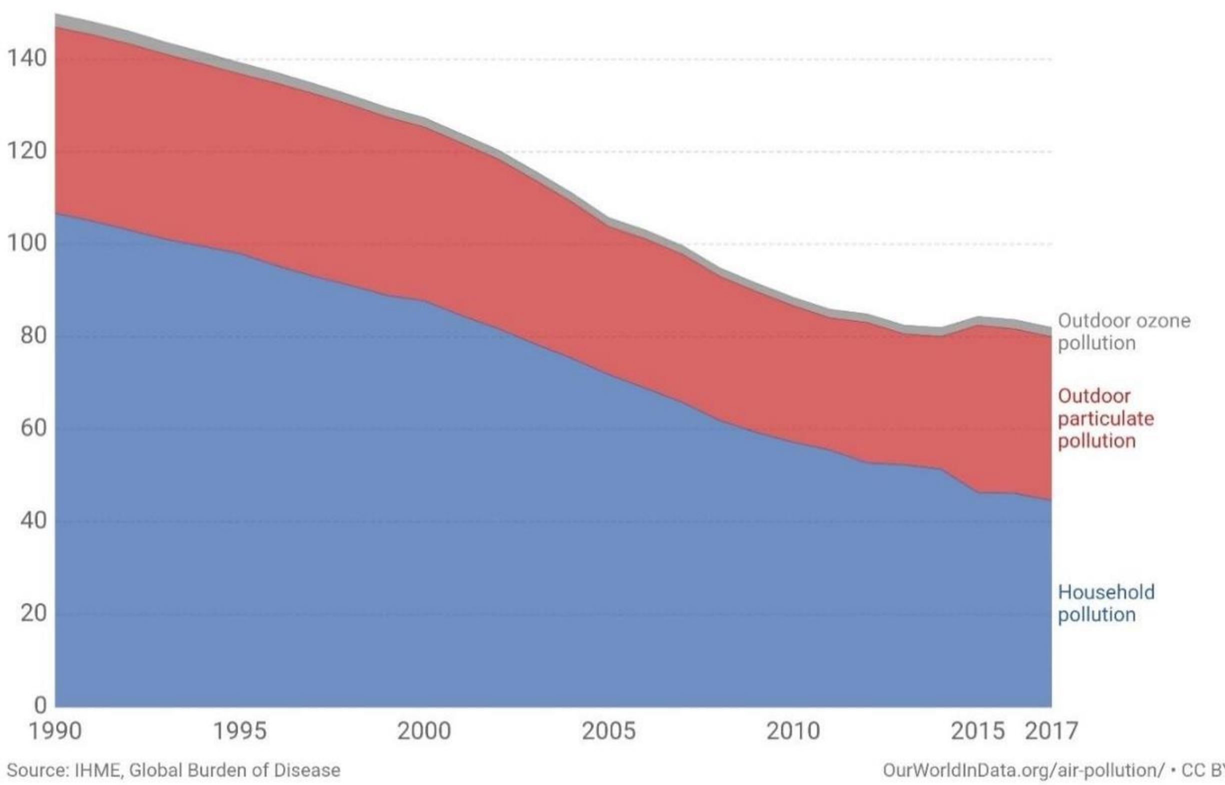


Figure 3.1 Showing death rates from air pollution in Nigeria.

Figure 3.2 below compares the number of deaths from outdoor air pollution from five countries with a large volume of daily crude oil production but with different approaches to gas flaring management. While Canada and Norway are reputable for their clear and concise approach to gas flare management as earlier discussed in this study, Russia and Nigeria have been less business-like. It must, however, be noted that the population of both Nigeria and Russia are significantly higher than those of Norway and Canada as the figure is silent on the total populations of the countries compared.

Number of deaths from outdoor air pollution.

Absolute number of premature deaths by country attributed to ambient (outdoor) air pollution of particulate matter (PM) and Ozone (O_3)

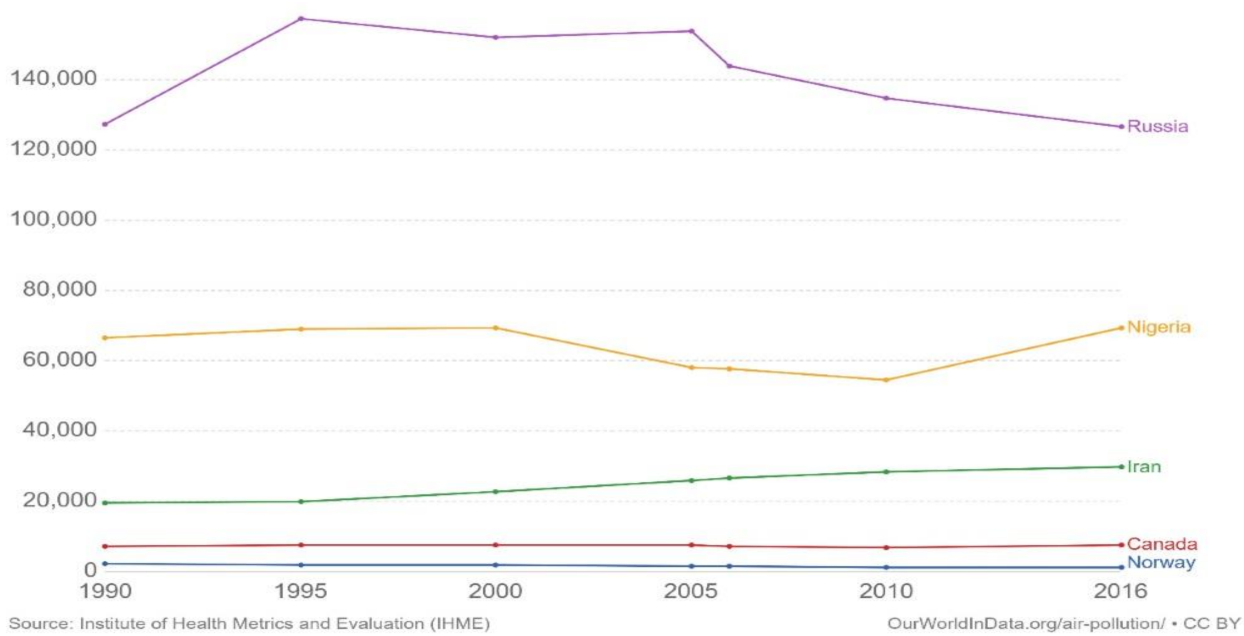


Figure 3.2 deaths from outdoor pollution in 5 reference countries.

3.2.1.2 Gas flaring is a significant source of air pollution in human settlements around oil and gas exploration sites in Nigeria.[57],[27],[71],[61],[72].

Having shown that air pollution and the burden of disease in Nigeria are related, it is important to verify gas flaring as a significant source of air pollution in the country. There are other common sources of air pollution, for example, Transportation emissions, open-air waste disposal, etc. but amidst all these, the effect of gas flaring must be significant to give a reasonable background to this investigation.

As earlier noted, Nigeria and Russia flare the most in the world. With about 35% of the volume of total gas flared around the world, there is a large volume of flared gas being constantly released in Nigeria oil-producing a region. A report on gas flaring and venting associated with petroleum exploration and production in Nigeria`s Niger delta concluded that the country flares about 75% of its associated gas, representing an average of 45 million tons of CO_2 per day.

According to Oyewunmi 2016, as much as 2.5 billion cubic feet of gas has been flared from oil fields and refineries across Nigeria over the last few decades[57].

While some figures from the studies considered might be somewhat outrageous, the Nigerian gas flare tracker satellites` recent updates show that the nation had flared a total of 3.0 billion mscf of gas between 03-2012 and 07- 2019.

There was a total CO_2 emission of 157.5 million tons, valuing the flared gas at 10.4 billion dollars with a power generation potential of 296.5 thousand GWh. The fine payable by the flaring companies are put at 5.9 billion dollars. These are humongous figures that lend credence to the assumption that gas flaring has a significant impact on the ambient air around the oil and gas exploration sites.

Figure 3.3 below shows the details.

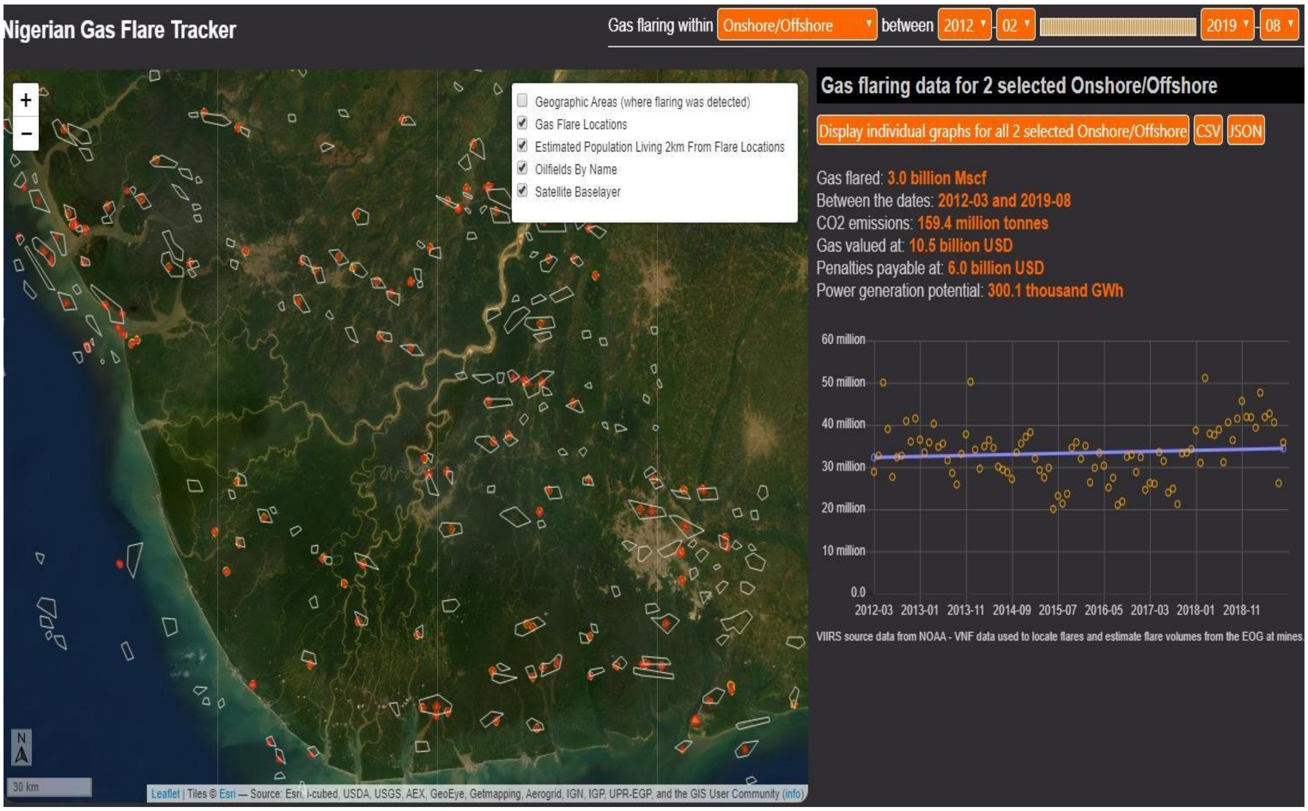


Figure 3.3. The gas flare tracker output. Showing a satellite view of the coastal gas flare points in red dots. The white boxes demarcate the oil fields. The flare data for selected oilfield is displayed on the right side of the window.

3.2.1.3 A considerable (a million and above) population lives within 2 km of gas flare sites in the oil-producing regions of Nigeria[73].

The Niger Delta region of Nigeria produces all the crude oil from Nigeria. Nigeria has a population density of 204.21 people per square kilometer, more than the density figures from any of the top ten gas flaring nations. The population density of the Niger Delta region is higher than the country`s figure[74]. The Delta region has a steadily growing population estimated at more than 30 million people in 2005 and accounts for more than 23% of Nigeria's total population. The population density is also among the highest in the world, with 265 people per square kilometer, per the Niger Delta Development Commission[75].

With a high-density population and a significant number of people within the theoretically established area of potentially high concentration of BTEX, one can assume that the outcome of this study would be useful.

3.2.1.4 a) Exposure to BTEX through gas flaring is a major source of BTEX exposure in the concerned communities[43]

b) Other sources of BTEX exposure like transportation, fossil fuel usage for domestic purposes do not present a comparative exposure source[40,76,77].

c) Ambient exposure from the other anthropogenic sources are not significant compared with the gas flaring source[78]

d) Effects of other factors like diet, smoking, etc. are not more pronounced than the effects of BTEX exposure [79]

BTEX compounds, especially benzene, are encountered daily through multiple sources. The most prominent sources are Transportation/ Automobile exhaust, Petrol dispensing stations, Domestic cooking, and related activities. For this project, it is necessary to have the exposure due to oil and gas exploration and refining activities (gas flaring) as a major source of BTEX exposure, and a contrary reality will undermine the proposed solution to the exposure.

Micheli et al. conducted a population-based case-control study to determine the risk of death for hematological malignancies for residents in proximity of Petrochemical refineries[40]. The results showed that for the subgroup of persons who plausibly spent most of their time at home like the unemployed, retirees, homemakers, etc., the relationship is significant. Hence, they concluded the risk is increased for people who spend more time in the vicinity of the refinery.

Fustinoni et al. identified other non-occupational sources of benzene exposure like smoking, public exposure to benzene from transportation[76]: cigarette smoking returned a strong significance for benzene exposure. Crebelli et al., on the other hand, examined the exposure to benzene from urban traffic[77] and cigarettes smoking, they concluded that there is significant exposure to benzene from traffic emissions, and it is greater than exposures from indoor sources. The report also stated that smoking cigarette presents a significant exposure regardless of traffic exposure or indoor exposure.

Cigarette smoking is a major source of benzene exposure in the Niger delta. A few studies addressed the prevalence of smoking in the oil-producing region of Nigeria and the country at large: Odey et al. researched the prevalence of smoking among the youths in a selected Niger delta state[77], they showed that the prevalence of smoking is 6.4% regardless of social classes. A similar but broader study[80] reported the national prevalence to be 8.9%: people in the oil producing communities may, therefore, smoke less than the national average. Applying the 6.4% to the Niger delta population of 30 million, gives 1.92 million smokers in the region, if the exposure to gas flaring affects more than 1.92 million people, we could assume that gas flaring is a major source of BTEX in the region. From table 3.2 above, an estimated 6.35 million people live within 10 km (6.3 miles) radius of all the flare point in the region, from fig 3.1, residents from under 10km may be exposed to varying amounts of concentration of BTEX.

3.2.1.5 (a) Air pollution as 5% of the burden of disease clause is co-significant with the effects of health status, the state of maternal healthcare delivery systems, and other obstetric factors.[83],[84],[85],[81],[86],[87].

b) Socio-economic factors like poverty, maternal education, physical activities, etc. are also accounted for in the other factors of the burden of disease.[87,80,78,81]

Multiple factors can be responsible for low birth weight in a newborn. According to a study that examined maternal risk factors for low birth weight babies in Lagos Nigeria[81], lack of adequate pre-conceptual care, inefficient antenatal care, and ineffective treatment of pelvic infections are some of the identified precursors to low birth weight. A similar study identified maternal age, socio-economic status, lifestyle, BMI, etc. as strongly associated with low birth weight[82], despite these factors, the significance of air pollution affects everyone exposed despite the presentation of the factors or the lack of it. Martin et al. looked at the Air pollution and birthed weight in Britain in 1946, and the result showed a strong association between air pollution index and birth weight; babies born in an area with the highest air pollution were 85 grams lighter than those born in cleaner areas. Notably, the report stated that "controlling for gender, father`s social class, mother`s education, and region did not change the estimates nor did further adjustment for birth order, birth interval and housing quality"[83]: these are the risk factors identified in Nigeria[82].

Martin 2000 researched outdoor air pollution, low birth weight, and prematurity[84]. The outcome showed that low birth weight and prematurity were strongly associated with air pollution, the study also opined that the associations of air pollution with birth outcomes do not seem to be due to bias or confounding. In a similar vein, Llop et al. researched preterm birth and exposure to air pollutants during pregnancy, pollutants examined were benzene and SO_2, their results showed that pregnant women exposed to benzene have an increased risk of preterm birth[87], especially at concentrations above 2.7µg/m^3.

Socio-economic factors like poverty, maternal education, physical activities, etc. are of important considerations in the incidence of low birth weight. Also, the position of Llop et al. is plausible. If air pollution due to benzene is significant, no other risk factors could be confounders.

3.2.2 Assumptions on cancer

Hemotoxin action has been identified as the most noted and the most natural systemic effect of BTEX exposure because of benzene. Prolonged exposure damages the bone marrow, reducing all the cellular elements in the peripheral blood and the marrow. Studies have shown that adverse outcomes in individual results at levels above 1ppm.

To investigate the cost of cancer from BTEX exposure, isolate other causes of the related cancers, and obtain a significance for the result of cancer from BTEX in gas flaring exposure. We have to find a correlation between exposure to BTEX and the cancer outcome after compensating for the possible confounders.

3.2.2.1 Benzene is the most probable cause of cancer among the BTEX compounds[88,89,90,43].

This project aims to mitigate low level, non-occupational exposure to BTEX; as such, it is salient to ascertain the effect of the most prominent compound in the group, benzene. Benzene is a known carcinogen[37], existing in different forms in the environment; it causes acute leukemia and probably many other forms of cancer[90]. In a study: Advances in understanding Benzene health effect and susceptibility, it was observed that there might not be any safe level of exposure to benzene as all levels constitute some degree of risk in a linear fashion. Benzene affects blood forming systems at low levels of exposure[90].

A cancer research publication designed to investigate changes in DNA methylation in subjects exposed to low – Dose benzene showed that low-level benzene exposure is associated with normal subjects with DNA methylation[89]. DNA methylation is associated with several outcomes, including carcinogenesis.

As against the outcome of earlier reports, Natelson et al. researched Benzene- induced acute myeloid leukemia and concluded that the notion that a cumulative dose of benzene being enough to cause AML is contestable citing the lack of precise exposure measurements and the small number of the presumed benzene induced cases of secondary AML available for study[88]. However, several other studies have linked low dose benzene exposure to cancer outcome: Glass et al. investigated leukemia risk associated with low-level benzene exposure and inferred that there is an excess risk of leukemia associated with cumulative benzene exposures[37].

In investigating residential proximity to benzene release sites and the incidence of Non-Hodgkin lymphoma, Bulka et al. results showed that using poison's regression, "for every mile the average distance to benzene release sites increased, and there was an expected 0.31% decrease in the risk of NHL" they, therefore, concluded that " NHL incidence was significantly higher in census tracts that were closer, on average, to benzene release sites." The same paper suggested that the toxic effects of benzene exposure can occur in levels as low as 1 part per million[43]. A similar study conducted in Canada but on a wider range of industrial plants with possible benzene exposure, however, differed in results, though not conclusive, Kenneth. et al. identified possible associations between NHL and proximity to industrial plants, which they concluded might be a result of chance or other factors[91].

3.2.2.2 Global Cancer Trend

Every sixth death in the world is due to cancer, making it the second leading cause of death (second only to cardiovascular diseases) In 2017, 9.6 million people are estimated to have died from the various forms of cancer. The Institute for Health Metrics and Evaluation (IHME) put relatively small error margins around this global figure: the lower and upper estimates are 9.2 and 9.7 million.

The most common cancers are tracheal, bronchus and lung cancer, colon and rectum cancer, and stomach cancer with 1.88 million, 896,000, and 819,435 cases, respectively, as presented in figure 3.4. However, there is a very large number of cases of leukemia with 347, 583. The types of cancer this research has been discussing is common.

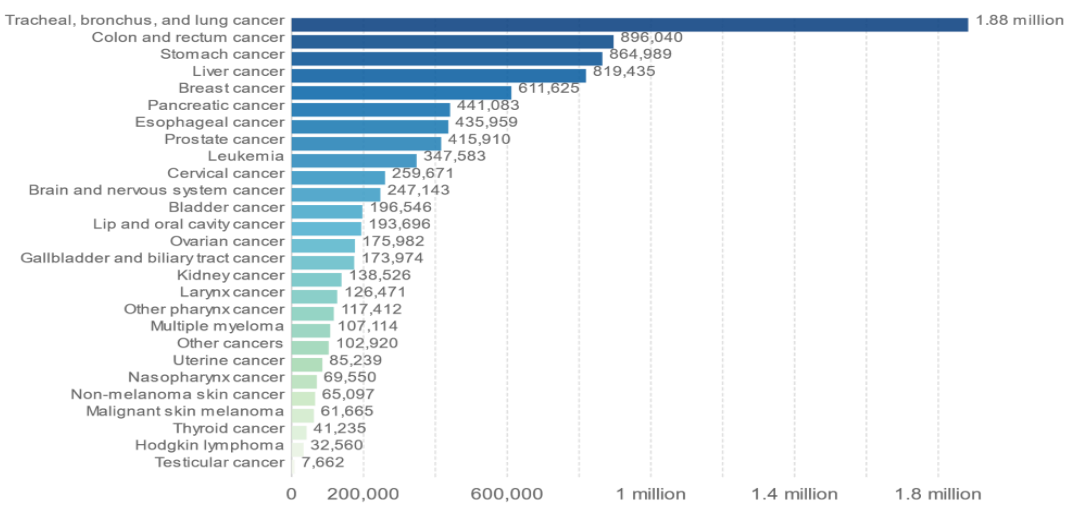


Figure 3.4 world share of the population with cancer types

3.2.2.3 Attributable Risk factors for cancer deaths in 2016

Inferring from IHME estimates for 2016, the Global share of cancer deaths is attributed to a spectrum of risk factors: These include known risks such as smoking, diet and nutrition, obesity, physical inactivity, alcohol consumption, air pollution, and carcinogenic environmental exposures.

