Quantification of Carbon Footprint for Oil and Gas Industry: The case study in Al Sharara Field, Libya

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By

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Master of Environmental Technology
MAY 2026

DECLARATION

I hereby declare that the dissertation is based on my original work except for quotations, graphs and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTAR or other institutions.

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APPROVAL SHEET

This final year project report entitled "**QUNTIFICATION OF CARBON FOOTPRINT FOR OIL AND GAS INDUSTRY: The STUDY CASE IN Al SHARARA FIELD, LIBYA**" was prepared by NABIL ISSA EHDIBA and submitted as partial fulfilment of the requirements for the degree of Master of Environmental Technology at Universiti Tunku Abdul Rahman.

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SUBMISSION OF DISSERTATION

It is hereby certified that NABIL ISA EHDIBA (ID No: 25AGM02968) has completed this dissertation entitled "Quantification of Carbon Footprint for Oil and Gas Industry: The case study in Al Sharara Field, Libya" under the supervision of Dr Lo Po Kim (Supervisor) from the Department of Engineering Technology, Faculty of Engineering and Green Technology, and Ch.M. Ts. Dr. Tan Kok Weng (Co-Supervisor) from the Department of Engineering Technology, Faculty of Engineering and Green Technology.

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Yours truly,

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ABSTRACT

Quantification of Carbon Footprint for Oil and Gas Industry: The case study in Al Sharara Field, Libya

Nabil Issa Ehdiba

This study quantifies the carbon intensity of the oil extraction in the Al-Sharara Field, a major and strategically important oil field in Libya. The research uses a cradle-to-gate Life Cycle Assessment (LCA) approach to measure the greenhouse gas emissions at key stages of the operation such as extraction, processing, flaring and transportation. The findings show that the key contributing factors of the total carbon intensity of the field include gas flaring, fuel burning and fugitive methane emissions. The findings have indicated that a significant amount of the associated gas is flared due to the infrastructure and operational constraints, which have significant environmental and health consequences. The study also highlights data and measurement challenges in accurately quantifying emissions, particularly in complex and data-limited cases. To address these issues, the study proposes some mitigation measures including gas utilization technologies, incorporation of renewable energy systems and improved carbon measurement techniques. These have the potential to significantly improve efficiency and reduce emissions. Overall, the study provides an efficient approach to measuring the carbon footprint of upstream oil operations and supports the transition to sustainable modes of energy in Libya.

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LIST OF ABBREVIATION

IPCC	International Panel for Climate Change
GW	global warming
GHGs	Greenhouse Gas Emission
CO2 Eq	Carbon dioxide equivalent
SCF	standard cubic feet
SSP	Shared Socioeconomic Pathway
CFCs	chlorofluorocarbon
HFCs	hydrofluorocarbon
SF_6	perfluorocarbon
LCA	life cycle assessment
LCIA	Life Cycle Impact Assessment
Bpd	barrels per day
NOC	National Oil Corporation
GIS	geographical information system
AGOCO	Arab Gulf Oil Company
SOC	Sirte Oil Company
EOR	Enhanced Oil Rec
IFRS	International Financial Reporting Standards
CCU	Carbon Capture and Utilization
EOR	enhanced oil recovery
Mmscfd	Million standard cubic feet per day
GOSP	gas and oil separation plants
APG	associated petroleum gas
HP	high-pressures
LP	low-pressure

PRVs	pressure relief valves
PRVs	pressure relief valves
NZE	net zero emissions
TDLAS	Tunable Diode Laser
FTS	fisher trpopsch synthesis
VRU	vapor recovery unit
LMS	Laser Methane Smart
LDAR	methane leak detection and repair
OGI	optical gas imaging
GTL	Gas to Liquid
OGMP	Oil and Gas Methane Partnership
CEMS	continuous emissions monitoring system

CHAPTER 1

1.1 Overview

Climate change refers to long-term changes in the weather and temperature. Some of these changes happen naturally, such as changes in the sun's activity or a major volcanic eruption. However, since the late 1800s, man-made activities, particularly the use of fossil fuels such as coal, oil and natural gas, have dominated as the cause of climate change.

Climate change refers to any major change in weather patterns over time that may be caused by humans or natural characteristics of the Earth. Global warming, on the other hand, is part of climate change which specifically refers to the recent global rise of average Earth temperature resulting from an increase in several key greenhouse gases in the Earth's atmosphere. These gases, such as carbon dioxide and ozone, exist naturally in the Earth's atmosphere and act as a protective blanket wrapping around the Earth to keep the Earth warm. However, by burning fossil fuels, such as coal and gasoline, cutting down trees and even some farming and industrial processes, humans release large amounts of greenhouse gases. These gases trap some of the heat that the Earth releases back into the atmosphere after it has warmed during the day, causing the temperature of the lower atmosphere to rise. Carbon dioxide, the main cause of global warming, has increased by about 50% since the Industrial Revolution and is at levels not seen in millions of years (Arias, Paola A.; Bellouin, Nicolas; 2021 Technical Summary IPCC AR6 WG1 2021).

Greenhouse gases, in the environment, trap heat that would otherwise escape to space. This is what makes the "greenhouse effect," which is naturally occurring and is what keeps the Earth warm. All objects, from a star to Jupiter, a gas, to the surface of the Earth, can be warmed by internal or external heat sources. The Sun transmits shortwave radiation to the Earth through space. This shortwave radiation penetrates through the atmosphere and warms the surface of the Earth. The surface then sends back longwave radiation. Greenhouse gases absorb a large amount of this longwave radiation, which, when combined with naturally occurring greenhouse gases, makes it more difficult for the Earth to lose heat and in turn causes the planet to become warmer.

Measuring and tracking the greenhouse gas emissions made by a company, organization or country is called carbon accounting or greenhouse gas accounting. It can also be used to measure the emissions savings of activities such as forestry projects and renewable energy projects. Carbon accounting provides a framework for individuals, organizations and communities to reduce their contribution to climate change by establishing a baseline of emissions, setting reduction targets and monitoring and reporting on progress towards meeting those targets. Tracking emissions and changes in emissions over time allows things to remain constant and clear. Simply, carbon accounting is measuring, recording and reporting the amount of greenhouse gases, primarily carbon dioxide emissions that have been emitted or removed. It allows organizations to determine the amount of carbon they are emitting and also allows them to find ways to reduce emissions and become more environmentally sustainable.

1.2 Problem Statement

Oil and gas production in Libya has created a set of new environmental problems. Burning immense quantities of naturally produced gas at oil producing sites releases millions of tons of carbon dioxide into the atmosphere, with further impacts on health and the environment due mainly to the lack of facilities to process and utilize this resource instead of burning it. The impacts are continuing.

Emissions of greenhouse gases such as carbon dioxide (CO_2) are frequently cited as the primary cause of global warming and changes to climate, there is a pronounced lacuna regarding holistic approaches to sustainability and carbon accounting, the application of integrated sustainability practices in supply chain management and business reporting is not common practice. Sustainability has only in recent years become a central task of public administration and environmental management. For a long time, sustainability was disregarded as a priority and administration disregarded the possible environmental effects of the depletion of resources.

Gas flaring in Libya has significant environmental and health impacts. As the world's largest flare outside of the former Soviet Union, Libya releases tens of millions of tons of greenhouse gases like carbon dioxide (CO_2), methane (CH_4) and nitrogen oxides (NO_x) into the atmosphere each year. These pollutants contribute to climate change and severe air pollution. Ecosystems and biodiversity are also affected through soil and water pollution, while local populations are also suffering from serious respiratory, sensing and carcinoma diseases because of the chemicals released during everyday gas production.

1.3 Objectives

i. To determine the carbon emission throughout the life cycle of crude oil production.
ii. To identify the key challenges in calculating carbon emissions associated with crude oil production.
iii. To propose effective strategies for reducing the carbon footprint of crude oil production processes.

1.4 Scope of study

The research aims to develop methods to measure, analysis and control the greenhouse gases emitted during the extraction of oil from Al-Sharara field, which is operated by Akakus Oil Operations, a Libyan and international joint operating venture comprised of the Libyan National Oil Corporation (NOC) and Repsol.

Al-Sharara is one of Libya's biggest oil-producing areas, located in the Marzuq Basin in the southwest of the country, around 700 km south of the capital Tripoli in the Sahara Desert (Figure 1.1). There are several gas and oil separation plants (GOSP) as well as many collection points for the oil and gas across the site. Some of the gas is used to generate power while the rest is flared. Sharara oil field can produce more than 300,000 barrels per day of light crude oil, a quarter of Libya's production.

Al Sharara oil field is situated in blocks NC115 and NC186. Rompetrol discovered the first oil drop in 1984 in block NC115, the first oil of the field being produced in 1996. The two blocks cover an area of about 8,700 square kilometers. (Africa's top study on the oil, gas, and energy situation, 2024). El Sharara oil field exports its crude oil through an export pipeline that runs 723 kilometers in length and has a diameter of 30 inches.