The remaining share represents deaths that would be expected to have occurred in the absence of any risk factors. Tomasetti & Vogelstein, 2015 concluded that just 33% of cancers are attributable to environmental exposures or heredity, while the rest are random mutations resulting from “bad luck” as it depends on the chance of DNA replicating in otherwise healthy, non-cancerous cells[93]. The study, therefore, argued that early detection is the only mitigation.

The paper has been roundly rejected by many researchers, suggesting analytical flaws in the analysis, especially as epidemiological facts suggest otherwise. Ashford 2015, Wu et al. 2016, etc. argued that the factor of ‘chance’ in cancer development was overstated by Tomasetti & Vogelstein while understating factors like environmental exposures. Wu et al. (2016) argued that factors like DNA replication account for between 10-30 percent of harmful outcomes, while up to 70% factors are external.

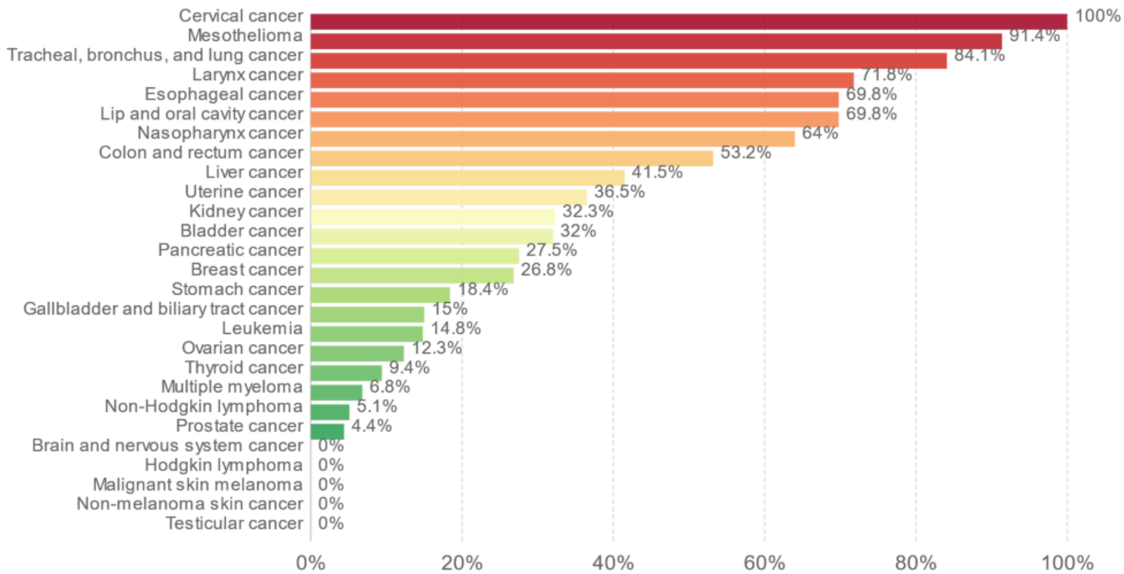


Figure 3.5 Attributable risk factors for cancer death, 2016.

Death from leukemia and Non-Hodgkin lymphoma is 14.8% and 5.1% attributable to risk factors, from the discussion so far, air pollution has been identified as a risk factor for these types of cancers.

3.2.2.3 Cancer incidence and mortality statistics worldwide and by region

Region	INCIDENCE of New cases	INCIDENCE of CUM. RISK	Death	MORTALITY Cum. Risk
Eastern Africa	**332177.00**	**13.47**	**230968.00**	**10.21**
Middle Africa	95735.00	10.86	68763.00	8.30
Northern Africa	283219.00	14.27	178754.00	9.39
Southern Africa	114582.00	19.93	61670.00	11.33
Western Africa	229459.00	11.42	153332.00	8.26
Caribbean	111933.00	20.23	63075.00	10.42
Central America	256782.00	14.70	119168.00	6.86
South America	1044017.00	20.56	490515.00	9.51
North America	2378785.00	33.13	698266.00	9.64
eastern Asia	5622367.00	21.54	3456734.00	12.88
S. eastern Asia	989191.00	15.29	631190.00	10.14
S.central Asia	1739497.00	10.26	1167183.00	7.22
Western Asia	399877.00	17.51	221957.00	10.17
central and Eastern Europe	1240057.00	24.95	699446.00	13.84
Western Europe	1370332.00	31.24	548355.00	10.99
Southern Europe	933181.00	27.55	422054.00	10.60
Northern Europe	686092.00	30.44	273623.00	10.32
Australia and New Zealand	233773.00	41.53	59247.00	9.39

Melanesia	15379.00	20.05	9257.00	13.07
Polynesia	1539.00	23.68	838.00	13.08
Micronesia	983.00	18.93	632.00	11.99
Low HDI	672218.00	11.79	464569.00	8.80
Medium HDI	2828475.00	11.94	1861723.00	8.21
High HDI	6515063.00	19.97	4020422.00	12.36
Very high HDI	8054578.00	29.05	3204212.00	10.52
World	18078957.00	20.20	9555027.00	10.63

Table 3.1 Cancer Incidence and Mortality Worldwide by region.

The cumulative risk of new cancer incidence is the combined risks of cancer outcome from exposures to all risk factors. The cumulative risk figures for West Africa, where Nigeria is is among the lowest in the world, as seen in table 3.1. Similarly, the cumulative risk for cancer death in the region is among the lowest in the World.

3.2.2.4 Factors of cancer prevalence

Multiple risk factors have been recorded for the prevalence of cancers. Among these are age, average personal income, GDP per capita of the country, etc.

3.2.2.4.1 Age.

Globally, age is a determining factor in cancer prevalence, most cancers occur in those above age 50, with 43% aged between 50-69 years while 27% aged above 70 years as shown in the figure below. While just about 5% of global cancers occur in children under 14 years. While growing old is not a causal factor for cancer, bad habits and exposure may start showing their effects as a function of a long time of exposure to such conditions.

Number of people with cancer by age, World.

Total number of people with cancer differentiated by age. this is measured across all cancer types.

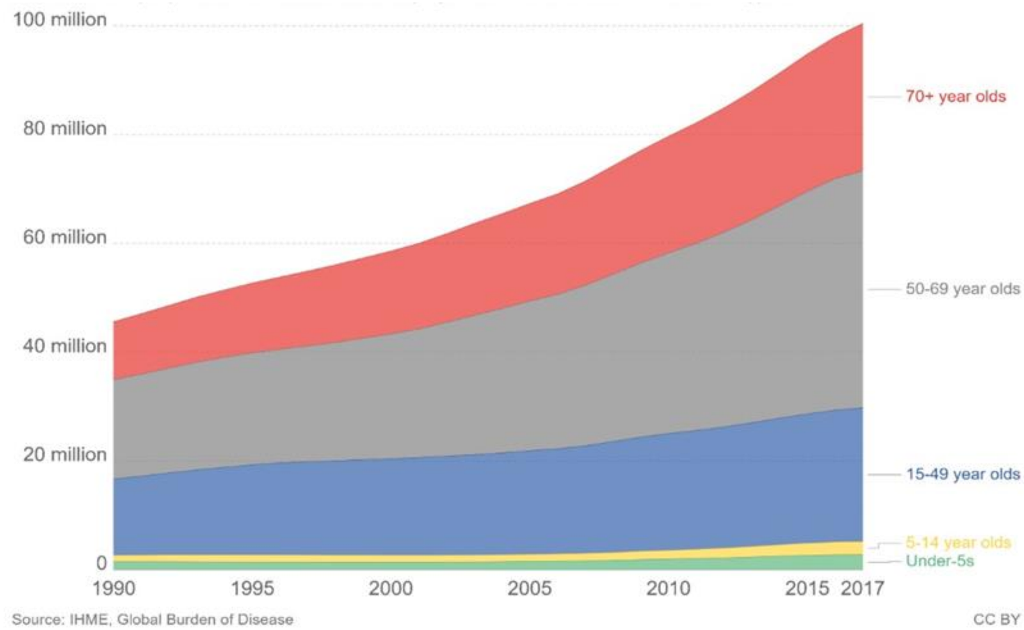


Figure 3.6 Number of people with cancer by age.

By comparison, childhood cancer cases in Nigeria are as high as 17 %, with a particularly high percentage for under 5 (15%). Data shows these cases are predominantly childhood cancers within the group of leukemia.

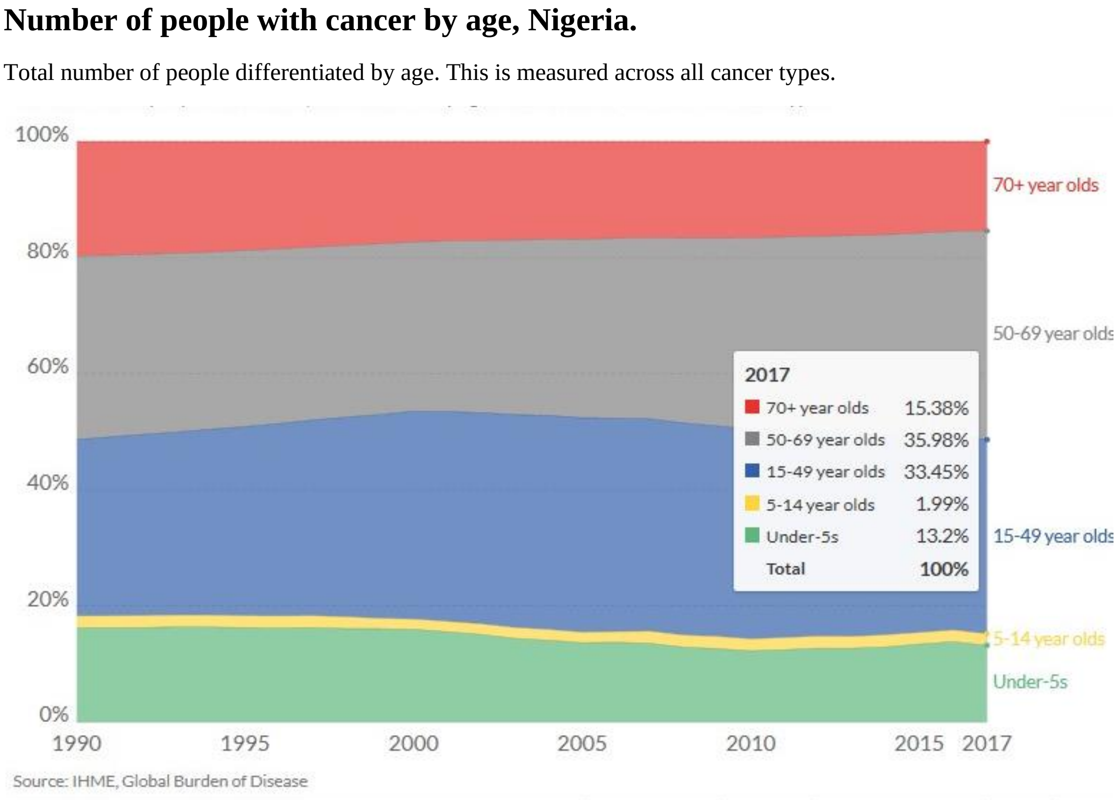


Figure 3.7 Number of people with cancer by age, Nigeria.

The divergence of the trend of childhood cancers in Nigeria from the global trend requires further investigation.

3.2.2.4.2 Personal Income and Cancer death

While cancer prevalence is linearly related to the income, the cancer death rate incorporates several factors like prevalence, detection, and treatment, making the death rate about the same globally.

It is expected that higher incomes mean better access to top-grade health facilities, diagnosis may happen earlier, and treatment may be more affordable.

Cancer	Number of New cases	% of New cases	Cum. the risk for New cases	Number of Death	Rank	% of Death	Cum. Risk of death	Number of the 5-year prevalence	Prop
Breast	26310	22.70	4.33	11564	1	16.40	2.01	52562	54.41
Cervix uteri	14943	12.90	3.27	10403	2	14.80	2.50	29601	30.64
Prostrate	13078	11.30	4.14	5806	3	8.30	1.78	19609	19.75
Non-Hodgkin Lymphoma	5367	4.60	0.48	3726	5	5.30	0.40	10612	5.42
Liver	5129	4.40	0.54	5154	4	7.30	0.55	4849	2.48
Colon	2887	2.50	0.36	1956	9	2.80	0.26	4789	2.44
Ovary	2792	2.40	0.48	2063	8	2.90	0.41	5508	5.70
Rectum	2784	2.40	0.29	1490	12	2.10	0.16	4709	2.40
Leukemia	2675	2.30	0.25	2218	6	3.20	0.23	5294	2.70
Stomach	2404	2.10	0.27	2110	7	3.00	0.24	3041	1.55
Brain, Nervous System	2378	2.10	0.14	1929	10	2.70	0.13	4754	2.43
Pancreas	1969	1.70	0.28	1901	11	2.70	0.28	1359	0.69
Lung	1347	1.20	0.15	1262	13	1.80	0.15	1523	0.78
Corpus Uteri	1331	1.10	0.34	666	19	0.95	0.19	2901	3.00
Larynx	1327	1.10	0.16	954	14	1.40	0.12	2402	1.23
Thyroid	1307	1.10	0.12	212	27	0.30	0.03	3139	1.60
Kidney	1259	1.10	0.08	676	18	0.96	0.06	2862	1.46
Nasopharynx	1203	1.00	0.07	777	15	1.10	0.06	2789	1.42
Bladder	1132	0.98	0.13	656	20	0.93	0.08	2275	1.16
Anus	1021	0.88	0.11	613	21	0.87	0.08	1766	0.90

Hodgkin Lymphoma	1005	0.87	0.08	562	22	0.80	0.06	2455	1.25
Kaposi Sarcoma	993	0.86	0.06	498	24	0.71	0.03	2004	1.02
Lip, Oral cavity	932	0.80	0.09	753	16	1.10	0.08	1797	0.92
Multiple myeloma	748	0.65	0.11	700	17	1.00	0.11	1209	0.62
Salivary glands	640	0.55	0.06	425	25	0.60	0.05	1127	0.58
Esophagus	569	0.49	0.07	549	23	0.78	0.07	527	0.27
Melanoma of skin	553	0.48	0.07	353	26	0.50	0.05	1110	0.57
Vulva	225	0.19	0.04	45	32	0.06	0.01	450	0.47
Gall bladder	217	0.19	0.04	145	29	0.21	0.03	264	0.13
Vagina	216	0.19	0.05	90	31	0.13	0.03	396	0.41
Oropharynx	207	0.18	0.02	149	28	0.21	0.01	450	0.23
Hypopharynx	108	0.09	0.02	92	30	0.13	0.02	133	0.07
Testis	100	0.09	0.01	32	33	0.05	0.00	256	0.26
Mesothelioma	6	0.01	0.00	6	34	0.01	0.00	10	0.01

Table 3.2 Nigeria New Cancer cases, death, and a 5-year prevalence summary

3.2.2.5 Nigeria cancer prevalence, cases, and death summary

Table 3.2 above shows the different cases of cancer in the country, their new cases, death rate, and 5-year prevalence. NHL, a major outcome of BTEX exposure, is ranked 5^{th} highest cause of cancer death with an annual new case of 5367 and 10612 5-year prevalence. The cumulative risk of developing NHL in Nigeria rates only lower than those of Breast, Cervical, Prostrate, and liver cancers.

In the same vein, Leukemia, another major outcome of BTEX exposure is sixth on the highest cause of cancer death in Nigeria, and it has an annual new case rate of 2675 and a death rate of 2218 with a 5-year prevalence of 5294.

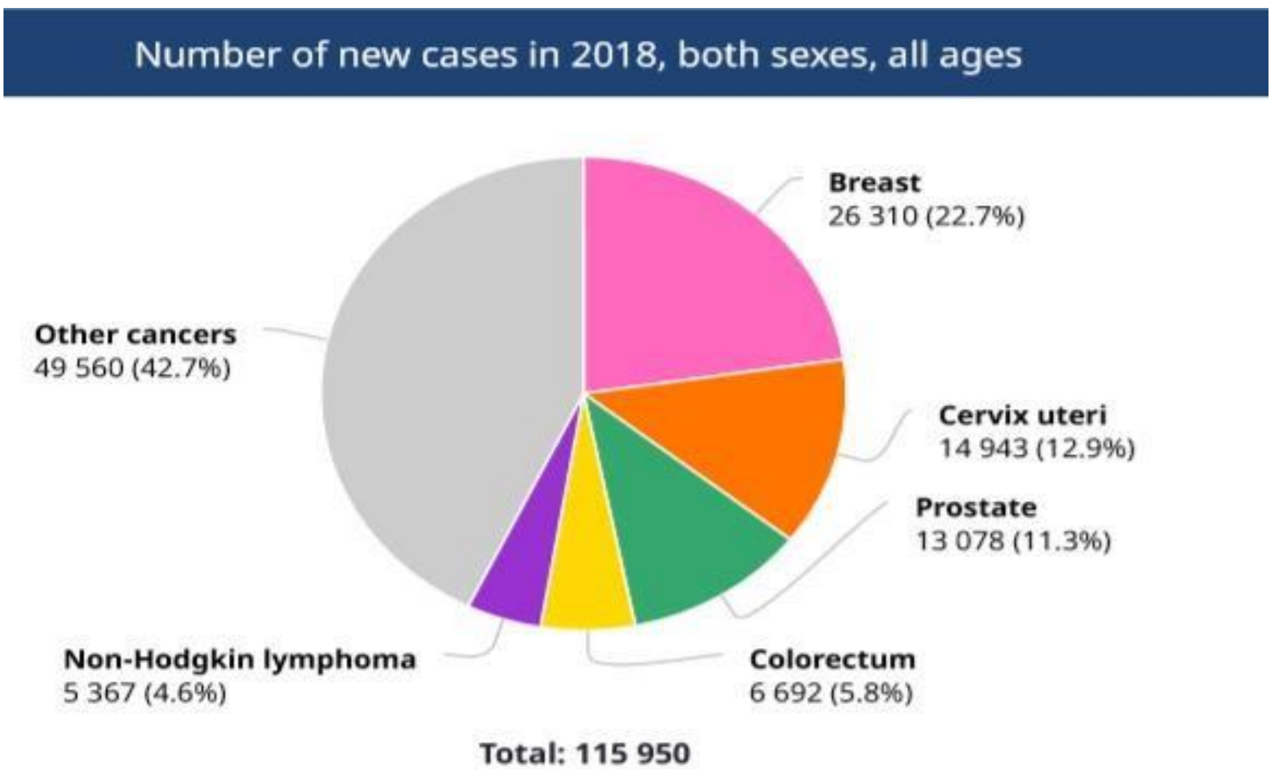


Fig 3.8 Number and percentages of new cancer cases in Nigeria 2018

3.3.2.5.1 Summary Statistics for Nigeria top 5 cancer types, 2018

Summary Statistics for Nigeria, 2018.	Column2	Column3	Column4
	Males	**Females**	**Both**
Population	99277846.00	96597394.00	195875239.00
Number of New cancer cases	44928.00	71022.00	115950.00
Incidence rate (Age standardized)	89.10	119.40	103.80
Risk of developing cancer before the age of 75	9.80	12.50	11.10
Number of cancer deaths	28414.00	41913.00	70327.00
Age standardized mortality rate	60.40	75.50	67.70
Risk of dying from cancer before age 75	6.50	8.40	7.40
5-year prevalent cases	74284.00	136768.00	211052.00
Top 5 most frequent cancers excluding nonmelanoma skin cancer	Prostrate	Breast	Breast
	colorectum	cervix uteri	cervix uteri
	Non-Hodgkin lymphoma	colorectum	prostate
	liver	ovary	colorectum
	stomach	Non-Hodgkin lymphoma	Non-Hodgkin lymphoma

Table 3.3 Summary Statistics for Nigeria's top 5 cancer types, 2018.

Table 3.3 identifies NHL as one of the top 5 cancer types in Nigeria, regardless of the gender in consideration.

3.2.3 Assumptions On low birth weight.

From the WHO data, 12% of child mortality is due to preterm birth and neonatal disorders. Three times as many children die before their first birthday as those before their 5th. The majority of those die within the first 27 days of life. Premature birth is a major risk factor in neonatal mortality. Premature birth may increase the risk of birth injuries, organ failures, and infectious diseases.

Regardless of the stage of development of any nation, birth weight has been described as probably the single most important factor affecting neonatal mortality. It is an important risk factor in both the physical and mental health development of such individuals in later stages of life. A baby with a birth weight of 2500 grams or less is said to be of low birth weight. According to Awoleke 2011, the incidence rate of low birth weight in Nigeria ranges from 11.4% to 12.1%[81], Maznah et al. put the figure at 12.1%, 11.4%, and 19.9%, for the south, middle belt and the northern part of the country respectively[82]. While several risk factors have been identified for low birth weight, exposure to benzene, and air pollution: two main interests of this study have been identified as prominent among the risk factors. For the acceptability of low birth weight outcome of benzene exposure from gas flaring, the weight of the other risk factors must be accounted for and the fraction resulting from benzene exposure established.

Causes of death in children under five years old, Nigeria.

Number of child deaths under five years old, shown by some of the leading causes.

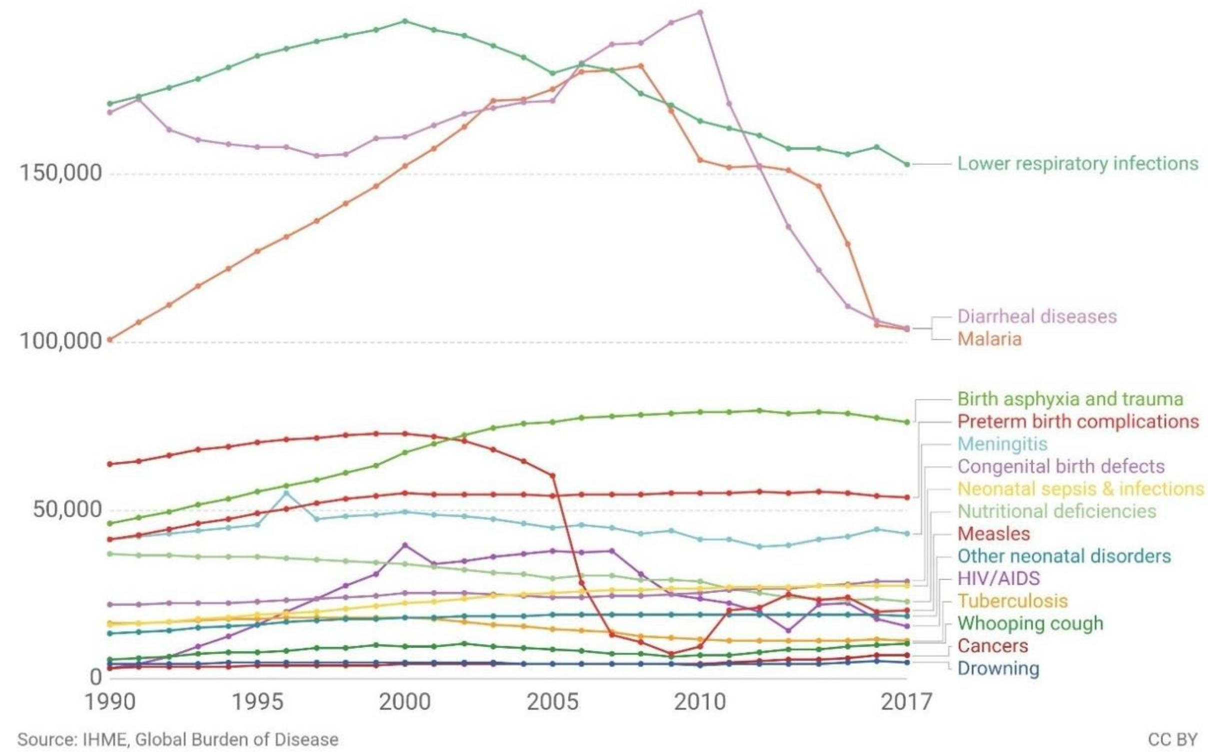


Figure 3.9: Leading causes of death in under five years old in Nigeria.

As per the WHO numbers, preterm birth complications are the fifth largest cause of death in under five years old in Nigeria, causing about 70,000 deaths in the year 2017. It is one of the causes of death that has never seen a substantial reduction in over two decades, as reflected in figure 3.3. Neonatal sepsis and infections and congenital disabilities are two other major causes of death in under-fives in the country that are closely linked with low birth weight, and they were the cause of death in as many as 40000 under-fives in the same year 2017 as shown in figure

3.1.4 Assumptions on Green completion

The assumptions on the gas turbine and the whole of the green completion stage are driven by profitability. For a profitable project that is self-sustaining and with a capacity to replicate, three factors are considered critical: The availability and access of the raw gas, the cost of funding the project and its sustainability and the state of the existing infrastructure. These three factors have been fingered in the low desire towards acceptable management of gas flaring in the country. As earlier discussed, (page 21), the state of the raw gas and its consistency is key in investing in green completion, in a similar vein, the state of the existing continues to limit interest in investment in the sector.

3.1.4.1 Volume of Gas available

The most important material in generating power with the gas-driven turbine is the gas. In completing this study, the assumption is that all the sites flared a constant volume of gas through the lifetime of the turbine. In operation, production volume is scarcely constant, so also is the release of the associated gas. The volume from the flare points in the country ranges from 0.193 million standard cubic feet to 46.9 million standard cubic feet per site; since the capacity of the turbine to be installed is to be determined by the volume of gas available, it is important to keep the output at a constant volume. Multiple smaller producing sites could be networked together with pipelines to keep the gas levels optimal. This ensures the volume of production does not drop over the lifespan of the turbine and justifies the expenses of exploration. Alternatively, the capacity of the turbine could be scaled down to match the capacity of the flare site.

It is also assumed that the Off-shore flare sites have a negligible contribution to the BTEX exposure onshore. About 40% of oil exploration activities take place offshore in Nigeria; hence, there is also a constant emission of BTEX offshore. This project assumes there is no coastal exposure to emissions from the offshore, considering the distance involved, the satellite images of the offshore flare points reveals zero population within high concentration zones of the emissions. Hence, no details of the peculiar offshore locations are used in coming up with figures for green completion.

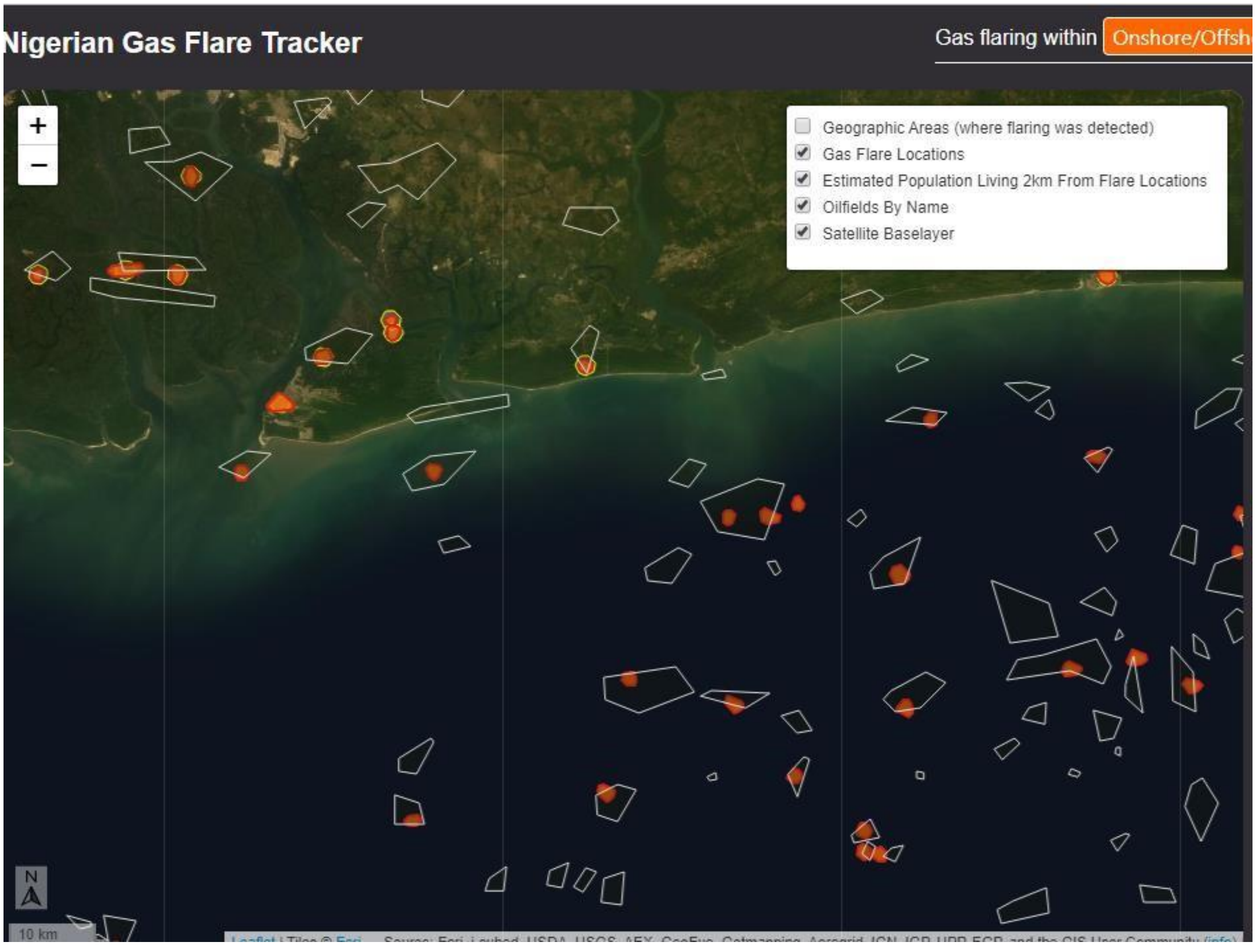


Figure 3.10: Tracker output showing some of the offshore flare points. Note the yellow ring around the onshore flare sites is absent around the offshore flares' sites, indicating the absence of populations around the offshore sites.

4.0 CHAPTER FOUR

4.1 RESEARCH METHODOLOGY

This chapter discusses the methodology for this research. The methodology is a description of the combination of processes that cumulated in the results of the investigation. There are three methodological approaches to research: Qualitative method, Quantitative method, and Mixed method; this research will employ a quantitative method of research, the quantitative approach is best for measuring, categorizing, identifying patterns and generalizing.

This research relied partly on the statistical pattern and general trend. It also made use of categorizations in differentiating between multiple levels of exposures and corresponding outcomes. In coming up with cost models, the research measures populations at different ranges using retrieved population densities from live satellite feeds. Hence, the quantitative method is the most appropriate.

4.1.1 Research Design

The Method starts by laying out what we knew prior to the research, the available information and archival data on Gas flaring:

We knew the case study country, Nigeria, flares a large volume of gas and the country is the 7^{th} largest gas flaring country in the world. Records show the country flared more than 3 billion mscf of gas between 2012 and 2019, valued at $10.5b. The penalties on the operators was in excess of $6b.

We also knew from the literature review that Gas Flaring can cause exposure to BTEX: this exposure can result in negative health outcomes.

Based on these two important known factors, the first step in the research was to determine the outcomes of exposure from the reviewed literatures.

Several outcomes were indicated to have resulted from exposure to BTEX in gas flaring, these included but not limited to cancers, sterility, Birth defects, skin diseases, Asthma, Spontaneous abortions, preterm complications etc. It would be impractical to go ahead and investigate all these outcomes, therefore, we systematically reduced the list to two statistically significant ones.

The statistical tool used in achieving this is the Meta-Analysis. A Meta-Analysis helps us to synthesize a common result from multiple studies.

The result of the Meta-Analysis is important in determining what cases to look out for in the case study population to warrant further investigation into the health cost of exposure to BTEX in Gas Flaring.

The outcomes identified through the Meta-Analysis indicated the need to examine the case study population in the light of cancer prevalence. The appraisal was done on three grounds: The cancer data trend from the world bank for Nigeria was compared with the other countries in the West Africa region believed to have the same risk factors for cancer prevalence, it was expected that the trend in these countries be similar.

The case study population cancer trend was also compared with that of the other Low Medium Income Countries: the expectation was for countries with similar Gross National Income per capita to have similar trend of cancer prevalence as the trend is globally.

Finally, the Nigerian cancer prevalence trend was compared to that of the top 20 gas flaring countries: the expectation was for a comparable rate except maybe for high Income countries, which are expected to have larger cancer prevalence as per the GNI per capita rating.

A combination of the results from the Meta-Analysis and the trend Analysis would determine the need to take a closer look at the study population or not.

A suspicion that the Meta-Analysis and the trend analysis can explain the cancer prevalence rate in the study population led to further research into the study population: The quest to determine the exposed population, the concentration of exposure and the resulting Incremental excess lifetime cancer risks (IELCR). The IELCR is the assessment of a population to determine the additional cancer posed by a precise exposure. This helps us to determine the increase in prevalence that can be attributed to an exposure to the cancer-causing agents in Gas flaring.

Having determined the additional cases of cancer brought by the exposure, this research determined the cost of these additional cancer cases given the local cost treatment per annum.

One important outcome of cancer risk assessment using the US EPA standards is the ability to determine if the action level is exceeded. If the result showed that action level is exceeded, an appropriate mitigation method would be recommended.

4.2 Meta-Analysis

Meta-analysis is a process of pooling multiple studies to use their results to arrive at evidence synthesis, combining the results of all relevant studies to give a summary estimate[92]. A Meta-analysis increases the power and precision for estimating the effect of a study because of the increased number of participants, reduced random errors, narrow confidence interval, and a greater chance of detecting real effects as statistically significant. It also improves the confidence in conclusions and decision making because small individual studies may produce a finding by chance. Meta-analysis often plays a role in designing new research. It could be used to determine if the study is necessary; the required information is retrieved by synthesizing data from prior studies: in which case, further research might not be needed.

4.2.1 Pros and Cons of Meta-Analysis.

Meta-Analysis offers a quantitative approach to synthesizing a result from multiple previous studies. The advantages of Meta-Analysis include:

Showing possible interaction or trend

Revealing possible bias in a study

Giving an insight into possible gaps in knowledge or research

Despite the advantages, critics of Meta-Analysis have argued a few disadvantages of the research method, including:

Meta-Analysis relies on published studies; these are usually studies that had statistically significant results. However, there are often insignificant studies, many of which are never published, this phenomenon creates a bias in results of Meta-Analysis.

Meta-Analysis gives room for inconsistencies when poorly designed studies are pooled together with better-designed ones. Similarly, studies often have differing conditions and variables, and can be done with different techniques; hence, there is a loss of efficiency when multiple studies are pooled.

All the pros and cons of Meta-Analysis are put into consideration in performing the Meta-

Analysis included in this research.

The meta-analysis is performed using reports and researches pulled from traditional resource banks like Google scholar, Medline, Bitmex, PubChem, PubMed, etc. Keywords in these searches would include air pollution, benzene, BTEX, gas flaring, etc. as indicated by the topic of such assumptions. The details of the meta-analyses are attached in the appendix 5.

A typical decision tree for a study to be included in the review is as follows.

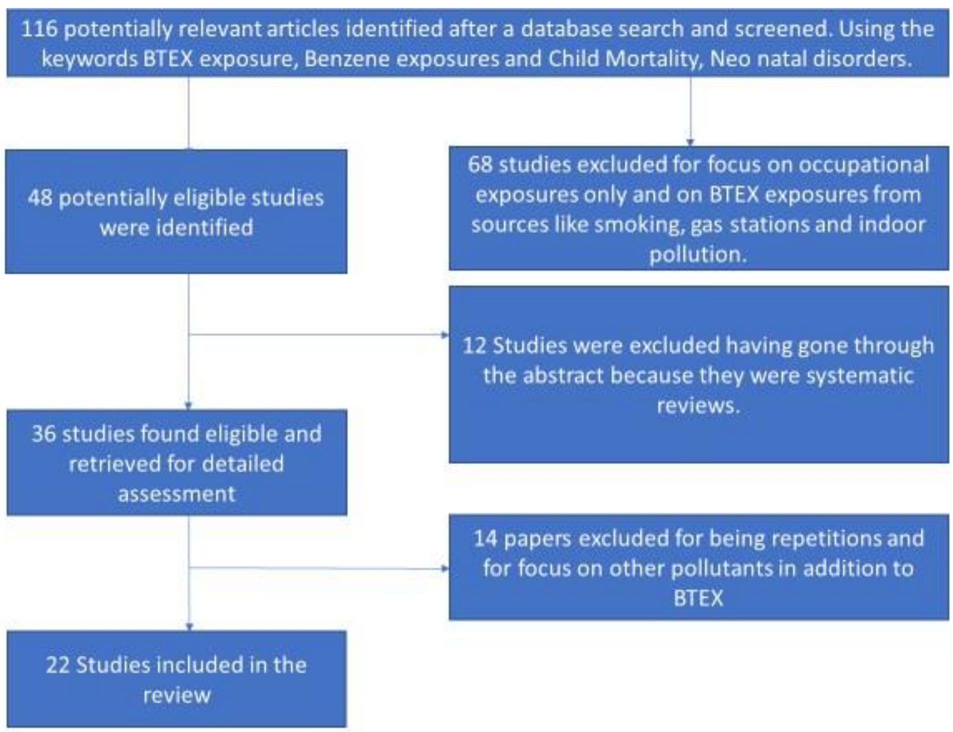


Figure 4.1: Decision tree for the Meta-Analyses.

After a general search using specific keywords as determined by the topic, a thorough study of the identified relevant reports was done. Each eligible study/ report must meet the preset criteria, like the focus of the rese0arch, not being a systematic review itself, non-repetition of other papers already selected, etc.

4.2.2 Meta-Analytic Review of Health Effects of BTEX exposure

In conducting the meta-analysis, the statistical factor of Odds Ratio is used to measure the strength of association between the different health effects and the exposure to the components of BTEX.

Odds Ratio is the odds of an event A occurring given the presence of an event B, and the odds of event B in the presence of A.

When OR is equal to 1 (OR=1), the two events are said to be independent, i.e., the presence of one has no association with the presence or otherwise of the other.

When OR is greater than 1 (OR>1), the two events are described as correlated, indicating that the presence of B raises the odds of A, compared to the absence of B, and vice versa.

When OR is less than 1 (OR<1), the events are less correlated.

With regards to this chapter 'OR' indicates whether a particular exposure to BTEX is a risk factor for any of the stated health outcomes.

OR can be calculated using either (a/c)/(b/d) or (a*d)/(b*c), Where

a, b, c, and d are represented as follows:

	Case	Control
Exposed	A	B
Unexposed	C	D

Table 4.1 Odds Ratio matrix

4.2.3 (i) Confidence interval

Sometimes the confidence interval in odds ratio may include 1, in such cases, the calculated odds ratio would not be considered statistically significant since it implies it is uncertain that the exposure of concern increases the chances of outcome at the specified level of significance.

For the full description of the results, the confidence interval and the p values will be stated: The confidence interval is used to describe the level of certainty of the odds. As the population is a relatively small sample, the upper and the lower limits of the CI put the true population into perspective. Our results will use 95% CI. If the CI crosses 1, then there is no difference between the two factors.

P-values are used to measure the statistically significant difference between the conditions, when $p < 0.05$, there is a statistically significant difference between the variables.

4.2.3 (ii) Fixed effect and Random effects

There are two approaches to combining data, fixed and random effects models. Fixed effect models assume that the resultant effects of the studies are the same while the random effects assume the effect varies across the included studies because of the inherent differences in the method and approach, hence, the degree of heterogeneity determines the choice.

For the Meta-Analysis in this study, the random effects model is used: I expect a moderate to high heterogeneity in the results to justify this choice.

4.2.4 (i) Meta-Analysis on NHL

Using the criteria stated in table 4.2. above, a total of 34 papers were screen, and the results are as shown in the table below.

Author	**Country**	**Results**	**Comments**
Blair et al 1993	US	OR, 1.1 (0.8 -1.4)	
Blair et al 1993	US	OR 1.6 (0.5 - 5.8)	Petroleum industry
Cartwright et al	UK	0.49 (0.21-2.00)	
Dryver et al 2004	Sweden	OR 1.45 (1.13 - 1.86)	
Dryver et al 2004	Sweden	OR 1.92 (1.20-3.08)	
Fabro 2001 et al 2001	France	OR 2.0 (1.1-3.9)	
Fabro et al. 2001		OR 2.3 (1.1-4.1)	10-year residence
"	"	OR 2.4 (0.9-5.9)	15-year residence
Franceschi et al 1989	Italy	OR 1.14 (0.57 - 2.28)	
"	"	OR 1.83 (0.87 - 3.84)	Petroleum Industry
Fritschi et al 2005	Canada	1.09 (0.75 -1.59	
"	"	1.19 (0.81-1.74)	Low concentrations
	"	0.31 (0.06-1.50)	Low dose, high freq 5+ yrs

	“	1.45 (0.92-2.29)	High conc
Gerin et al 1998	Canada	0.6 (0.4 -1.0)	Low dose
“	“	0.8 (0.4-1.6)	High dose
Hardell et al. 1994	Sweden	28(1.8 -730)	
		2.9 (1.6-5.6)	High dose
		1.8 (0.8-3.8)	Low dose
Kato et al	US	1.5 (0.41-5.70)	Occupational
		1.4(1.05-2.03)	Home and occupational
Author	**Country**	**Results**	**Comments**
Mao et 2000	Canada	1.2 (0.8-1.9)	Men
		0.6 (0.2-1.8)	Women
Miligi et al 2006	Italy	1.6 (1.0-2.4)	Medium occupational dose
		1.2(.7 - 2.0)	Medium Occupational dose, >15yr
		2.9 (0.9 - 9.0)	<15yr
Ott et al	WV, USA	1.0	
Persson et al 1999	Sweden	0.8 (0.1-3.8)	
Scherr et al	USA	1.2 (0.5-2.6)	
Schnatter et al 1992	USA	5.85 (0.3- 334)	
		0.54 (0.01 - 5.94)	
		1.44 (0.17 - 20)	
Schumacher et al	USA	0.77(0.56-1.07)	Whites

		0.94 (0.47-1.87)	Blacks
Siemiatycki	Canada	0.7 (0.5-1.0)	
		0.8 (0.4-1.7)	High Dose

Table 4.2 The Studies included in the Meta-Analysis

4.2.4(ii) Meta-Analysis on AML

The meta analytic review of the association between BTEX exposure and the occurrence of AML was performed using the specified criteria. 11 studies were included in the analysis.