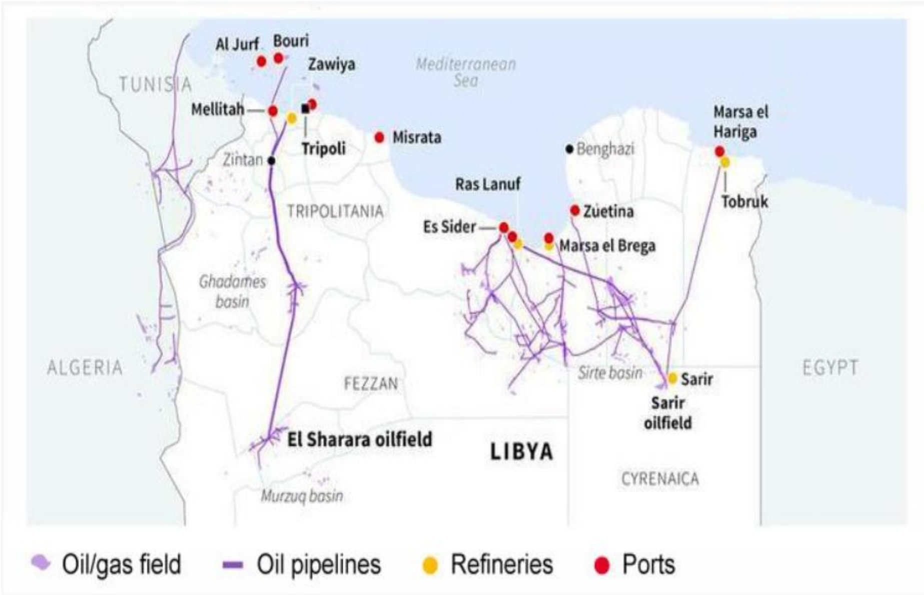

Figure 2.1: Map of al-Sharara fields and export pipelines until zawiya terminal port (United World, 2020b)

The operational boundary for the Al Sharara oil field extends to three emission scopes: Scope 1 - Direct GHG emissions from sources owned or controlled by the operator e.g. Gas flaring, fuel combustion, venting, fugitive leaks, field vehicles. Scope 2 - Indirect GHG emissions from externally generated electricity, steam, or heat consumed by oil and gas operations. This scope is Nill as the field operates under a single operator who generates all electricity via the field's turbines. Scope 3 - Other indirect emissions which include transport of crude oil to Zawia terminal, employee travel, supply chain activities.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains more about climate change, greenhouse gas emission and carbon accounting and addressing requires an analysis of the crude oil life cycle from exploration and production to transportation and distribution using ISO 14040/14044 standard for carbon accounting. also, background of Libya's Oil and Gas Industry. This framework can be utilized for decarbonizing Libya's oil industry, one of Libya's principal energy industries and a global one affecting the climate change.

2.2 Climate Change

Climate change is about long-term changes in temperatures and weather. These can be caused by changes in the Sun's activity or by major volcanic eruptions. However, since the 1800s, human activities have been the main cause of climate change, primarily caused by the emission of greenhouse gases, such as carbon dioxide (CO_2) and methane (CH_4). These gases behave like a blanket wrapped around the Earth, trapping the sun's heat and leading to increased temperatures. Most emissions of CO_2 come from the consumption of crude oil products, including gasoline for cars and diesel for trucks and buses. Other fossil fuels such as coal and natural gas (mainly used for heating) are also emitted into the atmosphere. Greenhouse gases are also released when trees and other vegetation are cut down or burnt during processes such as when forests are cleared to make way for agriculture or urbanization. Other activities which release methane include farming (especially rice and beef production) and the production, transportation and use of oil and gas. Other sectors which emit greenhouse gases include industry, transport, buildings, agriculture and land use change. Climate change is when these average conditions change, either naturally or through human activity. It is characterized by increased temperature, changes in precipitation and more extreme weather events. In 1990 the Intergovernmental Panel on Climate Change (IPCC) produced its first assessment of the issue and predicted that evidence of human-induced climate change would become apparent within a few decades. This assessment was produced 30 years on and there is now substantial evidence for human-induced climate change

2.2.1 Human-driven Global Warming

Rapid changes are happening globally in the Earth's climate system as human activities drive global warming at an unprecedented speed, increasing in intensity and rapidity. Climate change is more than just an increase in global temperature, which is observed and studied across the atmosphere, land, ocean and polar ice regions. Some of the key signs of climate change are outlined below:

Changes to the Earth's surface and atmosphere visible between 2011 and 2020 include a planetary peak of 1.1°C above pre-industrial levels. All four decades of the 21st century to date have been warmer than any previous decade, with temperatures rising at a pace unrivalled in the past two millennia. Global emissions of greenhouse gases continue to climb, reaching new highs. Levels of carbon dioxide in the atmosphere have exceeded 410 parts per million, the highest in 2 million years. Methane and nitrous oxide concentrations in the atmosphere also reached new highs in 2018, at 1868 parts per billion and 344 parts per billion respectively, both the highest in 800,000 years (IPCC,2021).

Patterns of global precipitation have changed since the 1950s, with an overall increase in rainfall over land, and particularly in the tropics. Species of plants and animals are moving towards the poles and to higher elevations in response to these changes in climate zones. In the Northern Hemisphere, seasonal lengths have increased to 14 days since the mid-20th century, resulting in an increasingly green landscape as crops have grown to need an extra week or so of warm weather each year at both ends of the season. Since the early 1980s, many areas have experienced longer growing seasons (IPCC,2021).

The world's frozen landscapes are melting at an incredible rate. Global snow cover has been steadily decreasing since 1950, glaciers worldwide are receding at rates greater than in at least the past 2,000 years, pouring billions of tons of freshwater into the world's oceans. Perhaps nowhere is this loss more pronounced than in the Arctic, where the area of sea ice in the Ocean during the warm months of summer has decreased by 40% since the 1980s, representing a loss not seen in at least the past millennium. Snow cover across the Northern Hemisphere has decreased generally since the late 1970s, causing formerly permanently frozen ground to thaw. Today, the melting of ice sheets on Greenland and Antarctica, as well as hundreds of mountain glaciers around the world, remains responsible for the majority of sea level rise.

The ocean is absorbing 90% of the excess heat generated by global warming. As a result, the world's seas are warming at a rate unmatched in at least the past 11,000 years. However, it's not just the rising temperature that's worrying – the seas are also going through a chemical transformation. Absorbing massive amounts of carbon dioxide has made the ocean surface more acidic than it has been in at least two million years. And the changes are not confined to the surface – warmer seas cause thermal expansion, and melting ice adds to sea level rise. Since 1900 global sea levels have risen by about 20 centimeters to levels now experiencing accelerations unmatched in at least 3,000 years. (IPCC,2021)

Figure 2.2 views of the Four Main Climate Systems Graphic representation of changes that have been observed in four critical parts of the Earth's climate system air, ocean, land, and ice. These changes demonstrate consistent warming throughout the climate system. Data from these systems indicate that Earth's temperature is rising.

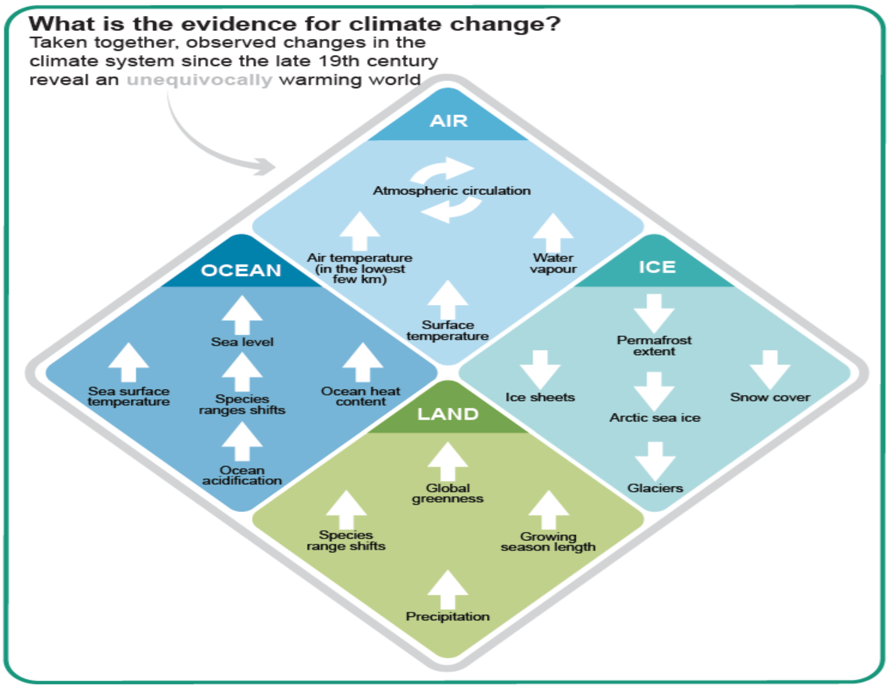

Figure 3.2 The changes in four main parts of the climate system (IPCC, 2021).

2.2.2 Global Surface Ocean pH Projections (1950–2100)

According to a comprehensive assessment published in Nature, the average surface ocean pH has decreased from approximately 8.2 before the Industrial Revolution to 8.05 in recent decades. This decrease in pH makes the oceans more acidic and affects marine ecosystems. The oceans are a major carbon dioxide sink absorbing 25–30% of the CO_2 released into the atmosphere because of human activity. The combination of the absorbed CO_2 with marine saltwater forms carbonic acid that affects the chemistry of marine carbonates altering the marine carbon cycle and lowering the pH. Projections of future ocean acidification suggest that with constrained emissions as SSP1-1.9, ocean pH will likely stabilize at approximately 8.0 by 2100. In contrast, very high emissions, as in SSP5-8.5, lead to decreases in pH below 7.7 so that acidity would be 100–150% greater than the pre-industrial state. These changes to the world's oceans have the potential to have significant and varied negative impacts on marine ecosystems and fisheries as well as altering global biogeochemical cycles.

Future trends in ocean pH are shown for the world's surface oceans in Figure 2.3 over the time span from 1950 to 2100 and compared to pre-industrial levels for different Shared Socioeconomic Pathway (SSP) scenarios. The figure illustrates that surface ocean pH has decreased over the historical period, from a value of approximately 8.1, and is currently experiencing levels of ocean acidification due to the absorption of anthropogenic carbon dioxide (CO_2) by the world's oceans. The extent of, and rate of increase in, ocean acidification will depend, however, on the trajectory of greenhouse gas emissions over time. Even at reduced levels of emissions under a low-emissions scenario (SSP1-1.9), the decrease in surface ocean pH is projected to slow down around the mid-century time frame. This partial flattening of the curve could allow ocean chemistry to partially recover under a global mitigation scenario consistent with the goals of the Paris Agreement should rigorous mitigation efforts are made to keep warming below 2°C (SSP1-2.6), or even 1.5°C (SSP1-1.9).

Figure 2.3 illustrates the important relationship between the concentration of CO_2 in the atmosphere and the acidity of the ocean, the sign of change indicates grave concern for marine ecosystems as such shifts pose dangers particularly to calcifying organisms (corals, mollusks, plankton etc.) that require carbonate ions for construction of shells/skeletons. Highlighting the urgent need to reduce emissions to protect the health of the ocean and maintain ecosystem resilience.

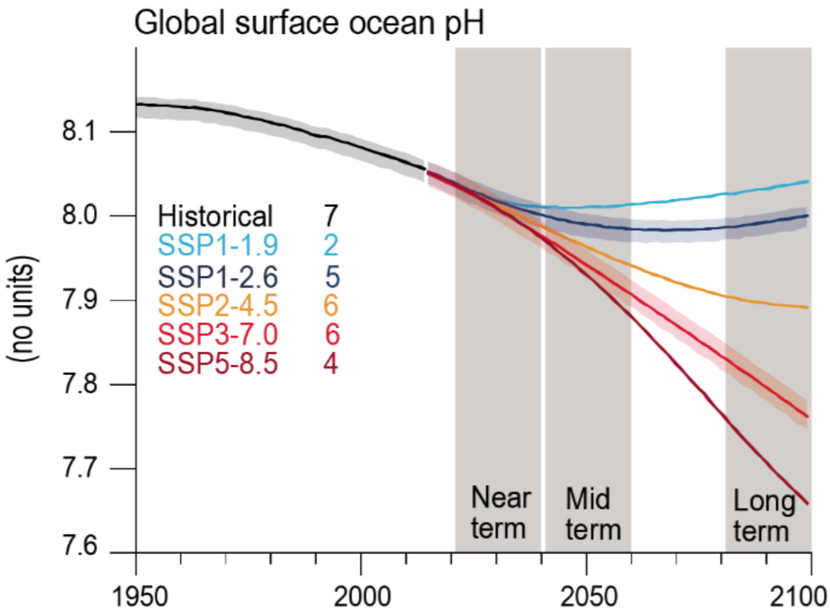

Figure 2.3: The sixth report of the IPCC, Cambridge university press, global average surface ocean pH, IPCC, 2021, climate change 2021

2.3 Greenhouse Gases Emission

Greenhouse gases in the atmosphere trap heat allowing planets such as Earth to have a surface temperature. The greenhouse effect occurs when greenhouse gases in the atmosphere absorb radiation emitted by a planet. During the day, the surface of Earth is warmed by solar radiation. As the planet loses heat at night, much of that escaping radiation is absorbed by greenhouse gases primarily. Earth surface temperature would be about −18 °C (0 °F) in the absence of greenhouse gases, instead of the current mean temperature of 15 °C (59 °F) (Forster et al., 2024).

Human-induced climate change has never looked more abrupt in the historical climate record. The rate of warming from 2015 to 2024 reached [0.2–0.4] °C per decade. High levels of greenhouse gas emission (53.6 ± 5.2 Gt CO2e per a year for the last decade, 2014–2023) and decreasing aerosol cooling contribute to the extraordinary rapid rate of warming and the most abundant greenhouse gases in the Earth's atmosphere, listed in decreasing order of average global mole fraction, are water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Other gases also affect the greenhouse effect, including the chlorofluorocarbon (CFC) compounds and, less abundantly, the hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), SF6, and NF3. Water vapor is responsible for about half of the greenhouse effect and is strongly interactive with other gases as negative feedback in climate change. (Matthews et al., 2021).

Since the onset of the industrial revolution (about 1850), human activities have contributed to a greater increase in carbon dioxide by more than 50% and methane by 150%. The emission of carbon dioxide is leading to approximately three-quarters of global warming with most of the remaining being caused by the emission of methane. (Wijerathna-Yapa and Pathirana, 2022).

Huge percentages of carbon dioxide emission by humans are attributed to the burning of fossil fuel with the remaining percentage attributed to agriculture and industry. Methane is produced by agriculture, production of fossil fuel, waste and others. It can take thousands of years to completely absorb CO2 in the atmosphere through the carbon cycle whereas methane has an average lifespan of 12 years in the atmosphere, (Ardia et al., 2022). Carbon is neutral with flow between atmosphere, Terrestrial ecosystems, the ocean and sediments. The balance of these flows has been maintained during the last one million years, (Ambrose et al., 2023). Even though the level of greenhouse gases has fluctuated quite significantly in the farther past. The amount of carbon dioxide in the atmosphere is now greater than it was three million years ago, The 2023 annual update of key indicators states that human-induced increase in temperature, greenhouse gases, and the energy imbalance on Earth are all at record levels, and in the event that emission rates persist, the world will not only pass 2.0 o C (3.6 o F) by 2040 This is one of the levels that the Intergovernmental panel on climate change (IPCC) deems to be dangerous.

2.3.1 Properties and Mechanisms

Greenhouse gases are actively infrared with their absorption and emission of infrared radiation within the same long wavelength as that which is emitted by the surface of the earth as well as by the atmosphere of the clouds, atmosphere gases such as Nitrogen (N_2) (78%) and oxygen (O_2) (21%), constitute 99 percent of the dry atmosphere of the earth (excluding water vapor). Since their molecules have two atoms of the same element, they are not asymmetrical in how they distribute the electrical charges and are therefore virtually completely unaffected by infrared thermal radiation, except that there is a very small effect due to collision, which also involves absorption. Another 0.9 percent of the atmosphere composes Argon (Ar), the monatomic gas that is therefore totally clear to thermal radiation. Conversely, carbon dioxide (0.04%), methane, nitrous oxide and even fewer trace gases, make up less than 0.1 percent of the atmosphere of the Earth, but due to the asymmetry of the distribution of the atomic elements they contain, Molecular vibrations can interact with electromagnetic radiation. This renders them infrared active hence their presence leads to greenhouse effect.