4.3 Cancer Trend Analysis

Multiple risk factors have been recorded for the prevalence of cancers. Among these are age, average personal income, GDP per capita of the country, etc.

Of interest in this part of the research is the correlation between the GDP per capita of a country and its cancer prevalence rate.

4.3.1 GDP per capita

An important factor in cancer prevalence globally is the country's income, GDP per capita. Given the population, cancer prevalence has a positive correlation with GDP per capita.

There is a lower prevalence at very low incomes and a significant increase with increasing income above 9000$, as shown in Figure 4.2 below.

Share of population with cancer vs GDP per capita, 2017.

Age-standardized prevalence of any form of cancer within the given population, versus gross domestic product (GDP) per capita, measured in 2011 international-$

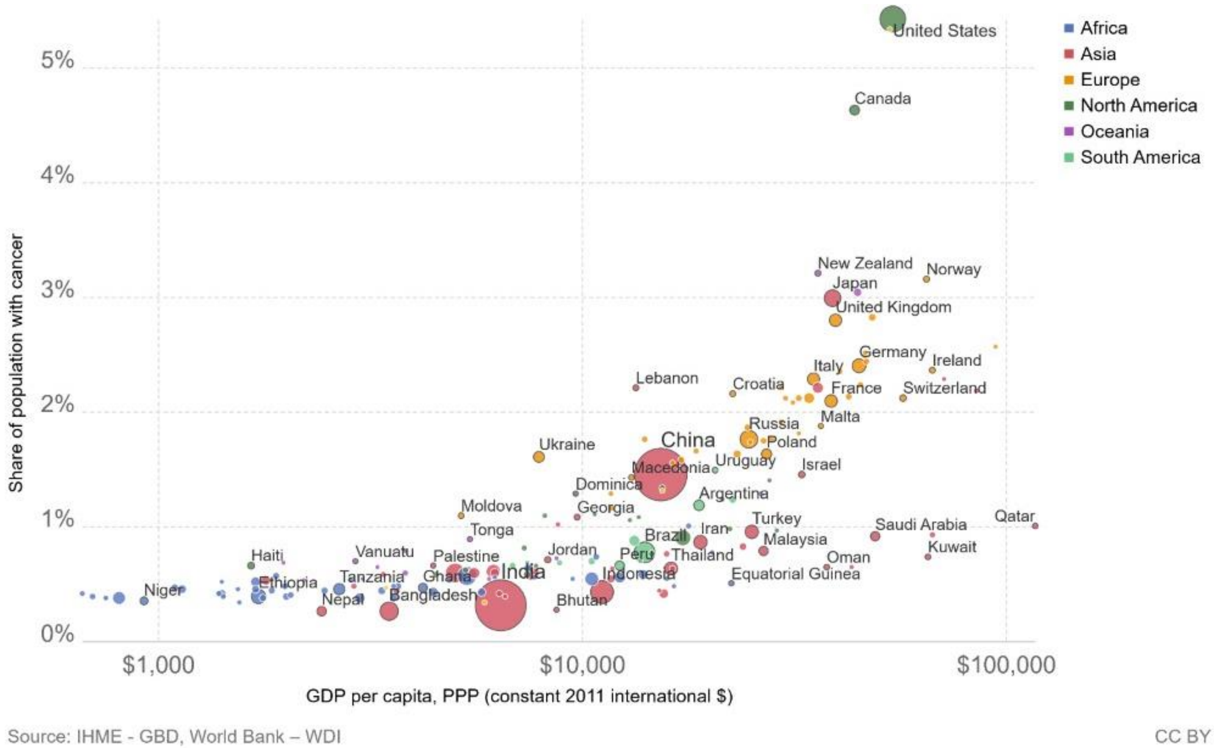


Figure 4.2: Share of population with cancer versus GDP per capita, World 2017.

Having identified the health outcomes of exposure to BTEX in Meta-Analysis as shown in the previous stage, i.e. Acute Myeloid Leukemia and Non-Hodgkin Lymphoma, we assessed the case study in the light of these outcomes.

To do this, we examined the Cancer data and Statistics of the case study from World Bank and the country`s Health department.

The trend of the data was compared with the trend in:

(i) The regional counterparts: We expected the trend to be similar since the countries in the region share similar demography, food, GDP, etc., all the risk factors earlier identified. The other countries in the region are Cameroon, Togo, Benin, Ghana, Ivory Coast, Senegal, Guinea, Mali, Burkina Faso, Gambia. It should be noted that none of these countries produce Crude Oil in the quantity comparable to what Nigeria produces. This clause could make the difference in the prevalence rate of cancer in the case study and any of her regional counterparts.

(ii) The average for all Low Medium income Countries: By the definition, LMIC have similar socio-economic indices, and we already know the positive correlation between the Socio-economic indices and the prevalence rate of cancer. The case study trend and the average for all LMIC globally should be similar.

(iii) The trend for the top 20 gas flaring countries: The final stage in the trend analysis was to compare the case study cancer prevalence and that of the top 20 gas flaring countries. We expected the trend to be similar if gas flaring contributes significantly to the cancer prevalence in such countries.

The results for this stage of the research is as shown in the chapter on results.

4.4 Nigeria Incremental Cancer Risk Assessment.

The Incremental Excess Lifetime Cancer risk is the probability of developing cancer as a result of a specific exposure to a specific carcinogen.

It is recorded as an increase in cancer cases in the exposed population as an addition to the number that would occur without the specific exposure.

This subsection on incremental cancer risk assessment addresses the risk of an additional case of cancer using conventional blueprints.

Two elements are important in cancer risk assessment, population data and concentration data. Obtaining these data is useful in assessing the case study population for the exposure to BTEX and the possible health outcomes of the exposure.

To obtain the data on population and exposure, we accessed the Nigerian Gas Flare tracker: this is the Nigerian government satellite feed that is commissioned to track the flare points in the country, this technology can also obtain the population within two Km radius of the all the flare points.

The main use of the satellite feed is to estimate the flare volume from each operator in the country so the government can estimate the fine accruing to such operator as punishment for flaring. This policy has not proven to be productive because flaring goes on and the fine are being evaded.

The output of the gas flare tracker is multiple layers of geographic information stacked in layers, to access the required information like population within 2km for instance, there is a need to "peel off" appropriate layers. The user guide to the tracker is attached in the appendix.

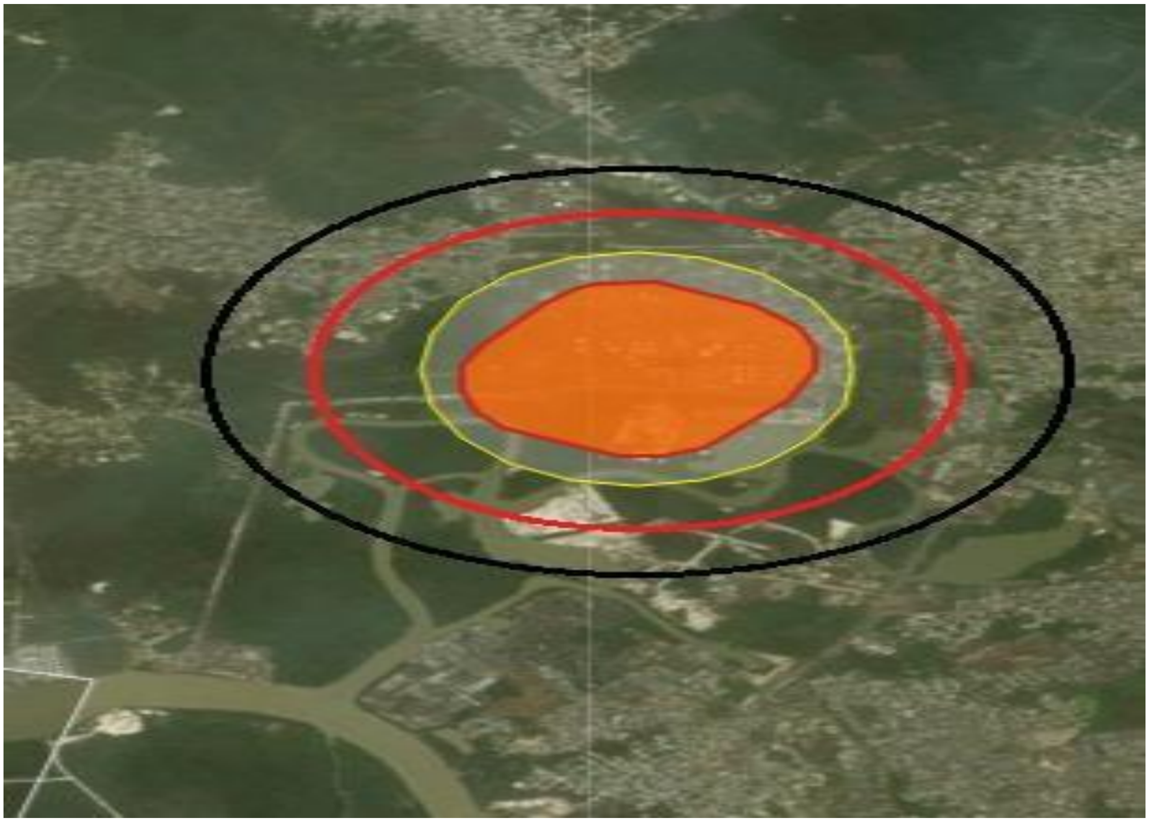


Figure 4.3: Areas of BTEX concentration delineated to high, middle, and low areas (Rapele Oilfield).

The orange patch shows the satellite image of the gas flare point source, the yellow circle is the satellite estimates of 2km radius from the point source with a population of 9170. The red and black circles are the 5km and 10km radii. Knowing the population within these ranges is essential for exposure estimates.

A population profile for the exposure is collected at a 2km radius from the flare point, retrieving population data from the government satellite feed, an extrapolation was done using the population density and the tracker population within 2 km to estimate the population within distances 5km and 10km respectively. Multiple researches have established concentration at different distances from the flare point. A 2km radius from the flare point has been discovered to be the area with the highest concentration of VOC. 5km radius is the limit of the near field definition. In comparison, at beyond 10km radius, the presence of VOC should not be registered. The aim here is to capture the largest possible population exposed to give a factual basis for the cost model.

The final stage involves an incremental cancer risk assessment. The standard formulas and US EPA standards are used to generate figures covering a range of distances from each gas flare point, and these assessments justified further actions to be recommended for mitigation of BTEX exposure from gas flaring.

Data generated/ retrieved from this stage of the research is used to develop excess cancer rates, and the total dollar values of these conditions. It is used to develop a profit baseline model for the proposed green completion

The EPA standards for Benzene is used to assess the incremental cancer risk using standard formulas.

The values of the Individual excess lifetime cancer risk compared with the EPA standards determine the next line of steps.

The Niger Delta region of Nigeria produces all the crude oil from Nigeria. Nigeria has a population density of 204.21 people per square kilometer, more than the density figures from any of the top ten gas flaring nations. The population density of the Niger Delta region is higher than the country`s figure[74]. The Delta region has a steadily growing population estimated at more than 30 million people in 2005 and accounts for more than 23% of Nigeria's total population. The population density is also among the highest in the world, with 265 people per square kilometer, per the Niger Delta Development Commission[75].

The table 4.3 below shows the coastal, 129 out of the total two hundred and two (202) active flare sites in the Niger delta and the number of people living within 2 km of such sites as monitored through the Nigerian gas flare tracker as at September 2019.

Oilfield	Actual Population Within a 2 km radius.	Pop@ 10Km	Volume flared (Mscf)	CO2 emission (Thousand tonnes)	Gas Value (million USD)	Penalty (Million USD)	Power gen. potential(GWh)
Aje 1	3878	96950	3.800				
Aje 2	3940	98500	0.000				
Opuekeba	173	4325	7.500	30.399	26.30	15.00	751.60
Opuama	149	3725	20.400	1.100	71.30	40.70	2000.00
Gbokoda	596	14900	12.500	0.666	43.90	25.10	1300.00
Otumara	414	10350	8.800	0.465	30.60	17.50	875.60
saghara 1	233	5825	15.400	0.818	53.90	30.80	1500.00
saghara 2	350	8750	8.200	0.436	28.70	16.40	820.20
saghara 3	695	17375	22.300	1.200	78.10	44.60	2200.00
escravos beach	646	16150	14.700	0.780	51.40	29.40	1500.00
Abiteye	788	19700	6.200	0.331	21.80	12.40	622.40
forcados Yokri 1	482	12050	1.000	0.053	3.50	2.00	100.10
forcados Yokri 2	329	8225	1.800	0.963	6.30	3.60	181.20
akepo 1	1	25	0.458	0.024	1.60	0.92	45.80
akepo 2	2277	56925	0.193	0.001	0.68	0.39	19.30
akepo 3	2387	59675	0.475	0.003	1.70	0.95	47.50
Odidi	1124	28100	27.700	1.500	97.10	55.50	2800.00
Rapele	9170	229250	18.600	1.000	66.20	37.80	1900.00
placemark 2	477	11925	9.500	0.507	33.40	19.10	1000.00
Batan	1724	43100	3.400	0.180	11.80	6.80	338.10
jones creek	600	15000	7.400	0.394	26.00	14.80	742.40

Oilfield	Actual Population Within a 2 km radius.	Pop @ 10Km	Volume flared (Mscf)	CO2 emission (Thousand tonnes)	Gas Value (million USD)	Penalty (Million USD)	Power gen. potential(GWh)
Makaraba	1292	32300	14.100	0.748	49.30	28.20	1400.00
Ovhor	2285	57125	46.900	2.500	164.30	93.90	4700.00
Oredo	842	21050	32.800	1.700	115.00	65.70	3300.00
Oki	573	14325	15.800	0.842	55.50	31.70	1600.00
gili gili	858	21450	8.800	0.468	30.90	17.60	0.88
Ogharefe	754	18850	10.800	0.573	37.80	21.60	1100.00
oben	1073	26825	46.900	2.500	164.30	93.90	4700.00
Amukpe	3190	79750	8.700	0.460	30.30	17.30	0.87
placemark	477	11925	9.500	0.506	33.30	19.00	1000.00
Umutu	2257	56425	22.200	1.200	77.60	44.30	2200.00
Kokori	2234	55850	4.900	0.262	17.20	9.90	492.60
ughelli w	2035	50875	2.200	0.117	7.70	4.40	219.90
ughelli e	3377	84425	14.100	0.750	49.40	28.20	1400.00
Afiesere	1945	48625	0.561	0.003	2.00	1.10	56.10
Eriemu	2693	67325	1.500	0.008	5.30	3.00	151.80
Oweh	908	22700	1.800	0.010	6.30	3.60	178.70
Olomoro	1417	35425	5.000	0.265	17.40	10.00	498.50
Isoko	760	19000	7.000	0.373	24.50	14.00	701.40
Ogini	788	19700	10.200	0.540	35.50	20.30	1000.00
Utorogu	3668	91700	29.100	1.500	102.00	58.30	2900.00
Oroni	2619	65475	3.100	0.166	10.90	6.30	312.60
Uzere	1239	30975	4.400	0.231	15.20	8.70	435.50
Benisede	2053	51325	10.200	0.542	35.70	20.40	1000.00
Opukushi	2039	50975	11.400	0.605	39.90	22.80	1100.00
clough creek	2845	71125	23.600	1.300	82.40	47.10	2400.00

Oilfield	Actual Population Within a 2 km radius.	Column 1	Volume flared (Mscf)	CO2 emission (Thousand tonnes)	Gas Value (million USD)	Penalty (Million USD)	Power gen. potential(GWh)
ogbainbiri	1236	30900	18.000	1.000	63.00	36.00	1800.00
clough creek 2	367	9175	15.700	0.835	55.00	31.40	1600.00
Bassa	132	3300	21.600	1.100	75.60	43.20	2200.00
clough creek 3	1724	43100	0.207	0.001	0.72	0.41	20.70
nun river	924	23100	6.400	0.338	22.30	12.70	636.00
Diebu	1789	44725	12.800	0.682	44.90	25.70	1300.00
Tebidaba	2437	60925	14.500	0.772	50.90	29.10	1500.00
Idama	1984	49600	8.500	0.449	29.60	16.90	845.20
Obodugwa	495	12375	6.100	0.323	21.30	12.20	608.80
obodugwa 2	1362	34050	42.700	2.300	149.50	85.40	4300.00
Kwale	940	23500	46.100	2.400	161.40	92.20	4600.00
Okapi	260	6500	32.400	1.700	113.50	64.90	3200.00
Okapi	260	6500	3.200	0.172	11.30	6.50	323.60
umusadege	1741	43525	11.900	0.632	41.60	23.80	1200.00
Matsogo	527	13175	3.400	0.179	11.80	6.70	336.00
Anieze	216	5400	5.100	0.273	18.00	10.30	513.50
Beniku	123	3075	5.100	0.273	18.00	10.30	513.00
placemark	1513	37825	16.300	0.864	56.90	32.50	1600.00
ogbainbiri	1236	30900	18.200	1.000	63.60	36.30	1800.00
Azuzuama	615	15375	0.237	0.001	0.83	0.47	23.70
Diebu	1789	44725	12.800	0.682	44.90	25.70	1300.00
Gbaran	2762	69050	19.700	1.000	69.00	39.40	2000.00
Etelebou	1506	37650	2.500	0.132	8.70	5.00	249.30
soku 2	2444	61100	14.900	0.789	52.00	29.70	1500.00

Oilfield	Actual Population Within a 2 km radius.	Column 1	Volume flared (Mscf)	CO2 emission (Thousand tonnes)	Gas Value (million USD)	Penalty (Million USD)	Power gen. potential(GWh)
soku 1	2169	54225	0.518	0.003	1.80	1.00	51.80
Obama	2042	51050	38.300	2.000	134.10	76.60	3800.00
Anieze	216	5400	5.200	0.275	18.10	10.30	517.50
oguta 1	318	7950	7.800	0.412	27.10	15.50	775.30
oguta 2	338	8450	29.300	1.600	102.50	58.60	2900.00
Izombe	2436	60900	20.700	1.100	72.40	41.40	2100.00
egbema 1	297	7425	10.100	0.538	35.40	20.30	1000.00
egbema 2	1824	45600	0.450	0.002	1.60	0.90	45.00
egbema 3	519	12975	1.400	0.007	4.90	2.80	139.00
obrikom 1	4317	107925	51.100	2.700	178.80	102.10	5100.00
obrikom 2	4317	107925	1.300	0.007	4.70	2.70	133.70
obagi 1	3292	82300	45.700	2.400	160.00	91.40	4600.00
obagi 2	3423	85575	1.100	0.006	3.90	2.20	111.20
Adibawa	576	14400	1.700	0.009	5.90	3.40	168.00
Ahia	322	8050	8.200	0.437	28.80	16.40	821.90
Ubie	2000	50000	0.853	0.005	3.00	1.70	85.30
Oshi	4305	107625	27.800	1.500	97.20	55.60	2800.00
kolo creek	4365	109125	3.600	0.193	12.70	7.30	362.70
Enwhe	1473	36825	2.500	0.134	8.90	5.10	252.90
Rumuekpe	1667	41675	3.600	0.194	12.80	7.30	364.80
Obede	1308	32700	0.681	0.004	2.40	1.40	68.10
Awoba	1312	32800	24.300	1.300	85.10	48.60	2400.00
nembe 1	2209	55225	1.800	0.009	6.20	3.60	178.50
nembe 2	2414	60350	8.900	0.474	31.20	17.80	891.90

Oilfield	Actual Population Within a 2 km radius.	Column 1	Volume flared (Mscf)	CO2 emission (Thousand tonnes)	Gas Value (million USD)	Penalty (Million USD)	Power gen. potential(GWh)
nembe 3	2347	58675	10.300	0.545	35.90	20.50	1000.00
nembe 4	3087	77175	10.300	0.547	36.00	20.60	1000.00
odeama creek	2784	69600	7.500	0.400	26.30	15.00	752.10
santa barabara	458	11450	7.400	0.392	25.80	14.70	737.00
Belema	1167	29175	11.000	0.585	38.50	22.00	1100.00
R kiri	1289	32225	23.100	1.200	80.70	46.10	2300.00
ekulama 1	1720	43000	5.500	0.292	19.20	11.00	549.50
ekulama2	514	12850	11.900	0.634	41.80	23.90	1200.00
Krakam	1626	40650	1.400	0.007	4.90	2.80	139.80
Akaso	228	5700	31.500	1.700	110.20	63.00	3100.00
C channel	2725	68125	19.700	1.000	69.00	39.40	2000.00
Alakiri	8922	223050	14.400	0.766	50.50	28.80	1400.00
Ebubu	14067	351675	13.800	0.736	48.50	27.70	1400.00
elenenwa1	11608	290200	3.800	0.202	13.30	7.60	381.00
Umuechem	2280	57000	1.500	0.008	5.30	3.00	151.10
Nkali	1711	42775	3.300	0.173	11.40	6.50	325.60
imo river	3159	78975	7.200	0.382	25.20	14.40	719.60
agbada 1	1922	48050	11.700	0.621	40.90	23.40	1200.00
agbada2	2663	66575	7.900	0.421	27.70	15.90	792.80
Obigbo	4361	109025	6.900	0.370	24.30	13.90	694.30
isimiri 1	1583	39575	4.700	0.250	16.40	9.40	469.60
isimiri 2	2635	65875	10.400	0.551	36.30	20.70	1000.00
Inda	5239	130975	39.100	2.100	136.90	78.20	3900.00
bonny 1	3617	90425	2.600	0.138	9.10	5.20	258.80

Oilfield	Actual Population Within a 2 km radius.	Pop @ 10Km	Volume flared (Mscf)	CO2 emission (Thousand tonnes)	Gas Value (million USD)	Penalty (Million USD)	Power gen. potential(GWh)
bonny 2	636	15900	0.700	0.004	2.50	1.40	70.00
bonny 3	534	13350	0.700	0.004	2.50	1.40	70.00
Otakikpo	8217	205425	7.900	0.419	27.60	15.80	787.80
Uquo	3546	88650	33.500	1.800	117.20	67.00	3300.00
Stubb	2098	52450	4.500	0.239	15.70	9.00	449.00
Okono	0	0	0.000	0.000	0.00	0.00	0.00
Afiando	0	0	0.000	0.000	0.00	0.00	0.00
KRPC	5797	144925	11.200	593.500	39.10	22.30	0.00
Kalaekule	253035	6325875	1496.53	702.176	5226.5	2986.4	146478.45

Table 4.3: The ongoing flare sites and population within 2 Km (1.243 miles).