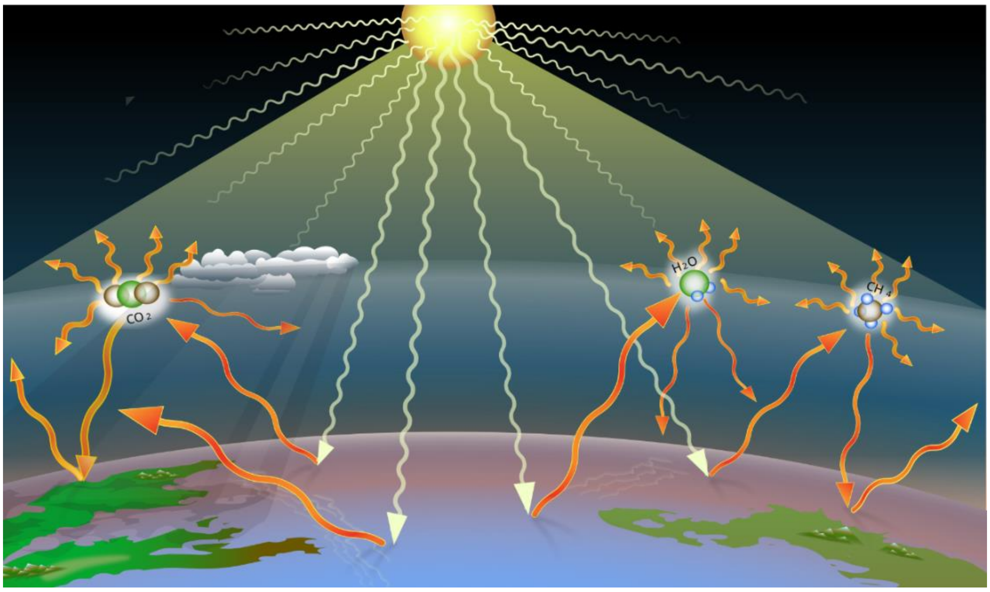

Figure 2.4: The GHGs mechanisms (www.sciencelearn.org.nz)

2.4 Comprehensive Analysis of the Crude Oil Life Cycle

Exploration activities in the first stage of crude oil life cycle are important since they influence the subsequent stages. Exploration work is conducted by scientists to find oil and gas reserves that exist naturally on the Earth's crust. On the surface, they look for indicators such as structural configurations from surface mapping, seismicity, magnetic and gravity fields, and satellite images, to predict the likelihood of the presence of hydrocarbons in underground formations. For that, they need the input and assessment from geologists and geophysicists to decide whether the find has potential from economic and environmental aspects. Exploration work using various technologies has long existed and recently has entered the era of sophisticated three-dimensional imaging and modeling in seismic data to obtain information about potentially profitable areas to drill for crude oil and to reduce dry wells (Sulistyawati et al., 2020).

Once a promising field has been identified, the process of finding oil moves into what is commonly known as the drilling phase of the life cycle. This is the process by which a hole is bored in the earth to access the oil located deep inside. Most of the advances in drilling technology have occurred in the realm of rotary drilling, whereby a large bit rotates while drilling downward to extract oil. In conjunction with rotary drilling, the process of hydraulic fracturing (or fracking) is commonly employed to release trapped oil from minerals such as shale. While advances in drilling and extraction have greater amounts of oil, the environmental impact of exploration is compounded by the effects drilling has on the Earth's surface. As with exploration, during the drilling phase there are numerous environmental issues and public health threats that must be mitigated, such as the management and disposal of drilling waste, and the amount of water required to drill an effective well. Once a well has been drilled, extraction procedures are implemented to remove crude oil from the reservoir. Techniques for extraction are determined by the characteristics of the reservoir and by the characteristics of the oil itself. In the primary extraction methods, reservoir pressure is utilized to extract much of the oil from the reservoir. Secondary and tertiary recovery processes were created to increase extraction rates and have been shown to be more economically sound than initially believed. Water flooding, for example, increases extraction by forcing oil through existing channels in the reservoir. In enhanced oil recovery, chemicals are poured into the reservoir to facilitate greater extraction. Each method, however, creates a host of challenges regarding both economics and the environment. Ultimately, the search for better extraction processes has continued to evolve with technology and the environment.

After extracting the crude oil, it is processed and altered to conform to specific market criteria. Crude oil must be refined to extract products such as gasoline, diesel, jet fuel and petrochemicals. Refineries are used to distill the crude oil using a variety of chemical processes. As raw material is solvable as a product, the refinery process must be as efficient as possible to maximize profits in the oil market and ensure energy security. As technology has evolved and environmental legislation has been introduced to tackle waste creation and emissions, the refining process has become more complex.

Crude oil from producing facilities is transported to refineries and then to markets across the country before being exported overseas from terminal locations. The various methods of crude oil transportation - by rail, tanker and pipeline - all have respective operational issues and risks. In the event of a spill or accident, crude oil can cause significant environmental damage and loss of economic value. Therefore, safe and effective transportation of crude oil is critical. Making operations safer, as well as detecting and responding to leaks, is key to reducing hazards associated with the shipping of crude oil.

The crude oil life cycle, beginning with exploration, continues through production. Every sector of this industry poses its own unique problems and advantages to human expansion. By taking an interdisciplinary approach and carefully managing these sectors, economic advantages can be maintained while still respecting the environment and local populations. Identifying potential reserves is the first step in the extraction and production process for crude oil, followed by the process of drilling. During drilling, wells are built into the Earth's crust to enable the extraction and subsequent production of crude oil. The process of drilling utilizes diverse technologies and requires large amounts of expertise from a variety of skilled labor. The sector has an outstanding record in terms of sustainability and the environment, particularly with respect to terrestrial and marine ecosystems (Ghasemi et al., 2025**).**

All stages of crude oil cycles Figure 2.4 from exploration to processing and transmission are interlinked and affect resource efficiency and sustainability. A comprehensive understanding of all links of oil cycle facilitates to handle the impacts of crude oil extraction and utilization for sustainable development, meeting the need of environment-friendly sources of energy for sustainable consumption of resources (Ali & Kumar, 2017; Adeola et al., 2022). Amidst rapid transformation taking place in the global energy scenario, it is very difficult to obtain energy resources with least possible environmental impacts. Therefore, it is essential for the sustainable development of the world to continue researching and developing on crude oil production and management.

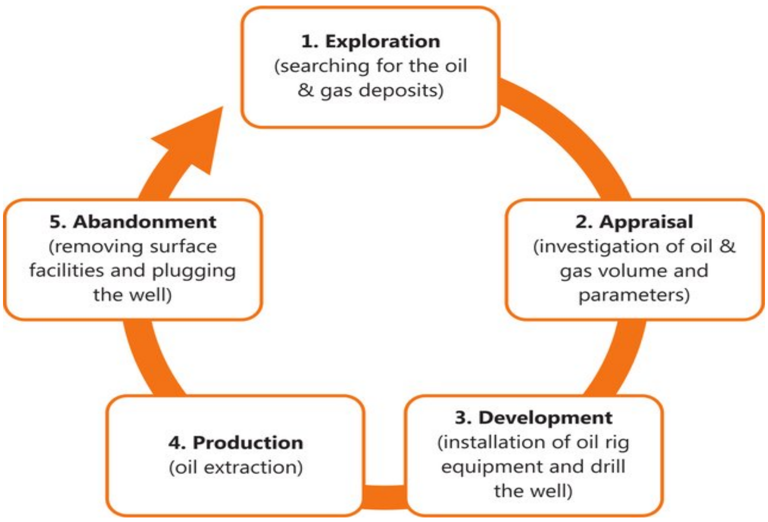

Figure 2.5: Life Cycle of Oil And Gas (Al-Azani, 2014)

2.5 Carbon Accounting / Carbon Footprint Assessment

To fight climate change globally, carbon accounting has become more widespread as a method to measure, manage, and mitigate greenhouse gas (GHG) emissions across industries, applications, and geographies. Carbon accounting is the process of quantifying all emissions generated during a company's or product's lifecycle whether direct or indirect. The practice enables stakeholders to know the actual impact they are having on the environment and devise sustainable strategies to reduce their carbon footprint (Zhang et al., 2022). It makes it possible to see emissions clearly, encourages accountability, and prompts action to reduce emissions to levels that are healthy for the environment.

Carbon accounting methodologies have been employed in a variety of forms, most notably carbon footprint calculation and lifecycle assessment (LCA). The carbon footprint is a quantitative expression of the total greenhouse gas emissions generated by a product, service, entity (e.g. company, country) throughout its lifecycle, typically expressed in grammes or tons of carbon dioxide equivalent (CO2e). By calculating a carbon footprint, companies can identify the most important areas for emissions reduction and get a complete understanding of the patterns of emissions and their sources. Scrucca et al. (2020) investigated the main approaches to calculate the carbon footprint and discussed the related steps to build a carbon footprint inventory, including data collection, selection of relevant emission factors and the critical importance of accurate and complete inventory management.

Carbon accounting systems play an important role in many companies. As sustainability is becoming an integral part of more companies' organization and processes, a precise carbon accounting system can add a lot of value especially for companies with complex supply chains. Measuring emissions helps create a culture for continuous improvement that is truly sustainable. In addition, measuring emissions allows companies to inform their stakeholders (e.g. customers, capital market participants, government agencies) about their emissions and invite them to join the company in its efforts towards mitigating climate change.

Carbon accounting also functions as a driver for strategic decision-making (Scrucca et al., 2020). Monitoring and reporting the carbon emissions associated with operations enables organizations to identify potential inefficiencies within their operations. However, by utilizing carbon accounting precisely, organizations are better equipped to execute targeted strategies for reducing carbon emissions. Carbon accounting, therefore, enables strategic change towards sustainability whilst simultaneously reducing costs and enhancing operational efficiency, affording organizations a competitive advantage within increasingly environmentally aware markets.

Carbon footprint assessments are critical in informing strategies to reduce carbon emissions. Individuals can adopt low carbon choices for transport and consumption of household appliances. Corporates can optimize their supply chains and embrace renewable energy. Governments have a critical role to play in designing policies that encourage low carbon behavior through mechanisms such as carbon taxation and supporting low carbon technology innovation. Understanding all components of the carbon footprint enables informed decision making and strategic intervention to support global sustainability initiatives.

2.5.1 Carbon Footprint for 3 Scopes of Carbon Emission

The concept of carbon footprint is of importance to the discussion on climate change. A carbon footprint is the total amount of emissions that are created by a person, organization, product, service, event or activity through indirect sources, and are measured in units of tons of carbon dioxide equivalents (CO2e). To address environmental challenges including climate change, ecosystems loss and health impacts, assessment of carbon footprint has become an essential environmental metric for governments, companies and the public. Knowing one's carbon footprint and comparing it with others can guide priorities for reduction. The Greenhouse Gas Protocol considers three types of carbon emissions i.e. Scope 1, Scope 2 and Scope 3.

Scope 1 emissions are emissions that occur as a direct result of activities that are owned and controlled by an organization. They typically occur from fuel consumption from corporate vehicles or because of business operations. Common sectors with large Scope 1 emissions include manufacturing and transportation. To reduce Scope 1 emissions, companies in the manufacturing sector can consider using more efficient equipment or less carbon-intensive fuels. Within the logistics sector, companies can transition from diesel-powered vehicles to electric vehicles and install monitoring systems to track emissions and reveal areas of inefficiency to make targeted reductions.

Scope 2 emissions represent indirect emissions from production of purchased electricity, steam, heat or cooling. For many organizations Scope 2 emissions are significant due to their consumption of energy. According to Awanthi and Navaratne (2018), improving energy efficiency significantly reduces Scope 2 emissions. Organizations can adopt improved energy efficiency through a sophisticated building management system, installing energy efficient technologies, such as LED lighting or energy efficient air conditioning systems. The adoption of renewable energy sources, such as solar or wind power, will reduce Scope 2 emissions even further. Many organizations such as Google and Apple have made commitments to obtain 100% renewable energy for their operations. Their actions in the technology sector have set a precedent in moving towards renewable energy and initiating changes in energy sourcing patterns.

Scope 3 emissions include all indirect emissions. Mostly even up to 90 % of the total carbon footprint, they require a lot of effort to measure and manage. Measuring Scope 3 emissions involves many stakeholders in the value chain and requires collaboration. As emphasized by Wiedmann et al. (2021), it is however crucial to measure them because they form the greatest share of emissions. An example of how Scope 3 emissions can affect emissions and community health is through waste management in urban settings. San Francisco for instance, has put in place a comprehensive system of waste management with a goal of reaching zero waste. This system has resulted in substantial reductions in the carbon emissions associated with the disposal of organic waste. Effective supply chain management, including sustainable sourcing and working with suppliers that are environmentally sustainable, helps to reduce Scope 3 emissions by reducing the carbon intensity of the materials and products going into production.

The reduction of carbon emission strategies in all three scopes is systemic and needs multi stakeholder strategies. According to Hertwich and Wood (2018), industries, governments, and non-governmental organizations should cooperate to create consistent strategies that would help to reduce emissions on a broad level. Programs like the Science Based Targets initiative encourage the setting of targets by companies that are aligned with climate science, thus improving accountability and creating a shared sense of responsibility towards sustainability goals. By embracing technological advances, energy conservation efforts and sustainable supply chain management, organizations can develop proper structures to minimize their carbon footprint and make a positive change in the environment and society.

2.5.2 Cradle-to-gate

The cradle-to-gate life cycle of crude oil includes processes from extraction to the refinery gate that have drawn considerable attention due to their scale and complexity. The extraction phase of crude oil includes processes such as drilling and production which can result in environmental damage to soil, habitat destruction and water pollution. In addition, the environmental effects are further intensified by the high-water consumption during extraction and processing stages. It is crucial to evaluate the water footprint associated with crude oil supply chain.

Crude oil extracted from the earth is distributed to seaport terminal by pipeline and either shipped by oil tanker for foreign sale or transferred to refineries for domestic use to obtain products such as petroleum gas (LPG)-naphtha, gasoline, kerosine/diesel oil and jet fuel etc. The facility that is used for refining crude oil also causes pollution in the air by releasing greenhouse gases and volatile organic compounds etc. and affects air quality and energy use has a significant carbon footprint. Therefore, there is a need for strict regulations to minimize these negative effects. Life cycle assessment (LCA) methods have been utilized to evaluate environmental impacts in petroleum refining operations and to identify opportunities for improving efficiency and reducing energy consumption and waste generation (Chan et al., 2018).

An analysis of the life cycle of crude oil from well to final product reveals many environmental impacts that need to be addressed by industry and government. In future, LCA will play a crucial role in guiding industry towards sustainable practices whilst meeting our energy needs (Subramaniam et al., 2020; Üçtuğ et al., 2025).

2.5.3 Cradle-to-grave

The different stages in the life cycle of crude oil, extending from extraction to the distribution of its different products on the market, in addition to the environmental damage resulting from burning these products throughout their lifetime cycle, are very important. Each stage in the life cycle of crude oil, such as extraction, production, distribution, use, and end-of-life, poses environmental problems and opportunities for sustainability. The methods used to extract crude oil from its sources cause severe damage to the environment. In addition to destructive effects of extraction methods on the environment, the location of oil extraction also has significant impacts. El-Houjeiri et al. (2019) conducted a life cycle assessment of greenhouse gas emissions from marine fuels and showed that the emissions vary greatly depending on the methods and locations of oil extraction. As such, it is very important to assess the impacts of oil extraction in the context in which it takes place.

The process of refining crude oil to produce gasoline and diesel fuel involves a complex array of chemical and thermal reactions requiring large amounts of energy; this, in turn, increases the overall greenhouse gas emissions from the crude oil (Haque, 2020). Also, the distribution phase accounts for how crude oil is transported from an extraction well to a refinery and to the end user. Distribution generally increases pollution, particularly because of the amount of energy used for transportation. According to Sahoo, Bergman, and Khatri (2021), the distribution of crude oil and derived oil products must be controlled to reduce environmental impacts as measured by lifecycle emissions. Transportation by pipeline, truck, or ship affects the environment.

In conclusion, the cradle-to-grave lifespan analysis of crude oil highlights the considerable environmental effects linked to each phase, from extraction to burning. Ongoing research and novel solutions are vital to mitigate the ecological impact of crude oil, as underscored by recent evaluations in multiple studies (El-Houjeiri et al., 2019; Bradley et al., 2025; Majid, 2025; Haque, 2020).

2.5.4 Life Cycle Assessment (LCA) Framework ISO 14040/14044 Standards

Life Cycle Assessment (LCA) methodology, established in ISO 14040 and ISO 14044 standards, provides guidance for assessing the environmental impacts of products and product systems throughout the entire life cycle. To meet the needs of current environmental issues and resource constraints, sustainable decision-making has become increasingly important. The foundation of LCA methodology is mainly based on life cycle perspective, environmental assessment, and interpretation. The concepts can facilitate a comprehensive understanding of the environmental impacts connected to a product's life cycle (Tam et al., 2022).

From an environmental perspective, a life cycle must be adopted according to the requirements of the standard ISO 14040. It requires assessing environmental aspects and opportunities to reduce environmental impacts that occur throughout the life cycle of a product, from raw material extraction to end of disposal (Frischknecht et al., 2020). Utilizing Life Cycle Assessment (LCA) in conjunction with Building Information Modelling (BIM) assists in sustainability-driven decision making within the construction stage, thus paving way for compliance with sustainable construction practices (Tam et al., 2022).

In addition to environmental evaluations, life cycle assessment (LCA) methods can also be applied for social evaluations. Current studies are exploring standards for social LCA and their limitations. However, also social LCA evaluations should contribute to a broader view of sustainability, going beyond traditional environmental factors. Within the environmental context, the widely used standard ISO 14040/14044 has given LCA a structured framework to apply Life Cycle Assessments and to measure and reduce environmental impacts. Sustainability is increasingly important for companies and today, environmental thinking and actions are considered smart business.

ISO 14040 / 1444 defines the overall process of life cycle assessment (LCA), the four steps of LCA process are shown in Figure 2.5.6

I. **Goal and scope definition:** identify products to be included in the LCA, goals and scope for the study, the intended applications and targets audience for the study report.

II. **Inventory analysis:** Collect all information concerning inputs and outputs at every stage in the life cycle of the product studied. Data is organized so that in subsequent steps of the LCA environmental impacts can be calculated.

III. **Impact assessment:** Life Cycle Impact Assessment (LCIA) methods are used to assess the potential environmental impacts of products. During this step, one first selects the relevant impact categories, classifies the data, and calculates the potential impacts using a set of standardized methods.

IV. **Interpretation:** The results of the LCA study then need to be interpreted using the collected data, identifying limitations and developing recommendations for improvement and for sustainable activities.