4.4.1 Estimating the Incremental Cancer risk

In the absence of country-specific values, the US EPA default values for exposure assessment are used to calculate Nigeria cancer incremental risk assessment.

Intake Rate (Chronic daily intake), this is the amount of Benzene per kilogram of body weight per day given by:

Chronic Daily Rate = $I = C\ \{(CR * EF * ED)/(BW * AT)\}$…………1

Where;

C= average concentration of contaminant at exposure (mg/m3)

CR= contact rate (m3/day)

EF=exposure frequency (in days per year)

ED= exposure duration (in years)

BW= Body weight (in kg)

AT =Period over which exposure is averaged (day)

For the resident leaving within 2km radius of the flare sites, they are reckoned as maximally exposed individuals, below is the US EPA values for exposure assessment for such group.

Parameter	Resident	Workers
CR	2L/Day for drinking water 100mg/day for soil and dust ingestion 30m3/day for air inhalation	1L/day 50mg/day 30m3/day
EF	350days/year	250 days / year
ED	Actual or 30 years if chronic	Actual or 25 years
BW	70kg (Adults), 15kg(children)	70kg
AT	Actual duration for non-carcinogen 365days/year *70 years for a carcinogen	Actual duration for noncarcinogen 365days/year *70 years for a carcinogen

Table 4.4: The US EPA values for exposure assessment.

From 1 above,

Chronic Daily Rate $I) = C\ \left\{\frac{(30* 350*30)}{70*365*70}\right\}$

Chronic Daily Rate = 0.00015*0.176125

Chronic daily Intake Rate= $2.64*10^{-5}$

For residents living within 2km radius of the flare points with a benzene concentration of 0.00015mg/m3, the CDI rate is $2.64*10^{-5}$

Since benzene is a known carcinogen, the individual excess lifetime cancer risk IELCR is given by:

IELCR= CDI * SF

Where SF is the slope factor.

From the US EPA slope factors for carcinogens, Benzene has an inhalation slope factor of 0.027 mg/kg/day

Hence,

IELCR = $2.64*10^{-5}$ *0.027

Individual excess lifetime cancer risk for the level of exposure within 2km radius of the flare is $7.13*10^{-7}$

The US EPA threshold for IELCR is 10^{-6}, above which risk prevention measures must be taken.

From the literature, the concentration of Benzene across flare sites varies depending on several factors like flare efficiency, crude composition, etc., hence, IELCR over a range of CDI is calculated and the values presented in Table 4.5 below.

CONC mg/m^3	CDI (mg/kg-Day)	IELCR	VS EPA ST	VERDICT
0.00015	2.64188E-05	7.13306E-07	BELOW	SAFE
0.0003	5.28375E-05	1.42661E-06	ABOVE	ACTION REQ.
0.0006	0.000105675	2.85323E-06	ABOVE	ACTION REQ.
0.0012	0.00021135	5.70645E-06	ABOVE	ACTION REQ.
0.0024	0.0004227	1.14129E-05	ABOVE	ACTION REQ.
0.0048	0.0008454	2.28258E-05	ABOVE	ACTION REQ.
0.0096	0.0016908	4.56516E-05	ABOVE	ACTION REQ.
0.0192	0.0033816	9.13032E-05	ABOVE	ACTION REQ.
0.0384	0.0067632	0.000182606	ABOVE	ACTION REQ.
0.0768	0.0135264	0.000365213	ABOVE	ACTION REQ.

Table 4.5: Showing the range of concentrations and the corresponding CDI and IELCR

Above a concentration of 0.0003mg/m^3, the CDI and consequently, the IELCR goes above the US EPA recommended threshold; therefore, appropriate steps must be taken to address the risk.

4.4.2 Additional cancer cases at different concentrations and 2, 5, and 10 km from all the flare points.

At 0.0768 mg/m3, the IELCR 3.65 in 10,000. Indicating an additional cancer risk of 4 people in every 10,000. For instance, for a population of 6,341,650 within 6-mile (10km) radius:

Additional cancer risk due to this exposure is = (6341650/10000) * 3.65 = 2314.7

The table below shows the additional cancer cases for the case study population at specific distances from the flare points.

CONC	**IELCR**	**Initial 2km**	**Next 3 km**	**Next 5 km**	**Total**
0.00015	7.133E-07	0.18	0.95	3.39	4.52
0.0003	1.427E-06	0.36	1.90	6.79	9.05
0.0006	2.853E-06	0.72	3.80	13.57	18.09
0.0012	5.706E-06	1.45	7.60	27.14	36.19
0.0024	1.141E-05	2.90	15.20	54.28	72.38
0.0048	2.283E-05	5.79	30.40	108.56	144.75
0.0096	4.565E-05	11.58	60.80	217.13	289.51
0.0192	9.130E-05	23.16	121.59	434.26	579.01
0.0384	1.826E-04	46.32	243.18	868.52	1158.02
0.0768	3.652E-04	92.64	486.37	1737.04	2316.05

Table 4.6: Additional cancer cases for the case study population at specific distances from the flare points.

Several studies have examined the cost of treating different types of cancers in Nigeria, for example, Korubo et al. in researching the Economic Burden of Malignant and Premalignant Hematological Diseases in Southern Nigeria gave the breakdown of these cost as shown below;

4.4.3 Summary of total cost by type of diagnosis

Diagnosis of cases	Number of patients	The total cost of investigations in NGN (USD)	The total cost of treatment in NGN (USD)	The total cost of care in NGN (USD)	The total cost of care per patient in NGN (USD)
AA	6	398,150.0 (1090.82)	610,000.00 (1671.23)	1,008,150.00 (2762.06)	168,025.00 (460.34)
AL	4	366,700.0 (1004.66)	427,800.00 (1172.06)	794,500.00 (2176.71)	198,625.00 (544.18)
CLL	16	1,161,050.0 (3180.96)	668,300.00 (1830.96)	1,829,350.00 (5011.92)	114,334.38 (313.25)
CML	37	2,403,350.0 (6584.52)	3,251,600.00 (8908.49)	5,654,950.00 (15,493.01)	152,836.49 (418.73)
HL	8	652,400.0 (1787.40)	1,583,800.00 (4339.18)	2,236,200.00 (6126.58)	279,525.00 (765.82)
NHL	27	3,276,100.0 (8,975.62)	6,800,200.00 (18,630.69)	10.076,300.00 (27,606.30)	373,196.30 (1022.46)
MDS	2	148,450.0 (406.71)	91,500.00 (250.69)	239,950.00 (657.40)	119,975.00 (328.70)
MM	20	2,235,800.0 (6125.48)	5,072,000.00 (13,895.89)	7,307,800.00 (20,021.37)	365,390.00 (1001.07)
MPN	8	561,850.0 (1539.32)	234,400.00 (642.19)	796,250.00 (2181.51)	99,531.25 (272.688)
PNH	1	74,450.0 (203.98))	24,000.00 (65.75)	98,450.00 (269.73)	98,450.000 (269.73)

Table 4.7: Summary of average local total cost by type of diagnosis

5.0 CHAPTER FOUR

5.1 Results

The results from the multistage methods are as presented below:

5.1.1 (i)Meta-Analysis on NHL

Study or Subgroup	Weight	Odds Ratio IV, Random, 95% CI	Year
Francheschi etal 1989	2.7%	1.14 [0.63, 2.08]	1989
Francheschi 1989	2.7%	1.77 [0.97, 3.22]	1989
Schnatter 1992	2.8%	5.85 [3.30, 10.36]	1992
Schnatter1 etal 1992	2.2%	2.11 [0.92, 4.83]	1992
Schumacher etal1992	2.8%	0.77 [0.43, 1.37]	1992
Schnatter etal 1992	2.8%	1.44 [0.81, 2.55]	1992
Schumacher 1992	2.8%	0.94 [0.53, 1.67]	1992
Blair 1993	2.6%	1.10 [0.59, 2.07]	1993
Blair et al 1993	2.7%	1.60 [0.87, 2.95]	1993
Hardell 1994	2.3%	0.79 [0.36, 1.72]	1994
Gerin etal 1998	2.6%	0.60 [0.32, 1.13]	1998
Gerin 1998	2.6%	0.80 [0.41, 1.55]	1998
Persson 1999	2.8%	0.80 [0.45, 1.42]	1999
Schumacher2 1999	2.8%	0.94 [0.53, 1.67]	1999
Mao 2000	2.8%	1.20 [0.67, 2.16]	2000
Mao etal 2000	2.6%	1.13 [0.58, 2.18]	2000
Scherr etal 2000	2.8%	1.38 [0.77, 2.48]	2000
Fabro3 2001	2.7%	2.40 [1.29, 4.45]	2001
Fabro 2001	2.7%	2.30 [1.25, 4.22]	2001
Siemiatycki1 2001	2.8%	0.70 [0.40, 1.24]	2001
Siemiatycki 2001	2.8%	0.80 [0.45, 1.42]	2001
Ott etal 2004	2.8%	1.00 [0.56, 1.78]	2004
Fabro et 2004	2.5%	2.00 [1.02, 3.91]	2004
Dryver etal 2004	2.5%	1.45 [0.74, 2.86]	2004
Dryver 2004	2.7%	1.92 [1.04, 3.53]	2004
Kato1 2005	2.6%	1.40 [0.74, 2.67]	2005
Kato 2005	2.7%	1.50 [0.81, 2.77]	2005
Fritschi 2005	2.7%	1.09 [0.60, 1.98]	2005
Fritschi1 2005	2.7%	1.19 [0.66, 2.17]	2005
Fritschi etal 2005	3.0%	0.31 [0.19, 0.51]	2005
Fritschi etal1 2005	2.7%	1.45 [0.78, 2.71]	2005
Fritschi 3 2005	1.6%	5.07 [1.66, 15.45]	2005
Fritschi2 etal 2005	1.5%	1.01 [0.32, 3.25]	2005
kato1	2.7%	1.50 [0.81, 2.77]	2005
Miligi etal 2006	2.7%	1.60 [0.87, 2.95]	2006
Miligi1 2006	2.8%	1.20 [0.68, 2.12]	2006
Miligi 2006	2.8%	2.90 [1.64, 5.14]	2006
Cartwright 2006	2.8%	0.49 [0.27, 0.88]	2006
Total (95% CI)	**100.0%**	**1.25 [1.04, 1.51]**	
Total events			

Heterogeneity: Tau² = 0.23; Chi² = 123.79, df = 37 (P < 0.00001); I² = 70%
Test for overall effect: Z = 2.40 (P = 0.02)

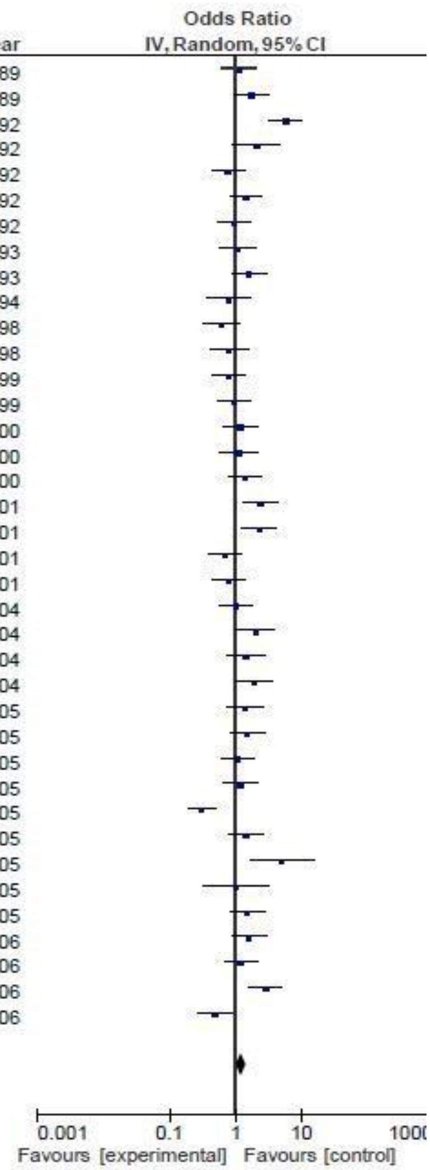


Table 5.1: The results of the Meta-Analysis on BTEX vs NHL

The results at an odds ratio of 1.25 (1.04, 1.51) showed that there is a positive correlation between the exposure to benzene and NHL.

The confidence interval did not include 1, therefore the result shows there is an extra 25% chance that an individual exposed to BTEX would develop a cancer outcome.

5.1.1.1 Heterogeneity

Expectedly, the i^2= 70%, indicating a moderately high heterogeneity in the review. This is percentage of total variation among the studies included in the review that is attributable to heterogeneity and not chance. Generally, a value of 25% shows a low degree of heterogeneity, while 50% is deemed moderate, 75% and above indicates a high heterogeneity.

Heterogenous results may reflect some underlying differences in the clinical or methological aspects within the studies.

Some of the major differences across the studies included in this review are the concentration at which they were conducted, differences in worksite attributes, some of the studies evaluated ambient air while some based their evaluations on personal air sampling, allowing for diverse variables. The funnel plot shows no publication bias.

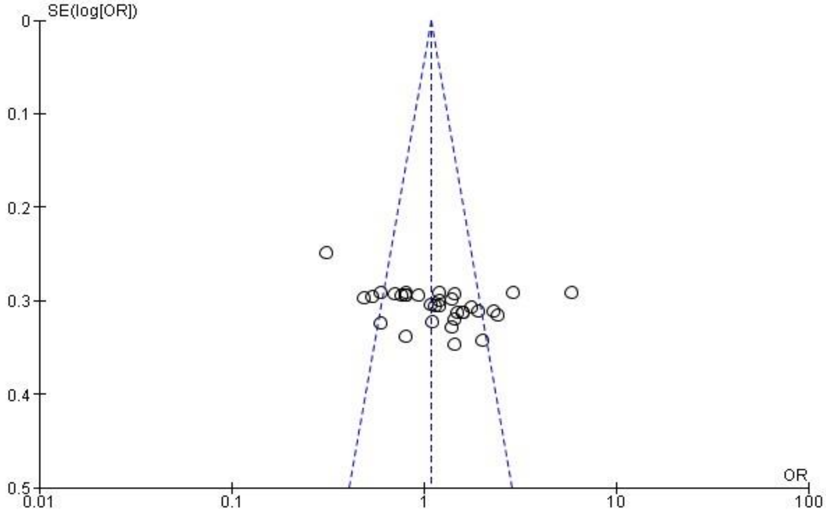


Fig. 5.1: The Funnel plot of the Included Studies

5.1.1 (ii)Meta-Analysis on AML

The meta analytic review of the association between BTEX exposure and the occurrence of AML was performed, the Risk ratio of 1.38 (1.03,1.84) shows a positive correlation between exposure and outcome.

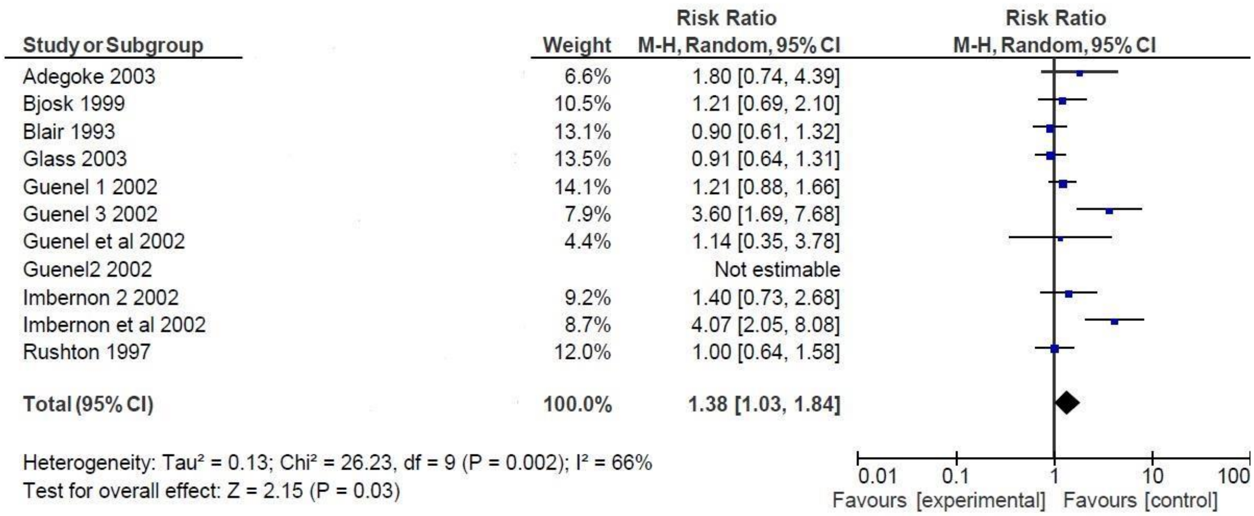


Table 5.2: The results of the Met Analysis on BTEX vs AML

Despite some of the studies having a confidence interval that crosses the “line of no effect”, the summary statistics has a C.I that is entirely to the right of the line.

The i^2=66% with p=0.002, a very small p, justifies the use of random effect in conducting the Meta-Analysis because the studies included are moderately heterogenous.

5.1.2 Trend Analysis Results

5.1.2 (i)Nigeria Cancer incidence and prevalence rates compared with her West African neighbors.

We compare the cancer figure from Nigeria with her West African counterparts, it helps to consider what the prevalence rate of cancer is within the West Africa region. Most of the countries in the region are LMICs, albeit with slightly less GDP than Nigeria`s. Figure 3.9 below shows that Nigeria has cancer prevalent that is significantly higher than those of all the other countries in the region.

Share of population with cancer

Share of total population with any form of cancer, measured as the age-standardized percentage. This share has been age-standardized assuming a constant age structure to compare prevalence between countries and through time.

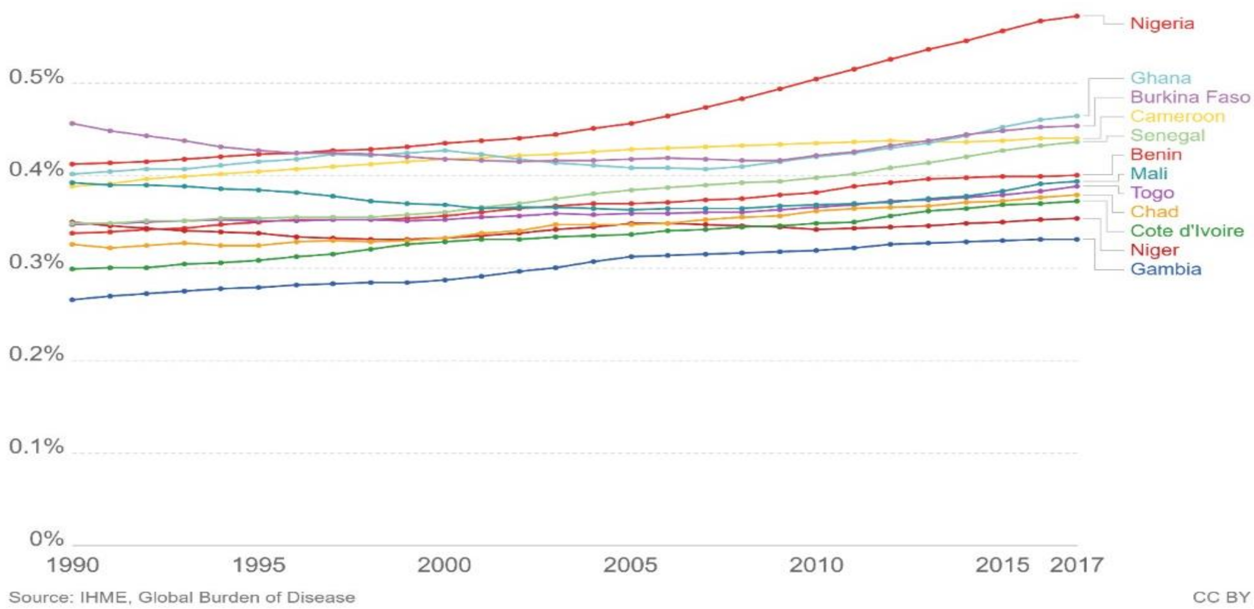


Figure 5.2 Nigeria Cancer incidence and prevalence rates compared with her West African neighbors.

Criteria	Nigeria	Sub-Sahara Africa	LMICs	WHO limit
PM 2.5 pollution, mean annual exposure (µg/cu. M)	27	17	27	10
PM2.5 exposure (% pop	94	72	92	
Air pollution damage (% of GNI)	1.0 % of $455.99B	0.9 % of $1,624.98B	1.1 %	

Source: World Bank

Table 5.3: Nigeria PM exposure compared with Neighboring countries and other LMICs

The figures in table3.1 show that Nigeria has more exposure than the average for her neighboring countries and ranks at par with the average for all LMICs around the world.