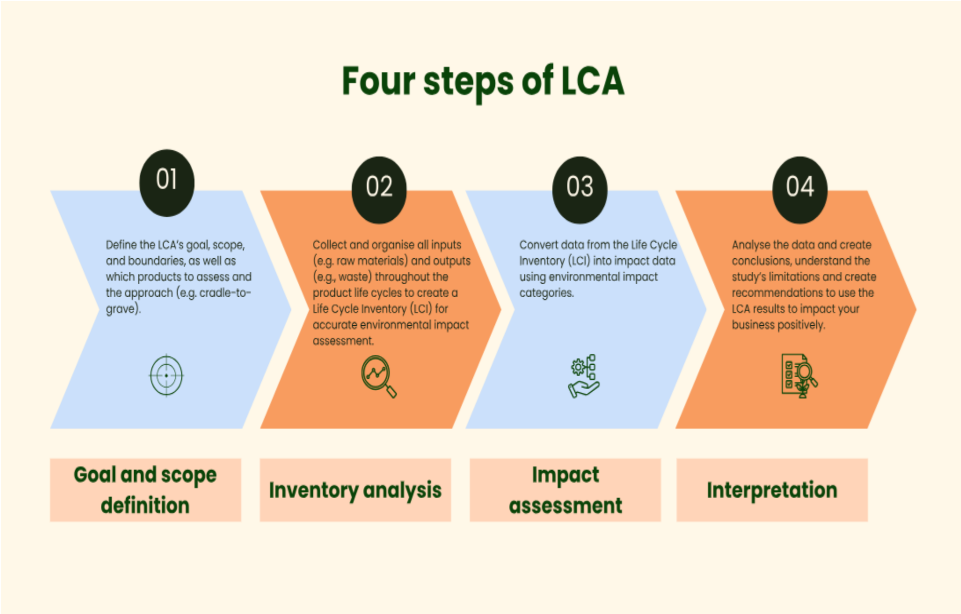

Figure 2.6: Four steps for LCA (Kashcheieva, 2025)

2.6 Background of Libya's Oil and Gas Industry

Since the late 1950s, the oil and gas industry in Libya has come a long way. It was one of the first countries in Africa to utilize its oil and gas resources on a significant scale, when the first export shipment departed in 1961. A huge influx of foreign capital and expertise quickly followed, as production and supporting infrastructure grew at a pace. By the end of the 1960s, Libya had become a major supplier of fuel to Europe, due to its geographic proximity and high-quality crude oil (Hibbs, 2020). Libya rapidly increased its production capability in the 1960s and early 1970s, with vast reserves to extract, suitable geology and proximity to European markets. By the early 1970s, it had become one of Africa's leading oil producers, reaching its highest daily output of more than 3.3 million barrels per day (bpd) in 1970.

The establishment in 1970 of the National Oil Corporation (NOC), a state-owned entity tasked with exploiting and overseeing oil reserves, was a pivotal moment in the history of Libya’s oil industry. By taking the management of oil resources and revenues under state control, the NOC allowed the government to utilize the proceeds from the sector to realize its ambitions and drive social and economic development. Nationalization of the oil industry in Libya, as across the oil-rich Middle East, transformed the relationship between state and resource, increasing both revenues available to governments and vulnerability to external market pressures. Libya’s subsequent economic development was largely underpinned by oil revenue, with the nationalized sector creating new opportunities and exposing the economy to unprecedented risks in accordance with global oil market trends.

Geographical distribution of significant oil fields is an important aspect to understand Libya's oil industry. The Sirte Basin hosts most of Libya's oil reserves and thus is a strategic element of the country's oil production capabilities. Due to political instability in the country, the Basin attracted great attention during the conflict period and even after it. Although national wealth of oil can be a trigger to conflict, it also can boost economy of the country in the long run. The Sirte Basin, in the central part of Libya, is one of the most productive areas for oil and gas search in the country and Africa in general. Most of Libya's oil and gas reserves are found in this basin which plays great role in Libyan economy. The other main basin in Libya is the Ghadames Basin which is in the northwest of the country. Although it has less reserve than the Sirte Basin, it has significant amounts of fossil fuel that are looking to be explored and produced to meet the needs of Libya's energy sector.

Assessment methods for the potential of oil fields are becoming more sophisticated. As a result, our general understanding of the implications for development of oil fields has increased, and new possibilities for sustainable governance in oil and gas producing countries have been created. Thus, there is an urgent need for better governance in

Libya's oil and gas sector. This sector applies remote sensing and geographical information system (GIS) for exploitation of its oil, especially in the remote desert regions. The use of these technologies for the oil and gas operations in Libya makes the economic development and environmental control a priority. This article on the use of remote sensing and GIS for Libya's oil and gas industry aims at demonstrating the importance of this field of research, preserving the natural complexity of the subject, and encouraging further analysis of the future developments in Libya's energy sector related to this issue and its consequences, also National Oil Corporation (NOC) is the state-owned together with its various subsidiary companies:

I. (AGOCO): One of the largest oil producers under NOC.
II. Waha Oil Company (WOC): Involved in oil and gas production and manufacturing.
III. Zueitina Oil Company (ZOC): Another significant producer
IV. Mellitah Oil & Gas B.V.: A joint venture involved in gas and oil.
V. Zawia Oil Refining Company: Handles refining, asphalt, and oil blending.
VI. Brega Petroleum Marketing Company: Manages storage and distribution of oil products.
VII. Ras Lanuf Oil & Gas Processing Company: Focuses on petrochemicals.

Libya is an important international marketer of oil and gas. The country has one of the largest reserves in Africa, is strategically positioned to export to Europe and is deemed to have some of the highest quality light sweet crude oil in the world. The National Oil Corporation (NOC) is responsible for the exploration and production of oil and gas, and for the resulting foreign sales as shown in Figure 2.7. However, the impact of the country's political tensions and instability on oil production and its impact on the global market has limited the country's ability to deliver on its potential as one of the world's key energy suppliers. Developing the country's petroleum infrastructure could aid in maximizing the country's reserves.

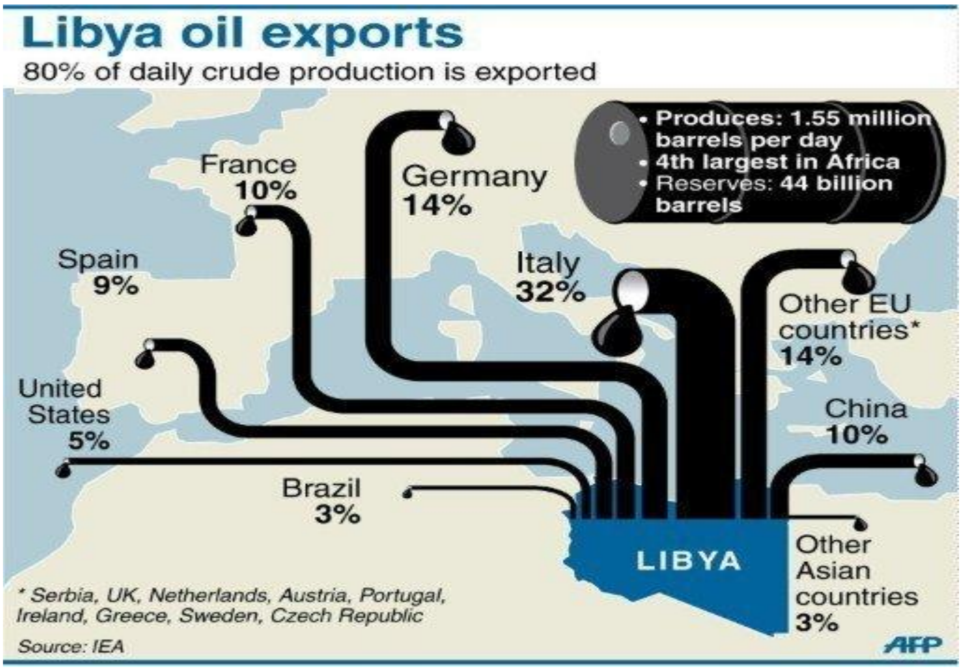

Figure 2.7: The customers of Libyan crude oil (IEA, 2011).

Libya's oil and gas resources are located within several large sedimentary basins as shown in Figure 2.8 some of which have been relatively more successful than others. The Sirte Basin is the most successful basin in eastern Libya, containing most Libya's oil reserves and production to date. The basin contains numerous faults and structural traps within a proven petroleum system, which in conjunction with an established infrastructure, have enabled exploration and production to continue at a pace well above the country's other basins. The Murzuq Basin in southwestern Libya contains substantial resources but those that have been defined are relatively underdeveloped due largely to the remote location of the basin. The Ghadames Basin, located in northwestern Libya on the border with Tunisia and Algeria, is both a significant oil and gas province and a key component of Libya's export earnings. The offshore Tripolitania Basin contains a further large reserve addition to those already defined onshore, although exploration and production costs are typically higher for offshore fields.

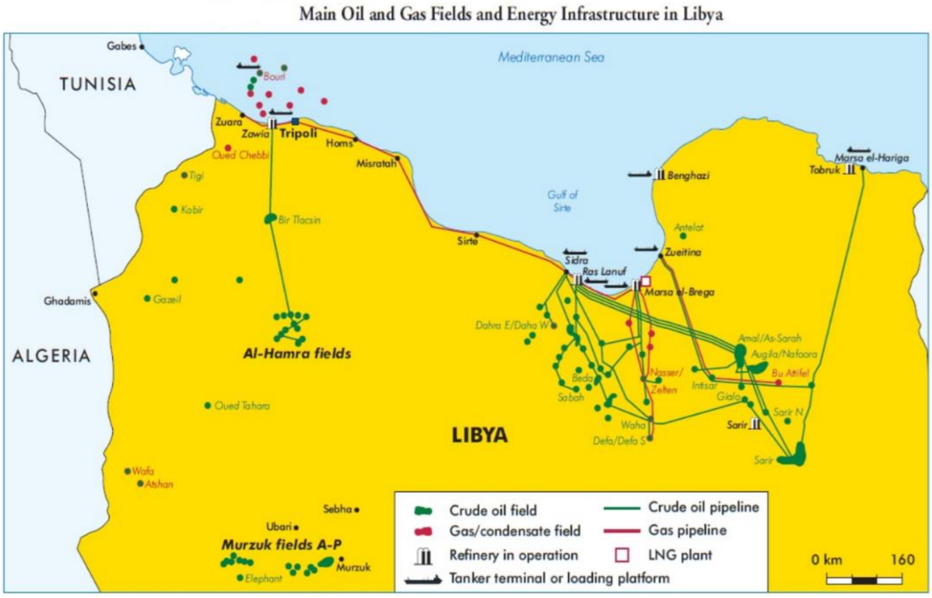

Figure 2.8: Libya Map of oil and Gas Fields and Oil Basins (IEA,2005)

2.6.1 Libyan Oil Production Capacity by Decades

Libya's oil production has undergone significant transformation over the past six decades evolving from a period of rapid industrialization to a state of structural instability. Oil was first discovered in late 1950s and by 1970, production peaked at 3.35 million bpd due to high quality of its sweet crude and its strategic location. Over the following decades, however, Libya experienced a period of decline and stagnation under the Jamahiriya regime from 1977 to 2011 as shown in Table 2.1, nationalization of foreign assets, sanctions imposed by the West and years of lack of investment contributed to a production plateau at about 1.6 million bpd by the early 2000s. The 2011 revolution followed by a civil war brought production levels to an all-time low of 0.007 million bpd in August 2011. By 2025, a fragile balance of power would enable production to return to a 12-year high of 1.37 million bpd. The oil sector remains, however, weak and underdeveloped; a medium-term goal of National Oil Corporation (NOC) is to lift production to 2.0 million bpd by 2028.

Table 2.1: The Decades Production Capacity in Libya

Period	Approximate Production Capacity (million bpd)	Principal Features
1960s	Around 1.0 – 2.0	Rapid field development and export growth
1970s	Up to 3.3	Peak production; nationalization of oil sector
1980s	Around 1.2 – 1.6	Decline due to sanctions and reduced investment
1990s	Around 1.0 – 1.4	Ongoing limitations and deteriorating infrastructure
2000s	Around 1.6 – 1.8	Post-sanction recovery
2010	Around 1.65	Stable production prior to conflict
2011–2020	Between 0.3 – 1.2	Severe fluctuations due to conflict
2021–present	Around 1.1 – 1.3	Partial recovery but unstable

(Source: Waddams, 2023)

2.6.2 Type of Crude Oil and Comparison Between Heavy and Light Crude Oil

The comparison between light and heavy crude oil reveals differences in oil characteristics, production techniques, and their economic and environmental consequences. While light crude oil has lower viscosity and greater API gravity than heavy crude oil, thus facilitating greater ease of extraction and refining, it also exhibits greater flow and therefore requires less energy to drill and extract.

Production methods for oil with different density are different due to their distinct features. Heavy crude oil is extracted by complicated methods with high operational costs such as by using steam injection or thermal recovery (Tirado et al., 2023). Light crude oil, on the other hand, is extracted with less expensive methods. Demand for light crude oil is more current in the market due to high refinery yields and low production costs. Heavy oils, relatively cheap on a per-barrel basis, have lower value in the products that they yield. However, heavy oil processing plants require large investments in upgrading (Ilyin et al., 2016).

Heavy crude oil extraction presents environmental challenges, specially increased greenhouse gas emissions during extraction and upgrading (Tirado et al., 2023). The ecological impacts of spills from heavy crude oil transport and production can be severe due to its high viscosity. Both light and heavy crude oils are vital for the world’s energy supply, and their production requires distinct methodologies that have economic and environmental implications.

2.6.3 Methods type of Extraction Crude Oil

Crude oil is typically extracted either onshore or offshore and then recovered in several different ways. Onshore extraction can be achieved by drilling horizontal wells into oil rich sands. Oil extracted in this manner can be pushed to the surface using either carbon dioxide or water injection or by applying heat. Offshore extraction involves a range of processes. Typically drilling occurs beneath the seabed where oil is then extracted using either primary or secondary traditional or enhanced recovery methods. These methods have extreme variations in performance, environmental impact and profitability.

In land operations for extracting crude oil, drilling is typically conducted using conventional methods that quickly deplete the reservoirs on shore. These methods were historically more cost effective due to the nature of shorter supply chains and less logistical complications in reaching the production site. However, with the depletion of easily accessible reservoirs, more efficient means of oil recovery are required. For the recovery of the heavier crude oils, thermal recovery methods and alternative technologies are employed. Recent studies have indicated that the use of such methods can enhance production from onshore fields, albeit at increased expenditure requiring large amounts of energy (Mokheimer et al., 2019).

Despite the extraction of oil from the reservoir being faster and cheaper than Enhanced Oil Recovery (EOR) methods currently used to extend the life of mature oil fields, the latter technologies have recently become key issues in oil production. Malozyomov et al. (2023). even though EOR processes, including both gas injection and thermal methods, can significantly extend the oil fields’ production life, also increasing the operating cost and environmental impact.

However, the technologies introduced to the offshore oil and gas field for efficient production and improved recovery from existing reservoirs have potential environmental implications and effects on sustainability. While enhanced recovery methods can achieve greater oil recovery efficiencies with improved economic benefits, the choice of technologies for oil extraction with environmental issues and other economic ramifications require serious consideration and study.
(Ochulor et al.,2024).

2.6.4 Political and Logistical Constraints Affecting Data Access

The oil and gas market in Libya faces political and logistical challenges. Ongoing conflict and instable circumstances have made it difficult for organizations to access the relevant data. This lack of information is costing the industry and its customers, as businesses are unable to make informed decisions in the face of uncertainty. Inadequate governance structure in Libya restricts the implementation of International Financial Reporting Standards (IFRS) in oil and gas segment. There is a general lack of data, and insufficient reporting infrastructure in place to provide a complete and accurate picture for strategic planning (Abushrenta, 2022).

The impact of non-enabling institutional environment on corporate practices in Libyan oil industry. Lack of a favorable regulation framework adds to the challenges of data access. Without efficient sustainability reporting mechanisms, businesses do not have the relevant instruments to streamline their activities according to Sustainable Development Goals (SDGs). This has compromised corporate responsibility and the making of informed decisions in a dynamic market
(Gerged and Almontaser, 2021).

Despite the best efforts to collect and analyze data, logistical challenges remain that impede access to vital information. Ongoing conflict has caused considerable damage to key physical infrastructure, exacerbated by broader Political Instability that prevents consistent communication within the oil industry. The ineffective new operational systems developed to manage data are insufficient to support timely decision making within the oil industry. The logistical barriers therefore are a combination of physical damage to oil infrastructure, and political instability (Barltrop, 2019).

The results show that sustainable supply chain management in the upstream oil industry in Libya is challenged. The limited access to data poses a challenge to companies in establishing resilient supply chains. This puts them at a disadvantage of adjusting to uncertain business conditions, causing them to have sub-optimal operational efficiencies. The interaction of political turmoil and logistical problems creates a vicious circle of inefficiency that severely limits the strategic potential of the Libyan oil and gas industry, an essential component of the national economy. The issue of data access is critical in enhancing efficiency in industry and sustainable development (Aljaat, 2025).