5.1.2 (ii) Nigeria cancer prevalence compared with the average for Low Middle-income countries (LMIC)

The prevalence of cancer in Nigeria, when compared with those of other countries in the LMICs category, is higher by more than a percentage. There might be several factors to explain that including the fact Nigeria is one of the very few countries in the LMIC category with such a huge oil and gas exploration industry, which in turns mean higher exposure to carcinogens. It may also be because of the relatively large population compared with the other countries in the category.

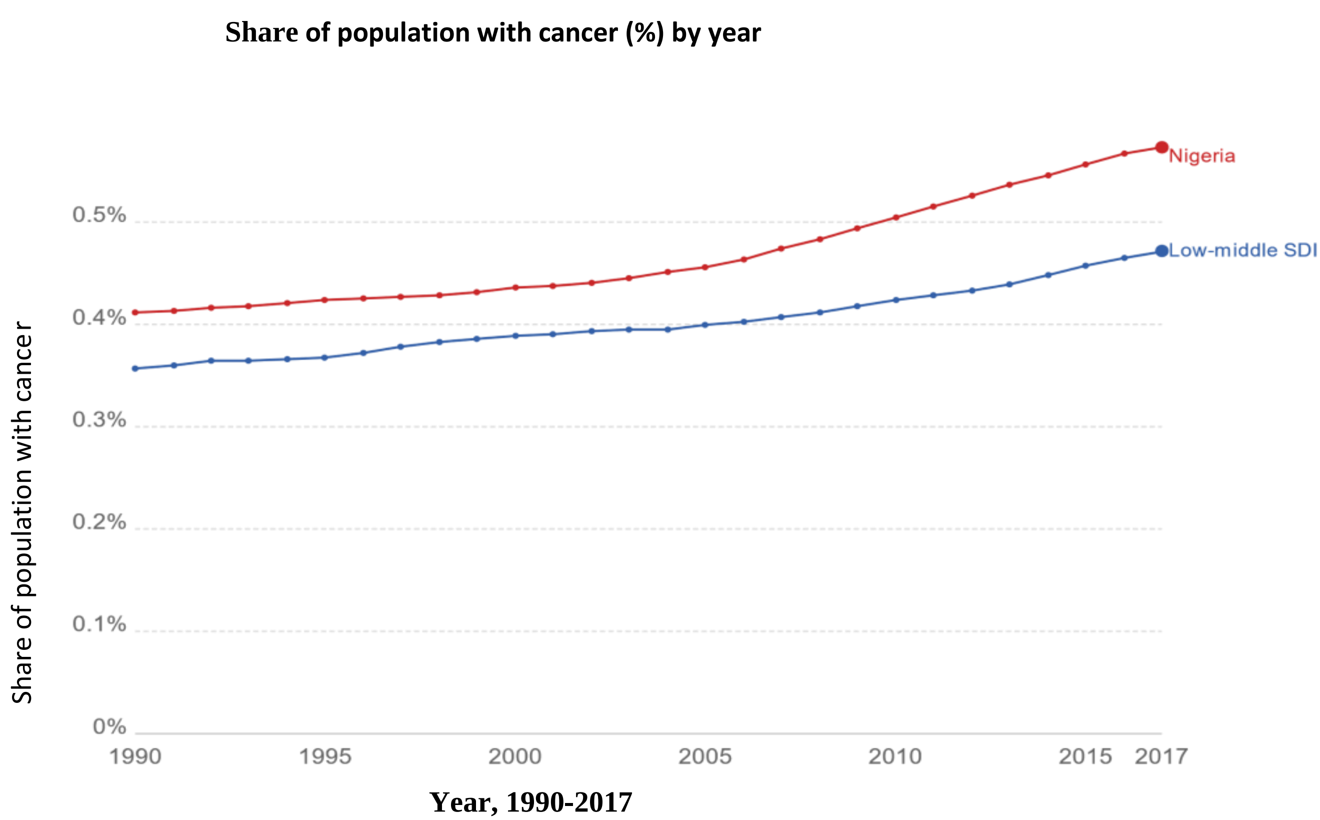


Figure 5.3 Nigeria cancer prevalence compared with the average for Low Middle-income countries (LMIC)

5.1.2 (iii) Nigeria cancer prevalence compared with the top 20 gas flaring nations, Canada, and Norway.

When compared with other countries in the top twenty gas flaring countries, figures for cancer prevalence in Nigeria do not stand out. In this instance, other factors of cancer prevalence previously explained come into play. Age and longevity, higher personal income, and higher GDP per capita in countries like the United States, Canada, and Norway result in higher cancer rates recorded.

Share of population with cancer, 1990-2017

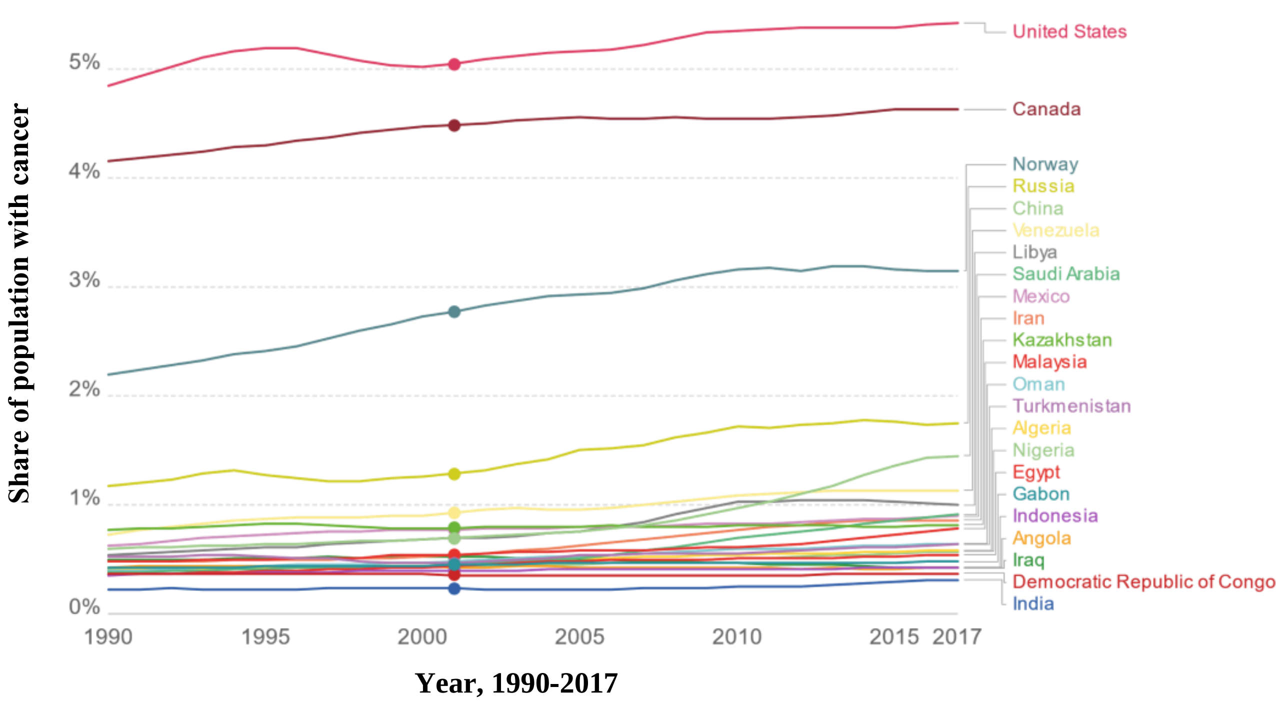


Figure 5.4 Nigeria cancer prevalence compared with top 20 gas flaring nations, Canada and Norway

5.1.3 IELCR results

The table 5.4 below shows the additional cancer cases for the case study population at specific distances from the flare points.

CONC	IELCR	Initial 2km	Next 3 km	Next 5 km	Total
0.00015	7.133E-07	0.18	0.95	3.39	4.52
0.0003	1.427E-06	0.36	1.90	6.79	9.05
0.0006	2.853E-06	0.72	3.80	13.57	18.09
0.0012	5.706E-06	1.45	7.60	27.14	36.19
0.0024	1.141E-05	2.90	15.20	54.28	72.38
0.0048	2.283E-05	5.79	30.40	108.56	144.75
0.0096	4.565E-05	11.58	60.80	217.13	289.51
0.0192	9.130E-05	23.16	121.59	434.26	579.01
0.0384	1.826E-04	46.32	243.18	868.52	1158.02
0.0768	3.652E-04	92.64	486.37	1737.04	2316.05

Table 5.4: Showing the aggregate IELCR at 2, 5, 10 km from the flare point

5.1.3.1 Results of the Cost of Additional cases of Cancer.

Using the total cost of care per patient in dollars in the table above for the type of cancers in consideration, AL Acute Leukemia and NHL Non-Hodgkin Lymphoma,

Cost of AML and NHL in the Case Study

CONC	IELCR	Initial 2km	Next 3 km	next 5 km	total	AL @ $544	NHL@ $1022.6
0.00015	7.133E-07	0.18	0.95	3.39	4.52	2460.80	4625.14
0.0003	1.427E-06	0.36	1.90	6.79	9.05	4921.60	9250.26
0.0006	2.853E-06	0.72	3.80	13.57	18.09	9843.24	18500.58
0.0012	5.706E-06	1.45	7.60	27.14	36.19	19686.44	37001.10
0.0024	1.141E-05	2.90	15.20	54.28	72.38	39372.88	74002.20
0.0048	2.283E-05	5.79	30.40	108.56	144.75	78745.76	148004.39
0.0096	4.565E-05	11.58	60.80	217.13	289.51	157491.52	296008.78
0.0192	9.130E-05	23.16	121.59	434.26	579.01	314983.04	592017.57
0.0384	1.826E-04	46.32	243.18	868.52	1158.02	629964.70	1184032.54
0.0768	3.652E-04	92.64	486.37	1737.04	2316.05	1259932.8	2368071.57

Table 5.6: The estimate of cost of treatment by exposure at different distance and concentration

6.0 CHAPTER SIX

6.1 DISCUSSION

The results of the Meta-Analysis showed that Acute Myeloid Leukemia (AML) and Non-Hodgkin Lymphoma (NHL) are two outcomes that are strongly attached to BTEX exposure. The two outcomes are types of Cancers. NHL is a cancer from the white blood cells that results from the development of abnormal lymphocytes. The common symptoms are fever, belly pain, coughs and chest pain. AML is a cancer of the blood and bone marrow. It causes premature blood cells with symptoms like fatigue, bleeding, spots on skin and shortness of breath.

Some of these symptoms have been indicated as the outcomes of BTEX exposure in gas flaring by several studies, however, they might just the symptoms of the two cancers stated here.

The two outcomes of the Meta -Analysis formed the basis for the Cancer Trend analysis. The result showed that Nigeria has a considerably higher cancer prevalence rate than all the neighboring countries. She has double the prevalence of some of the neighbors in fact. This fact runs against the expected trend: a close rate among the countries with similar risk factors.

Similarly, the result of the trend analysis with other LMICs shows that Nigeria has a higher prevalence rate than the other countries with similar socio-economic factors. The expected result should be a close trend than what obtained.

Finally, the comparation with other top Gas flaring countries showed a similar rate. The countries flaring large volume of gas tends to have similar cancer prevalence rate.

Considering the foregoing, we concluded that Gas flaring may contribute to the departure from expected trend of the cancer prevalence rates, and therefore, we cancer investigate for exposure and assess the cost.

The IELCR results confirm the assumption that gas flaring and the resultant BTEX exposure explains the divergence of the nation`s cancer data trend from the expected. The results showed that there are cases of exposure beyond the recommended action levels. The additional cancer cases from the exposure could be as high as 2316 per million. The additional cost of treating these additional cancer cases could also be as high as $3,628,003.

Hence, a mitigation action must be implemented.

The mitigation action recommended is Green Completion.

6.2 Green Completion

This is a process of cleaner management of associated petroleum gas in oil and gas exploration. The waste gas is captured at the well head and used for either reinjection, electricity generation or compressed for sales as liquified gas. The process eliminates flaring or venting which lets the waste gas into the atmosphere with the attendant negative effects on human, animals and the environment. It also eliminates the economic loss resulting from burning the associated petroleum gas.

6.2.1 The economics of green completion.

According to the US EPA, a control strategy for air quality management is a specific technique and measure designed and implemented to achieve reductions in air contamination. Such a strategy must meet a predetermined air quality standard.

6.3 Factors of the control strategy.

There are three important factors in designing a control strategy: Environmental factors, Engineering factors, and economic factors. The choice of strategy must be cost-effective, considering future possibilities as a cost-effective choice of today may become inadequate in the future or become difficult to upgrade if the need arises.

6.3.1 Environmental factors:

These are factors like the location of the emission source, the meteorological conditions obtainable, noise levels of the control, and the attendant ancillary pollution resulting from the control itself. In the case study of this dissertation, chapter three showed a high population of residents is within the zone of significant concentration of emissions. Localized emission could result in further exposures.

Potential pollutions like noise pollution due to the installed turbine has to be put into consideration and adequate engineering control put in place to mitigate such.

The most effective form of emission management apart from outright elimination of the process is to control at the source for reuse. The hierarchy of environmental protection is as shown below.

Fig 6.1 Environmental Protection Hierarchy

6.3.2 Engineering factors:

These are the performance characteristics of the control, potential reactivity, and adequate utilities. Environmental elements must be put into consideration in determining the engineering installation proposed.

6.3.3 Economic factors:

Capital costs, maintenance costs, operating costs, equipment lifetime, administrative, legal, and enforcement cost. As discussed earlier, the existing management method employed by the state involves payment of fine for every cubic foot of gas flared. Any alternative suggestion must present empirical evidence of being able to generate comparable economic value if not better to be attractive enough for consideration.

6.4 Methods of Natural Gas Utilization.

The green completion policy would utilize a combined cycle gas-driven turbine to capture the emission at the source and re-use in generating electricity. Natural gas has been an efficient driver of turbines in electricity production, on a large scale, such power generation are usually centralized and involves moving the gas over large distances to the location of the power plants. Employing the technology for gas flare management, however, involves utilizing the waste gas to generate power on-site or in a near field.

There are three major methods of utilizing natural gas components of oil and gas production: gas to liquid conversion, Power generation, and reinjection.

6.4.1 Gas to Liquid:

This is a catalytic process involving the chemical conversion of natural gas, primarily methane to liquid hydrocarbons like Naphtha and diesel. GTL is particularly attractive when the gas resource is stranded in remote locations where conventional transportation is uneconomical. This method is well suited to the clean natural gas but may require further refining to manage waste, wet gas generated for gas flaring.

6.4.2 Gas to Wire:

This is a concept that manages associated gas by onsite conversion of the waste gas to electric power. The method eliminates the transportation of products and is considered efficient both in economic terms and for the environment.

6.4.3 Reinjection.

This procedure simply reinjects the associated gas back into the well; it is useful in increasing the pressure underground and re-energizing production**.**

6.5 The economics of waste gas management methods.

Studies have compared the ROR rate of return of the three, albeit under differing socio-political and economic realities: Electricity production gives the highest rates of return. For example, M.R Rahimpour et al[94] compared the economics of gas flare recovery methods from Farashband refinery, Iran, comparing the three methods of flare management: their results show that Gas to liquid provides the least ROR of the three methods. At the same time, the ROR from electricity generation is 22.2% higher than gas compression and reinjection. Also, Electricity generation has the lowest payback period among the options as well as requiring a comparatively mild capital investment.

Parameter	GTL	Compression	electricity
capital (`000,000$)	33.4	3.36	31.94
annual Profits (`000,000$)	9.06	1.23	14.05
ROR ($)	27	36	44
Payback period (Years)	3.3	2.8	2.3

Table 6.1 Comparing payback period among flare management options

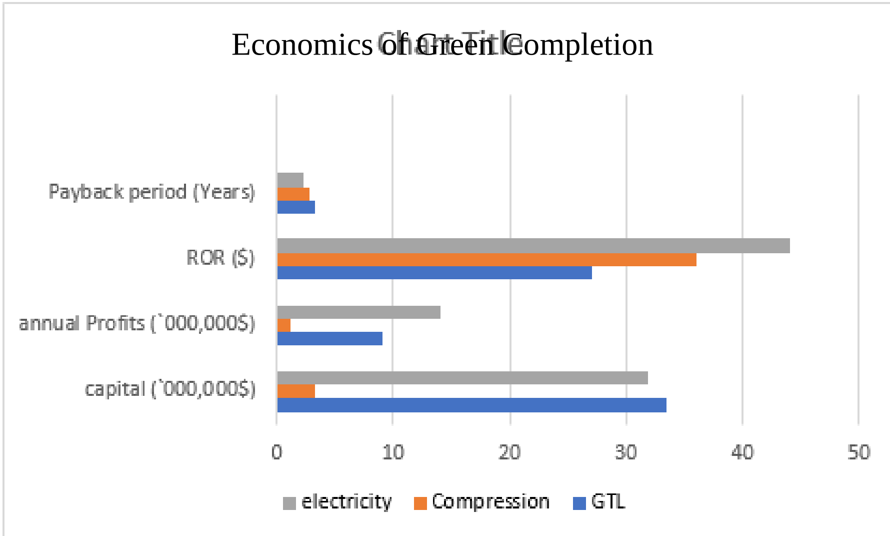


Fig 6.2 Comparing the Economics of Electricity generation, GTL, and Compression in gas flare management simulation in Farashband refinery, Iran.

R. khalilpour et al. (2012) evaluated the three utilization alternatives for stranded natural gas, the study looked at the economic comparison of the three options and used the net present value NPV as the decision criterion. The study concluded that while GTL methods present a better economic reality, a mix of local technical, non-technical, and socio-economic factors informs the most effective method. One important factor for consideration in the case study is the local energy market that is substantially underserved. The region presently generates about 33% of its power requirements.

6.5.1 Cost of funds

This economic valuation and proposal assume the availability and consistency of the gas turbine, which assumes it is in good working condition all year round operating at full power capacity, which is 580 MW daily and selling all the produced electricity to the national grid. A deviation from this will have a multiplier effect on other projections like the breakeven point, Internal rate of return, and possible replication dates.

The cost of funds is variable, but the current rate of 15% assumed. Interest rates and other associated costs of funds are often subject to change, the current rates were used, but changes will impact the bottom line.

prime cost rate of 3.33%, these are the designer’s figures and as such are assumed for this project

6.5.2 Existing Infrastructures

The state of the existing infrastructures is not included in costing the implementation of this project. In essence, these include access to the national grid, access to existing gas pipeline network, and road access to sites. These could add significantly to the overall expenses of the project and are peculiar from site to site.

6.6 Gas Turbine operation.

Air and natural gas are the ingredients that combine in the generator to produce electricity. The process involves air being drawn into the compressor section of the turbine. The air molecules are squeezed under great pressure, and the compression increases the temperature of the air. Fuel, in this case, natural gas, is injected into the combustor, and it ignites, converting the chemical energy to heat energy. The hot gas is then forced through the blades, making them spin at a great speed, typically, 3000rpm, thus converting the heat energy to mechanical energy. This mechanical energy is transmitted to the rotors attached to the turbine. The rotor is a magnet located within coils of wire called stators, the fast rotation of the wire in the coils creates a strong magnetic field that induces electrons in the coils causing them to move, converting the mechanical energy to electrical energy.

For a combined cycle turbine, the steam bye product of the gas turbine is used to drive a steam turbine. This recycling generates up to 50% additional power according to GE

The financial implications of using this technology for waste gas management includes estimating the expenditures on the turbine and the installation of the same, and then, the anticipated incomes from the sales of electricity.

6.7 Gas Volume requirement

To properly determine the appropriate turbine size, the availability of the gas in a sufficient quantity must be ascertained. Watanabe, 2006 recommended a gas reserve of between 10bcf and 1tcf for a site to host a GTW project profitably. The region currently has a proven reserve of 187 tcf, [95]flaring as much as 70% of its produced gas[96]

A reference to the Nigerian gas flare monitoring website, http://gasflaretracker.ng/, shows that within the first five months of 2019, a total of 213.3 million mscf was flared, of this figure, 110.8 million mscf was flared onshore, while the remaining was flared offshore.

The data source also showed that during the said time frame, 202 flaring sites were operational in the region. These sites jointly flared gases worth 746.7 million USD with a power generation potential of 21.3 thousand GWh (table 3.2).

6.8 Conditions for site viability

The viable site must have a production capacity of at least 930 000 mscf Daily. This is matched with the daily consumption of the turbine to be recommended. Other considerations include the estimated capital investments, as well as estimated financial income from sales of electricity.

Production sites with less than 930,000 mscf will require pipeline connections to near flare sites to be viable. On the other hand, the capacity of the turbine may be reduced to accommodate the production capacity of such sites. Records show that the existing pipeline gas pipeline networks are grossly inadequate and may not be suitable for transporting waste gas as they were installed to handle the natural gas for other uses.

6.8.1 Volume of Gas requirements.

Note that the volume of gas that a unit of gas turbine utilizes is given by a flow rate of 930,000 m3 of gas per day. At this rate, the volume of gas the turbine is expected to consume annually is given by:

930000 × 365 = 339,450,000 m3 (1ft3 = 0.02831685m3)

=1198756362 ft3, (12 Bcf)

(assuming a heat content of 1,036 Btu per cubic foot)

One thousand cubic feet (Ccf) of natural gas equals 1.036 MMBtu

Therefore,

339450000 Ccf = 339450 X 1.036 MMBTU = 351, 670.2 MMBtu
Cost of gas (@$2MMBtu) = $844,008.48

6.9 Turbine types and choice

The economic evaluation of the green completion will be done using a combined cycle gas turbine with a capacity of 580 MW. The choice of this rating and type of turbine is influenced by the cost, lead time for construction, current, and expected future trends in the industry, and, most importantly, efficiency, as much as 60% more.

Combined cycle units are sensitive to ambient temperature and may undergo derating on hot days; they, however, are less sensitive than simple cycle turbines.

The “combined cycle” trend of the turbine market is expected to continue to grow, up to about 50% of the market within the next ten years.

Cost estimate	140MW	Column1	Column2	580MW	Column3	Column4
	US ($000)	**Asia ($000)**	**Euro ($000)**	**US**	**Asia ($000)**	**Euro ($000)**
Civil/Structural	7240	5130	5280	20120	14100	14620
Mechanical						
Gas Turbine (OEM Price)	99740	99740	99740	262930	262930	262930
SCR	1260	630	450	3460	1730	1230
Gas Compressor	2840	2790	2780	3480	3410	3390
Electrical	9720	8070	7590	28990	24500	23180
Piping	9480	6680	8680	28190	20250	26880
Instruments and control	1660	1510	1470	4300	3890	3760
Balance of plant/ general facilities	21640	14810	12830	46700	34380	30810
Total direct costs	153580	139360	138820	398170	365190	366800
Indirect costs	13490	4960	3470	33870	12810	9210
Engineering and home office costs	13040	5180	3840	32750	13380	10210
Project contingency	12060	9950	9280	30280	25690	24660
Total plant cost	192170	159450	155410	495070	417070	410880
Gas Turbine cost (FOB- OEM), US$/KW	730	730	730	460	460	460
Total Plant cost, US$/KW	**1410**	**1170**	**1140**	**860**	**720**	**710**

Source: Energy Sector Management Assistance Program ESMAP Technical Paper 122/09 (Study of Equipment Prices in the Power Sector)

Table 6.2: Comparing the cost of common types of CCT (140MW vs 580MW)

6.9.1 Plant Emission rates

Of utmost importance for the environment is the emission rates of the plant by-products. The emission rate measures the rate of pollutants emitted from the plant. The bye products are oxides of carbon, oxides of Nitrogen, oxides of Sulphur, and Particulate Matters. Adequate engineering controls must be put in place to manage the localized emission expected from the plant. Table 3 below shows the emission rates of a combined cycle power plant.

SO2 (Lb./MMBtu)	NOX (LB/MMBtu)	PM10 (Lb./MMBtu)	CO2 (Lb./MMBtu)
0.0002	0.0073	0.0058	117

Source: National Renewable Energy lab. (NREL)

Table 6.3. Emission Rates for a Combined-Cycle Power Plant

6.10 Assumptions.

The economic evaluation assumes the availability and consistency of the gas turbine (in terms of being in good working condition) is 100% throughout the year (i.e., the plants operate for 365 days of the year).

It was further assumed that the units of gas turbines operate at full power capacity, which is 580 MW daily, and selling all the produced electricity to the national grid.

The cost of funds is variable, but the current rate of 15% assumed.

Gas turbines used onshore has an effective life of 30 years, with a diminishing value rate of

6.67% and prime cost rate of 3.33%

At least two years moratorium on loans

There is an existing access to the national grid.

From the table above, using the figures for Europe,

The cost 580 MW turbine @ $710 /KW = 580000 X 710 = $411,800,000 (cost per KW could be significantly greater considering multiple socio-economic and political factors)

6.11 Financial Output from a 580MW gas turbine in Nigeria

The country uses a residential/business tariff system, the pricing per kWh ranges from $0.013 to $0.153, differing from region to region and across rural to urban areas. We will use the average of the range, $0.083 as our benchmark for calculating the expected income from the turbine

1 MW = 1000KW

Gas turbine capacity of 580 MW in KW: is given by: [580 X 1000 = 580,000 KW]

580,000KW = (580,000 X 24) KWh

580 MW turbine will produce 13, 920, 000 KWh daily.

Cost of electricity per kilowatt-hour in the country is = $0.083 per KWh Therefore,

the projected daily financial income:

580,000KW X 24hrs x $0.083 = $1,155,360 (per day)

The annual income per unit of 580 MW turbine` = $1,155,360 x 365 = $ 421, 706, 400.

A 580MW combined cycle gas turbine will generate $421,706,400.00 annually

6.12 Cost-profit analysis

Income	**Description**	**Price ($)**	**Amount ($)**
Net Sales	5, 080,8000,000 KWh of electricity	0.083/KWh	421, 706,400
Gross Income			**421,706,400**
Deductions			
Cost of raw gas	351670.2 MMBtu	2.4	844008.48
Cost of equipment	580MW turbine	860 per KW	411,800,000.00
Cost of labor	20 employees,10 upper and lower cadre		209150.4
Cost of REC	Equipment	500,000	500,000
Miscellaneous	Lot	500000	500,000
The total cost of operation			413,853,158.9
Cost of funds	Bank loans	15.33% pa	63,443,689.3
Depreciation	Equipment	6.67% pa	27,537,305.7
Total Cost			**504,834,153.86**
Income before Tax			-83,127,753.86
Income Tax 30%			0
Income after tax			**-83,127,753.86**

Table 6.4: Projected Income Statement for the first year Projected Income Statement for the Second year

Income	Description	Price ($)	Amount ($)
Net Sales	5, 080,8000,000 KWh of electricity	0.083 per KWh	421,706,400
Gross Income			**421,706,400**
Deductions			
Cost of raw gas	351670.2 MMBtu	2.4	844,008.48
Cost of labor	20 employees, ten middle cadre and ten lower cadre		209,150.40
The total cost of operation			1,053,158.88
Cost of funds	Loans	15.33% pa	72,987,890.70
Depreciation	Equipment	6.67% pa	27,467,060.00
Balance B/F			**-83,127,753.86**
Total Cost			**185,689,022.32**
Income before Tax			236,017,377.68
Income Tax 30%			70,805,213.30
Income After Tax			**165,212,164.38**

Table 6.5: Projected Income Statement for the Second year

Projected Income Statement for the Third year

Income	**Description**	**Price ($)**	**Amount ($)**
Net Sales	5, 080,8000,000 KWh of electricity	0.083 per KWh	421, 706,400
Gross Income			**421706400**
Deductions			
Cost of raw gas	351670.2 MMBtu	2.4	844008.48
Cost of labor	20 employees, ten middle cadre and ten lower cadre		209150.4
The total cost of operation			1,053,158.88
Cost of funds	Bank loans	15.33% pa (variable)	84,176,934.34
Depreciation	Equipment	6.67% annually	27,467,060.00
Total Cost			**112,697,153.22**
Income before Tax			309,009,246.78
Income Tax 30%			92,702,774.03
Income After Tax			**216,306,472.75**
Balance B/F			**165,212,164.38**
Total Cash Available			**381,518,637.13**

Table 6.6: Projected Income Statement for the Third year

From the three-year income statements above, this proposal can break even by the third year and can then be ready for reinvestment in the fourth year. It should be noted that the lead time for turbine construction is averagely 16 months; hence the second plant can be ready by the sixth year.

6.13 The effect of price drop on the payback period

Nigeria uses a residential/business tariff system, the pricing per kWh ranges from $0.013 to $0.153, (25.731 to 41.66 Naira, the local currency) differing from region to region and across rural to urban areas. We used the average of the range, $0.083 as our benchmark for calculating the expected income from the turbine. Please note the fluctuation in foreign exchange may result in an unstable dollar value.

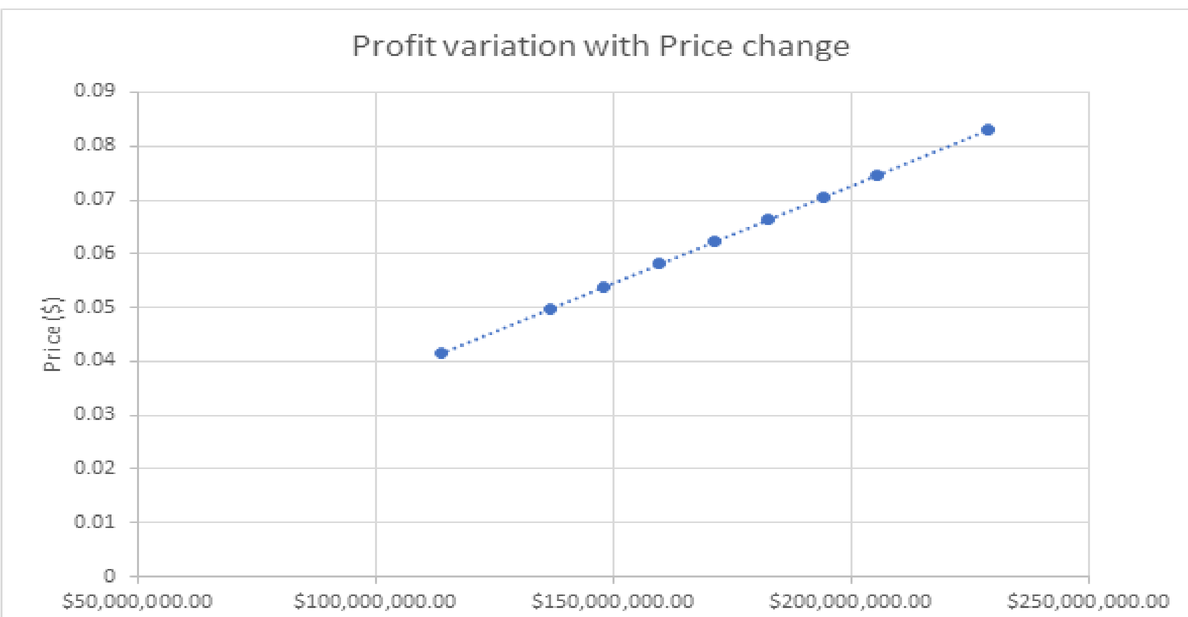


Figure 6.3: Estimates of the effect of change in price on profitability

This is a graph of the impact of lower market price of electricity in the Nigerian energy market on the annual profit. There is a linear relationship between the price and the profit since all other variables remain constant. For example, a 50% drop in the price would reduce the profit after tax after the 4th year by 50%, that is, $113,651,424.5.

A 50% reduction in the bottom line therefore doubles the payback period.

A large drop in price within the initial three years must occur for the payback period to be affected. From fig 1.1 above, a 40% drop in price to $0.05 per KWh within the first year would result a drop-in profit to $136,676,594, doubling the payback period. This is an extreme scenario.

7.0 CHAPTER FIVE

7.1 CONCLUSION

So far, this research has looked at the ramifications of gas flaring, importance to the industry, known products of flaring, and their effects on man and the environment. This research has assessed the incremental burden of disease risks attached to the exposure to BTEX in gas flaring and have used the same to generate a dollar value for the cost of gas flaring based on the exposed population in the case study. In a similar vein, the research has proposed mitigation using a green completion strategy based on a combined circuit turbine generator and has completed an economic analysis of the strategy. This chapter discusses the framework for managing BTEX exposure from gas flaring in an oil and gas exploration near fields combining all the outcomes of the previous analysis. A guide for a more detailed set of guidelines is called a framework, and it serves to put functionality into solving the identified problems by pooling together the different aspects of the process into a single frame.

The chapter begins with a summary of the units of the framework, proceeded to discuss the details of coupling the various units. The peculiarities, concerns, and factors are put into perspective, and a framework for the design is presented.

7.2 The summary of the framework components.

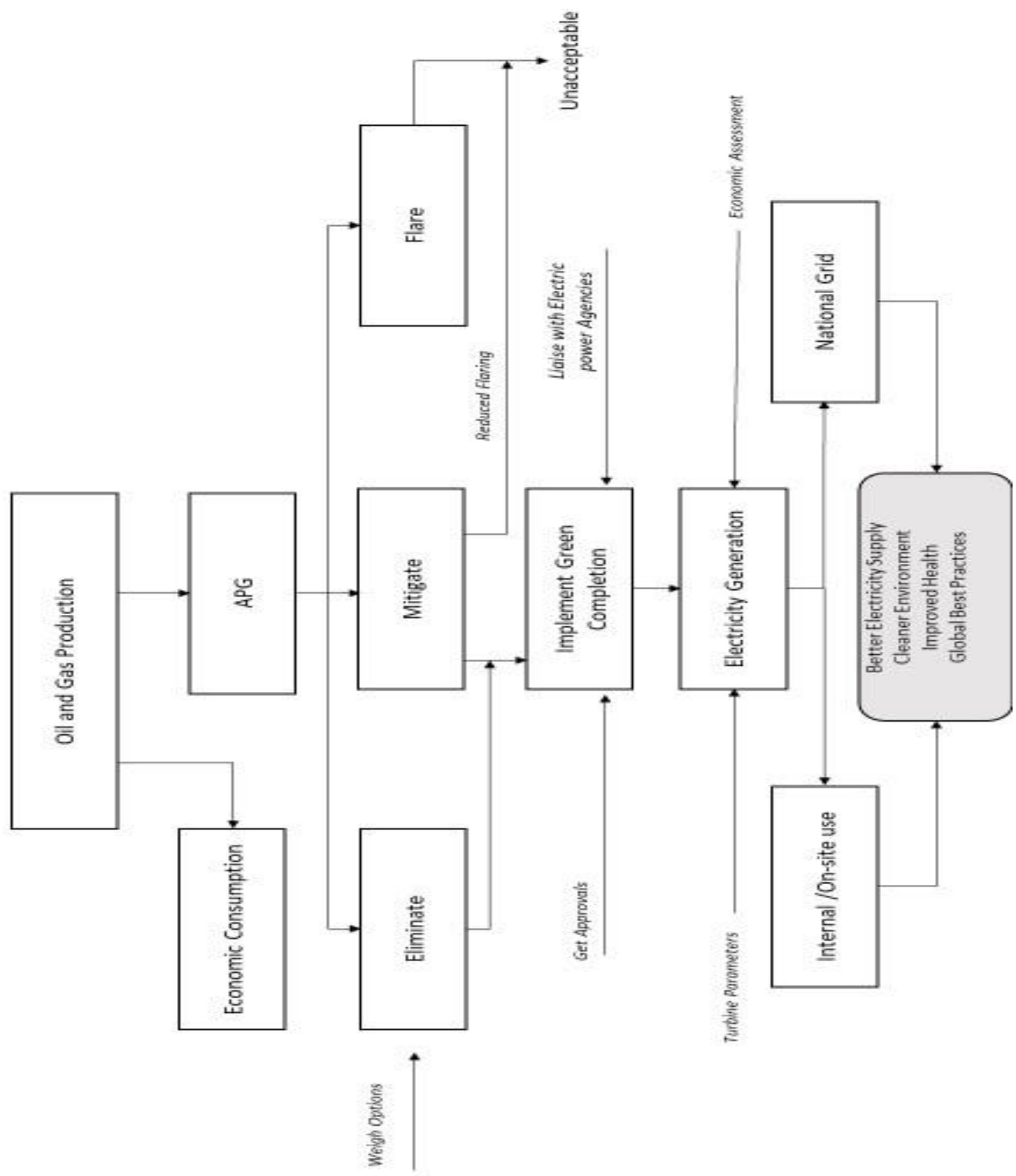


Fig 7.1 The summary of the framework components.

7.2.1 Elements of the framework.

(i) Crude Oil and Gas production: From Fig 7.1 above, oil and gas exploratory activities primarily yield crude oil that is refined into various petroleum products and natural gas, as stated in the literature review. The activities are accompanied by a substantial release of Associated Petroleum Gas (APG); this is the main source of the gas flared in the course crude oil exploration.

(ii)APG: Associated petroleum gas is more than 70% methane. It comes to the surface under great pressure during oil and gas exploration, it is also called solution gas or sometimes wastes gas. While there is waste gas from different stages of oil prospecting, exploration, and refining, APG during exploration is the main reason for gas flaring.

(iii)Petroleum Products: The process of refining crude oil requires flaring for safety purposes; generally, this is much less than APG flared at the source.

(iv) Ongoing Utilizations: As much as 20% of the generated waste gas are being utilized to sustain pipeline pressure, among other uses, these are often flared at the point of refining. A part of these is used to recharge old wells too.

7.3 Management Strategy (Flaring vs. Green Completion)

There are multiple approaches to managing waste gas in oil and gas exploration and production. Gas flaring is quicker and considered cheaper in the short run, while this research argues for a better alternative with a greater and clean long-term result.

7.3.1 Elements in the framework

(a) Flared Gas: the existing method of disposal of the waste gas through open-air incineration. The maximum efficiency obtainable in operation ensures that VOCs end up in the environment with the risk of exposure.

(i) Exposures: The potential exposures in a gas flare are numerous; however, of interest is the BTEX components of the products.

(ii) Health effects: Studies have identified various health outcomes of exposure to BTEX, most prominent are different forms of cancer, especially, NHL and AL, there are also strong associations between exposures and congenital disabilities, congenital diseases, etc.

(iii) Other effects: Other effects of exposure are environmental, although this research focused on the health effects, the environmental impacts of gas flaring are enormous and of great global impact.

(iv) Cost of effects: The Cost of managing the effects of the exposures goes beyond the economic costs, the impacts could also have other socio-political effects on society.

(b) Green completion: The proposed alternative to gas flaring that ensures total control of the waste gas products of O&G explorations. The goal is to capture all the waste gas and install an efficient procedure that converts the captured product to other uses.

(i) Cost of green completion: the main cost associated with green completions is the capital. For this dissertation, the investment includes the cost of purchase of turbines, the associated engineering costs, and the recurrent overheads. It is expected that such initial costs are completely assimilated by the generated profits from the sales of the electricity output.

(ii) Cost of Engineering waste control: The objectives of this dissertation include the total management of BTEX in the waste gas. It is, therefore, noteworthy that a common concern around power plants is the control of the plant exhaust. Several technologies exist for engineering control, and it is important to have that concern taken care of in the implementation of this policy.

(iii) Electricity: The output of green completion is electricity. This is particularly important for the case study because of the acute shortage of electricity in the region. The shortage is also common to LMIC. The imparts of sufficient electric power on the industrial/economic development is massive. In essence, the profits of having green completion as a policy, therefore, goes beyond the immediate economic returns, it has a multiplier effect that could considerably steer the economy away from the near-total dependence on the oil and gas industry. For this research, the effect is limited to the profits generated from the local sale of the energy produced.

7.4 Flare points be pooled together to achieve economies of scale

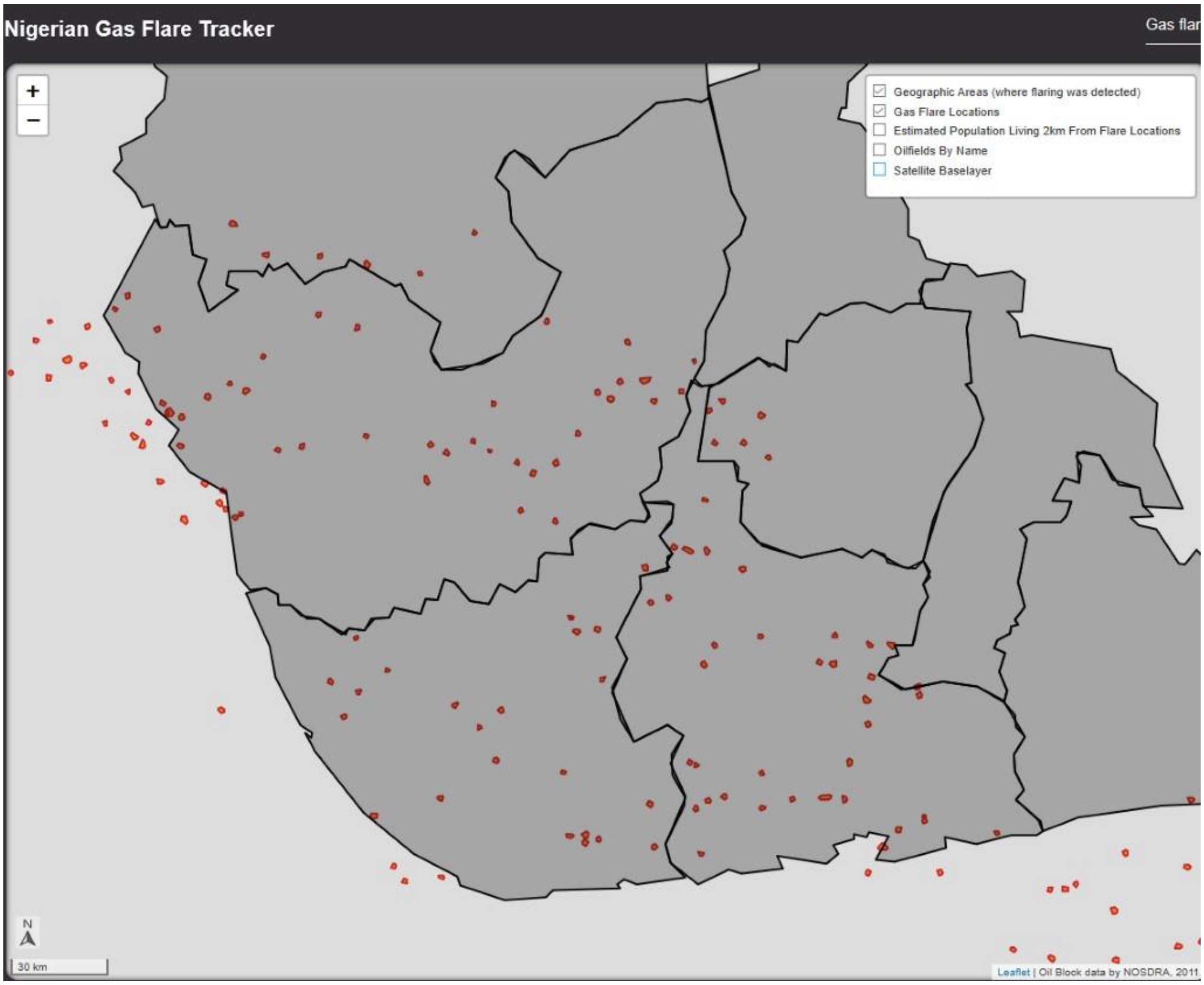


Fig. 7.2 Gas flare points around the Niger Delta in red.

The fig 1.2 above shows the considered gas flare across the region. There are evidences of proximity in a few locations that might make clustering attractive. This is subject to other site viability conditions like the volume of gas available.

In clustering, there is a need to run pipeline networks across the areas involved, there are Social issues to be considered: there are “ancestral lands”, heritage sites etc. that communities are emotionally attached to, these will require wider consultations, agreements and concessions.

It should be noted that an environmental impact analysis will be required in all cases: the region is largely creeks, farmlands, waterways etc.,

Extensive clustering will achieve an economic of scale, but multiple issues are thrown into the mix that could substantially change the economic outlook.

To cluster flare points, the total volume of gas available must be considered, this informs the capacity of turbine appropriate for such locations.

To properly determine the appropriate turbine size, the availability of the gas in enough quantity must be ascertained. Watanabe, 2006 recommended a gas reserve of between 10bcf and 1tcf for a site to host a GTW project profitably. The region currently has a proven reserve of 187 tcf, [95]flaring as much as 80% of its produced gas[96].

8.0 CHAPTER SIX

8.1 FRAMEWORK VALIDATIONS

8.1.1 Introduction

The framework as shown in fig 8.1 is tested to validate its effectiveness: recall the hypothesis,

1. Green completion policy can be shown to be a method to reduce the exposure of the oil and gas host communities to BTEX through gas flaring by at least 80%.
2. The Green completion will yield a Net impact benefit greater than 1 when considering a 6year return on investment period from introduction of the technology into the energy drilling operations.

The validation must show that the framework developed achieves the set-out hypothesis. Validation in research is a dependent concept, and it varies with research methodology and objectives. It is the extent to which such methodology or framework measures and performs as it is designed. Generally, validation instruments may not achieve 100% efficiency, but it should reasonably demonstrate the evidence of practicability beyond reasonable doubts[97]. The process of validation includes data collection and analysis to ascertain the accuracy of the various units and the totality of the proposed framework and to put the structure to some standardized test to demonstrate efficiency. Validation of instruments is often done with various statistical and mathematical tests.

Instrument validation comes in three parts: internal, external, and constructs validation. While external validity addresses the applicability of the proposed framework to a generalized population beyond the sample or the case study, internal or content validity relates to the appropriateness of the framework and its ability to achieve the set goal accurately. Construct

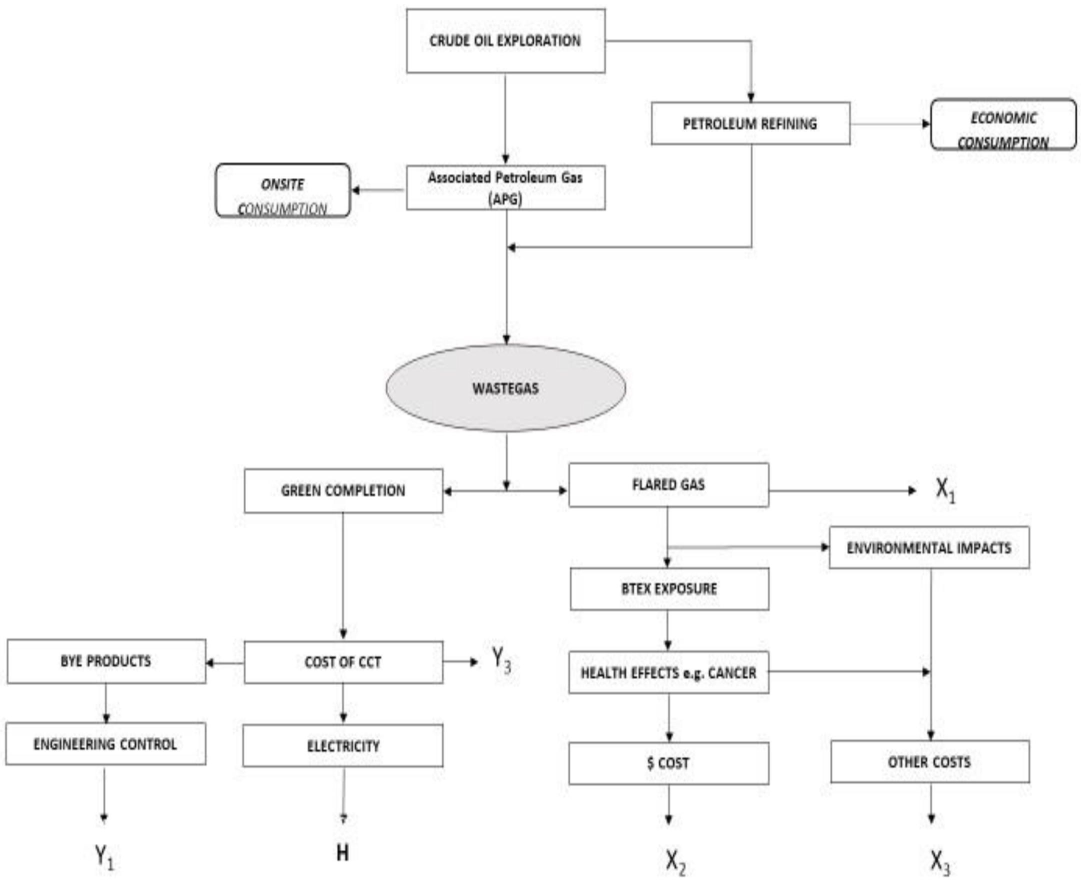


Figure 8.1 Gas flaring Management Framework

validation is the measure of how the conclusions accurately describe the actual results, the match between the outcomes of the research, and the final deductions made from it.

As shown in fig 8.1 and the research hypothesis, the end goal includes Cleaner environment for better health, specifically from the hypothesis, the elimination of BTEX exposure from gas flaring, and an increase in the supply of electricity, which offsets the cost of implementing the green completion strategy.

8.1.2 Hypothesis 1 Validation

Statement: Green completion policy can be shown to be a method to reduce the exposure of the oil and gas host communities to BTEX through gas flaring by 80%.

The recommended combined cycle power plant combines two thermodynamic cycles to optimize the final efficiency: from 4.4 above, "the steam by-products of the gas turbine is used 100% in driving the steam turbine" for an additional 50% efficiency[98]. The used steam from the steam turbine was analyzed by multiple studies, the National Renewable Energy lab. Stated the composition of the final products as below.

SO2 (Lb./MMBtu)	NOX (LB/MMBtu)	PM10 (Lb./MMBtu)	CO2 (Lb./MMBtu)
0.0002	0.0073	0.0058	117

Source: National Renewable Energy lab. (NREL)[98]

Table 8.1 Sample and Concentration at the exhaust of Combined cycle turbine

Evidence shows no BTEX sampled in the products of Combine circuit turbine[98].

Range of BTEX concentration across studies:

0.00015 to 0.0768 mg^3/kg

Sample of BTEX steam turbine output = 0,

Hence, green completion can reduce the BTEX exposure from gas flaring to under 80%.

Imagine the compressor of the turbine as a gas flare point where all the operational variables have been removed since it is initially a vacuum. The removal of the operational variables means we can achieve almost 100% destruction and removal efficiency DRE which is the major short coming with gas flaring in the open air.

8.1.3 Hypothesis 2 validation

Statement: The Green completion will yield a Net impact benefit greater than 1 when considering a 6-year return on investment period from introduction of the technology into the energy drilling operations.

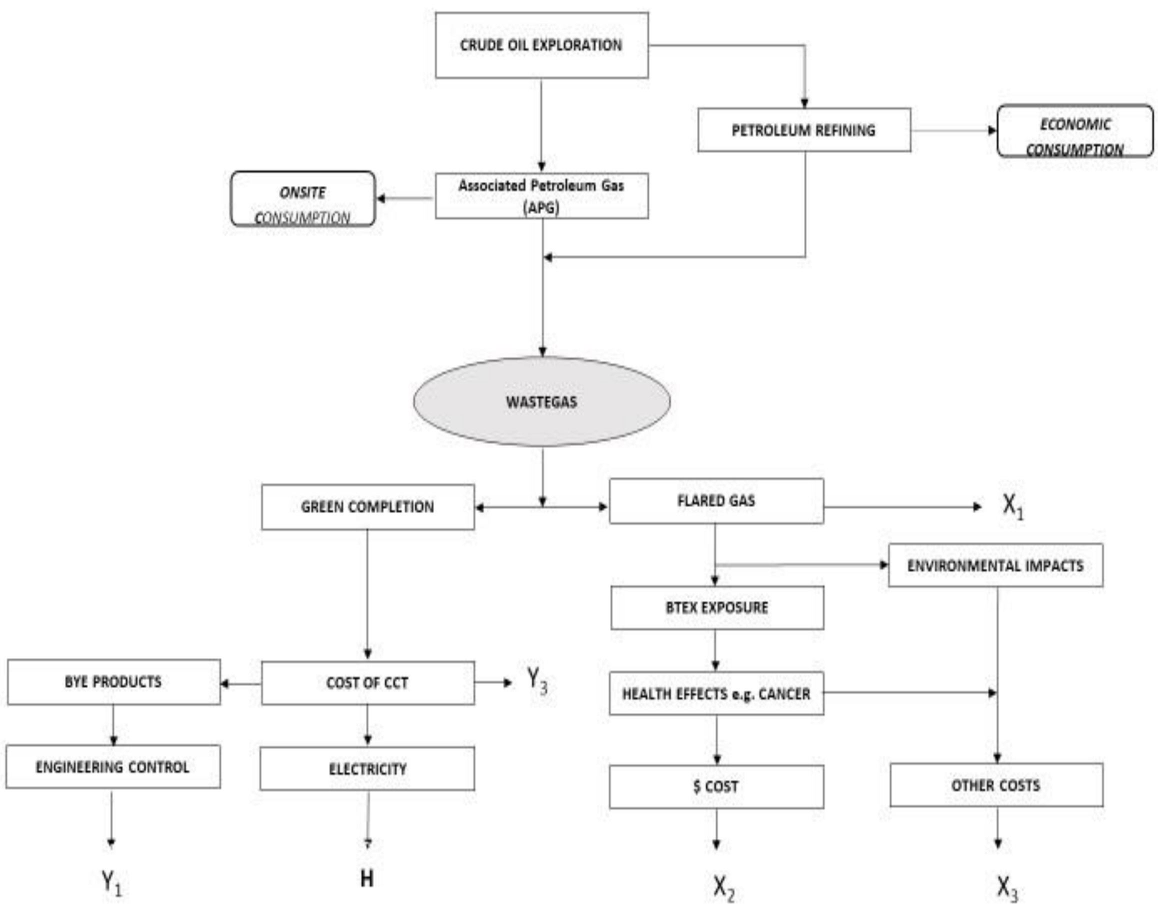


Figure 8.3. Hypothesis 1 validation.

H = Profit from Electricity sales

Yi and Y2 = cost of Green complication

X1, X2 and X3= Health, environmental and other associated cost of flaring.

H1 = H-Y1+Y2 = $216,306,472.75 (Table 4.6 projected income after tax for the third year)

X2 = Cost of BTEX exposure treatment. = $3,628,004 (Table 3.3, Addition of the cost of treating NHL and AML for the additional cancer cases due to the specific exposure)

The implementation of this strategy removes the exposure and saves the country $3,628,004 in health expenses.

8.2 Other Internal Validity instruments.

The model of this research is also supported by the outcome of meta-analyses, incremental cancer assessments, and the cost-profit analysis of green completion. In contrast, external validity is the comparative analysis of the framework against global best practices in gas flare management.

The methodology employed looked at the different outcomes of exposure to the components of gas flaring limited to BTEX compounds. It identified Benzene as the most potent carcinogen in BTEX as designated by USEPA, and hence, it is a signature component of BTEX. Benzene formed the basis for statistical analysis of exposure, risk assessment, outcome costing and assessment, and other benefits of the framework. Standard engineering and accounting principles were used to analyses the economic implication of the green completion strategy.

The statistical and mathematical interactions of the figures generated were used to establish the internal validity of the proposed framework.

8.2.1 Meta-Analysis

The Meta-Analysis allowed us to investigate multiple studies to validate the conclusion from the literature that cancers and congenital disabilities can result from exposure to the known components of gas flaring: BTEX, especially Benzene.

A statistical analysis of the results of the Meta-Analysis gives the following results

RR = 1.23 (1.02 -1.48)

Heterogeneity $Tau^2 = 0.20$, $Chi^2 = 97.07$, df= 31($p < 0.00001$), $i^2 = 68\%$

Test for overall effect Z = 2.17 (p =0.03)

The result shows a strong risk of cancer in cases exposed to Benzene at different dose over a period both in occupational and non-occupational environment.

In all the studies, there is a strong association between exposure to BTEX and occurrences of two types of cancers, Non-Hodgkin Lymphoma and Leukemia.

8.2.2 Incremental Cancer Assessment

Cancer is a major outcome of BTEX exposure, country summary statistics from chapter three shows that the case study has a cancer incidence rate of more than 90 per 100,000 annually with NHL being the 4^{th} most common type of cancer in the region.

Comparative analysis shows the case study has higher incidence and prevalence rates than her West African neighbors, than the average for all low- and medium-income countries (LMIC) and ranks high compared to other top-20 gas flaring nations. The cumulative risk for new cases of both types of cancers in Nigeria is 0.4 and 0.25, respectively, for NHL and Leukemia.

An Incremental Excess Lifetime Cancer Risk (IELCR) Assessment was carried out to validate the number of the cancer prevalence rate due to the exposure to BTEX from gas flaring. The estimate was made using the US EPA values the result of the assessment is as follows:

At a concentration of 0.0768 mg/m3, the IELCR 3.65 in 10,000. Indicating an additional cancer risk of 4 people in every 10,000. For instance, for a population of 6,341,650 within the 6-mile (10km) radius:

Additional cancer risk due to this exposure is = (6341650/10000) * 3.65 = 2314.7

The table below shows the additional cancer cases for the case study population at specific distances from the flare points.

The results show that, on the average, as many as 2315 additional cases of cancer could develop due to this exposure of the lifetime of the more than six million residents of the region, in an extreme case, the number could be much higher.

In any, using the US EPA standards, the action is required when the cancer risk of exposure exceeds one in a million.

8.2.3 Cancer Cost Assessment

Validating the dollar value of the Assessed cancer risk in the case study, the local cost of treatment across the region was sampled and translated into its dollar equivalence.

Using the previous estimate of additional 2315 cancer cases for the population.

8.2.4 Green Completion cost-profit Analysis

The cost-profit analysis of the Green Completion strategy validates the economic viability of using the strategy to manage gas flaring.

With the values of a standardized rate for gas consumption and electricity production, this research estimated that a proposed 580MW gas turbine would generate 13,920,000 kWh daily, at a local cost of 0.083 dollars per kWh, potentially generating $ 421, 706, 400 (USD) per annum.

On deducting the capital and recurrent costs, the project is expected to break even in the third year of operation and be ready for reinvestment starting from the fourth year.

It is expected that a second generating plant can be ready by the sixth year if no further external investment is made.

8.2.5 Cancer Cost Against Green Completion Profit Assessment

The physical, emotional, and financial cost of cancer in a struggling economy versus the profits from green completion validates the urgent importance of using this strategy to managing waste gas.

As earlier noted, the country generates less than 40% of her required power; hence, this policy proposal is of two prongs advantage.

8.2.6 Other benefits of the framework.

Apart from the cancer cost of the exposure to BTEX in gas flaring, the environmental effects of the resulting pollution are eliminated; the multiple power generating stations will provide employment opportunities and boosts economic developments.

8.3 External Validity

Gas flaring is a global problem. Electric Power is central to technological drive and economic prosperity; hence, this policy proposal applies to all gas flaring nations. While the technicalities, equipment ratings, and other variables might not be the same for all locations, the concept is valid for flaring management.

In this case study, it is assumed that cancer from BTEX in gas flaring is a major source of cancer in the region, elsewhere, there might be diverse, more pressing sources, but the definition of good health is universal. This proposal contributes to a global reduction in the burden of disease.

8.3.1 International best practices

The Clean ambient air quality remains an important part of workplaces and the environment at large, to achieve this, green completion for industrial processes must be incorporated in the planning phases of all of such processes, this reduces cost and ensures the efficiency.

8.3.2 Replicability

This project is replicable. Pipelines, turbine ratings, etc. may need to be revised to fit in the available gas supply and the power requirements. Costs of different stages may also vary depending on existing infrastructures and the terrain, among other factors, but the basic concepts remain valid everywhere.

8.4 Construct Validity.

This research measured BTEX exposure in gas flaring near fields, assessed the health risk attached to the exposure, estimated the cost and profit attached to green completion: all of which were the variables set out to be measured, fulfilling the requirement of construct validity.

9.0 CHAPTER SEVEN: CONCLUSIONS/RECOMMENDATIONS

9.1 Introduction

This chapter summarizes the research. It is an overview of the aims and objectives as set out in the first chapter, a look at how each of these has been achieved. The chapter concludes what has been presented this far and made recommendations as deemed fit.

It presents potential objections to this project from socio-economic and political views and made arguments against those.

The chapter concludes by making recommendations on areas of future research in the application of green completions to existing oil fields for gas flaring controls.

9.2 Measure of Aims and Objectives

Recall that this study aims to present a framework that eliminates gas flaring and, consequently, BTEX exposure in oil and gas producing environment through green completion while providing a solution to electricity supply shortage from the same using Nigeria case study. Some objectives were developed to achieve this aim, as outlined in the first chapter.

And these are measured here, as presented in the table 9.1 below.

Research Aim	Objectives	Approach	Chapter
To present a framework that eliminates gas flaring and consequently, BTEX exposure in oil and gas producing environment through green completion, while providing a solution to electricity supply shortage from the same using Nigeria case study	To review the literature on gas flaring, BTEX exposure and its effects on human health	A broad review of literature on Air pollution and pollutants, review of data, and statistics on health effects of exposure to various pollutants, especially BTEX. Review of GF components and outcomes of exposure to them. A comprehensive review of global gas flaring activities, data, and management practices.	One, two
	To determine the health outcomes of BTEX exposure	Literature review and meta-Analysis, Using the outcome of Review Manager software to identify health effects and exposure association	Two and Three
	To evaluate the economic cost of BTEX exposure	GIS identification of flare points, and the retrieval of population data around the flares, Incremental cancer risk assessment (IELCR) using GIS data. Estimating additional cancer cases and	Three

		economic cost using local health market data.	
	To determine the financial import of green completion	Identification of engineering, financial, and human materials and the component of GC, Development of comprehensive multi-year BEME for engineering completions of GC and A 3-year projected income statement for the project.	Four and Five
	To develop a framework for mitigating BTEX exposure through gas flaring.	The appropriate combination of all previous components to generate a clear plan for BTEX exposure management. Policy formulation for gas flaring control plan.	Six

Table 9.1 Measuring the objectives.

9.2.1 Arguments for control of Gas Flaring

The need to curb gas flaring has been in the limelight for about four decades, while the economic viability and desirability of various management techniques are well known.

There has been little success, as seen in Canada and Norway: most other countries have struggled to reduce their flares.

Now, it is cheaper to flare gas than to engage in any long-term investment that may require additional expertise and quite a few uncertainties; because of this, there is a potential loss of investment, which is crucial for an LMIC economy.

(i) Loss of FDI: Stricter regulations and policies may drive some investment away. Nevertheless, governments must recognize that some investors and companies are becoming increasingly environmentally conscious and socially responsible.

Authorities must, therefore, seek out such and be ready to provide some incentives and tax concessions if possible, for green operations, this is working in successful countries like earlier discussed. Adequate publicity and research are required for the appropriate government agencies.

(ii) No immediate cost: the results of exposures are essentially long term and may not pose an immediate concern to the government or the people. On the plate of social responsibility, the authorities owe the people, prevention, as it is often said, prevention is more affordable than treatment. The future socio-political and economic stability and prosperity depend partly on the health status of the people who are insured now with green completions in the concerned regions.

(iii) Economic contributions and diversification

The struggle with electric power sufficiency is one evidence of the potential economic contribution from GC. As seen with this research, green completion can provide sustenance for the nation in power.

The lifespan of the current crude reserve in the region is forty years: for an economy that is 90% dependent on oil, it is hence important to use the available avenue to develop the other sectors of the economy and ensure major diversification in preparing for the years after oil exploration.

Electricity is required to power such economy; it empowers entrepreneurship and SMEs for profitability, a major shortcoming in LMIC

For these and many more reasons, it is important to always remember that the country will remain long after the oil is gone, but without a well thought out policies to save the people's health and the environment, there will be nothing left behind when oil is gone.

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Appendix