2.7 Past Studies about Quantification of Carbon Footprints in Oil and Gas Industry

2.7.1 Carbon Capture and Utilization (CCU) Projects: A Case Study from Russia

Cherepovitsyna et al. (2024) evaluate CCU within the structure of Russian oil and gas sector enterprises. The findings reveal significant potential to decrease atmospheric emissions when CCU is integrated into specific stages of oil and gas business including the upstream and midstream sectors of the NPO. The results show that almost all Carbon Capture and Utilization (CCU) projects are in a pilot stage or demonstrate their application in small-scale experiments and have not been fully implemented within the industry in Russian setting. Moreover, according to the findings, the most promising and cost-effective methods of using captured CO2 in current situation are enhanced oil recovery (EOR) and chemical conversion. The paper only provides insight into one of the world's largest energy markets Russia with its highly specialized energy structure and rules, therefore the findings may have limited relevance in other countries. The paper combines qualitative findings; little light is shed on quantitative assessment of life cycle reduction of atmospheric carbon emissions. Furthermore, the section dealing with economic justification provides only a general overview; there is little in terms of robust techno-economic modeling capable of facilitating high-quality carbon accounting.

2.7.2 Quantification of Carbon Footprint in Petroleum Refinery Process

Jamaludin N.F., Shuhaimi N.A., Mohamed O.Y., Hadipornama M.F., (2023) established process-based methods to estimate greenhouse gas emissions from oil refineries and determines that the largest emissions come from energy intensive processes such as crude distillation, catalytic cracking and hydrogen producing units. Emissions are further characterized in terms of throughput and efficiency, and emissions reductions potential from process optimization and energy recovery technologies are presented.

The Limitations of This study: This study has limitations in how it treats emissions. It uses a relatively simple method to calculate emissions and does not treat indirect emissions (those in Scope 3) for any commodity. The study treats only one type of refinery and thus cannot generalize to other types of refineries. The study does not include a full life cycle assessment (LCA) of the emissions associated with the products from a refinery, and so cannot provide an understanding of emissions at the system level.

2.7.3 Carbon footprint of offshore platform in Indonesia using life cycle approach

Iswara et al. (2022) carried out Life Cycle Assessment (LCA) for carbon emissions of offshore oil and gas platforms in Indonesia. The highest emissions originated from operational phase of which the largest contributor was emissions from fuel consumption for power and flaring. Other significant emissions originated from the upstream activities namely emissions from logistics and material transportation. Therefore, optimized use of energy and reduction of gas flaring in offshore production system were two critical approaches to minimizing emissions in offshore operations.

The limitations highlight some uncertainties related to the emission parameters and assumptions used for the LCA study. The End-of-Life study has some site-specific limitations, and the findings may not be relevant to the decommissioning of offshore installations in different geological or operational circumstances. The study does not include a comprehensive sensitivity analysis for emission factors which can be considered a limitation to the findings of the report.

2.7.4 Diagnosis of GHGs Emissions in an Offshore Oil and Gas Production Facility

Blanco and Gallo (2024) applied comprehensive diagnostic is exposed into the emissions of greenhouse gases from an offshore oil & gas production facility. The main sources of emissions such as gas flaring, diesel usage, venting and power generation are highlighted. The impact of operational problems and ageing facilities is demonstrated. Solutions such as real-time monitoring and efficient use of energy are recommended.

The research has limitations in that it is based on a single facility case study and therefore not necessarily generalizable to other offshore installations. The analysis only considers operational emissions and does not consider all the emissions associated with the complete life cycle of the facility including those associated with the construction, and decommissioning. In addition, the use of short-term data has restricted the ability to investigate changes and trends in emissions over time.

2.7.5 Carbon footprint estimation for oil production: Iraq case study for the utilization of waste gas in generating electricity.

Al-Fehdly, H., ElMaraghy, W. and Wilkinson, S., (2019) Associated gas in oil production operations is often regarded as waste and continuously is burned off i.e. flared. This paper reveals the potential of associated gas as an energy resource to be consumed instead of being wasted. Using estimates of the carbon footprint of crude oil production in Iraq the paper details how moving from burning associated gas as flare to utilizing it to generate electricity could reduce energy inefficiency and produce major environmental benefits. Additionally, this alternative approach to conventional fossil fuel generation for electricity might reduce greenhouse gas emissions by up to 50 million tons of CO_2 per annum at current oil production rates.

However, this analysis has relied on simplified methods of estimation and has made several assumptions that, though considered appropriate, may not be fully accurate in real life oil field situations. Consequently, the analysis lacks considerable accuracy and is not generally applicable.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 The Background of Al-Sharara oil

Libya relies heavily on its crude oil production and export. This constitutes a significant portion of the gross domestic product (GDP) of the country, and it earns nearly 95 percent of the export earnings. The oil deposits in the country are substantial, and the country is among the largest oil producers in Africa. This predisposes it to be a significant participant in the world oil market. Crude oil business not only generates numerous employments, but it is also the energy industry of Libya. It addresses the energy needs of the country and simplifies the investment of people in infrastructure and governmental services. The fluctuation of prices and political circumstances that influence oil markets demonstrate the significance of learning the entire life cycle of crude oil, its extraction, and delivery to the market.

Al-Sharara oil field is in the Marzuq Basin in southwest Libya. It is one of Libya's biggest oil and gas production locations. As shown in Figure 3.1, the field is in the Sahara Desert, about 700 kilometers south of Tripoli. It has a lot of gas and oil separation plants (GOSP) and places to collect oil and gas. Some of the gas is used to make electricity, which powers the field, and the rest is flared off. The Sharara oil field can produce more than 300,000 barrels of light crude oil a day. This is more than a quarter of Libya's entire crude output. The El Sharara field sends crude oil to the Mediterranean through an export pipeline that is 723 kilometers long and 30 inches in diameter. The El Sharara Oil Field is Libya's biggest oil field as of 2020.

Figure 3.1: A Vertical Image Showing Sharara Oil Field in Ubari Region
(www.middleeasteye.net/news/libyas-largest-oil-field-attacked-armed-group)

The Al Sharara oil field comprises oil reserves in blocks, NC115 and NC186. The initial discovery in block NC115 was made by Rompetrol in 1984 and the field began to pump in 1996. Over 8,700 square kilometers are covered by the NC115 and NC186 blocks. (Africa's best report on the oil, gas, and energy scene, 2024). The geographic area of the research is the Al-Sharara field in the Murzuq Basina as shown in Figure 3.2. Includes well pads, processing facility, flare stacks, power generation facilities and other support structures within the field boundary.

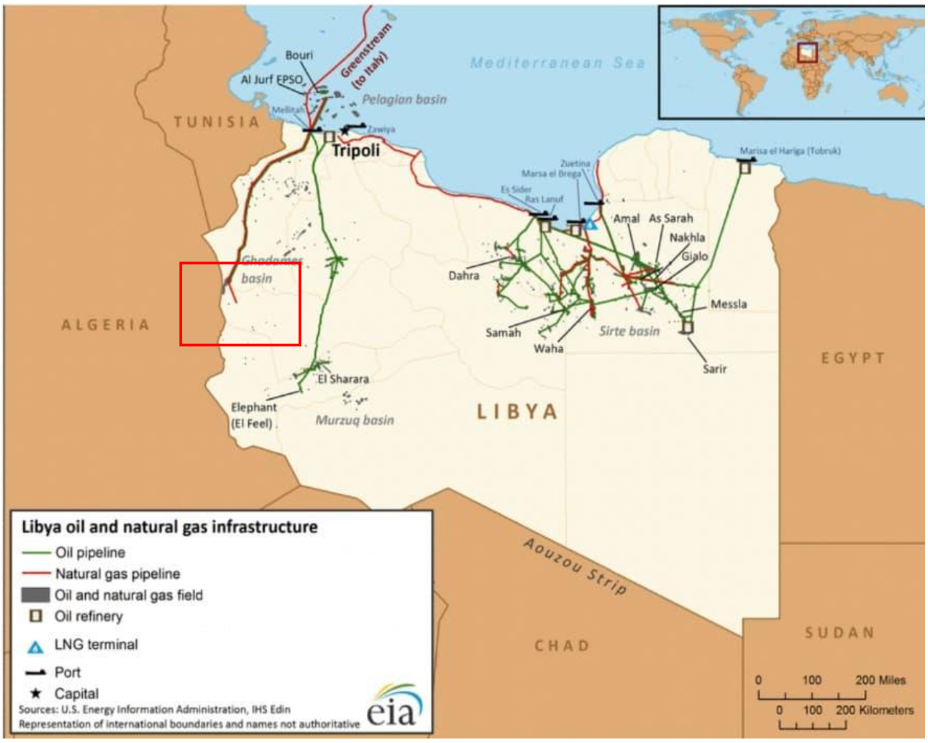

Figure 3.2: The location of Sharara field in Libya / (EIA, 2015)

Libya boasts the largest proven crude oil reserves in Africa, standing at more than 48.4 billion barrels as of 2024. This is what makes Libya a very significant participant of the global energy markets (OPEC, 2025; U.S. Energy Information Administration, 2024). The field is estimated to have about 3 billion barrels of high-quality light sweet crude (Repsol, 2024; Oil & Gas Middle East, 2024). Sharara is a joint venture between the Libyan National Oil Corporation (NOC) and an international consortium of partners, consisting of Repsol, TotalEnergies, OMV and Equinor. Its capacity is about 300,000 barrels per day (bpd) but the output has fluctuated over the years because of sociopolitical instabilities (Akakus Oil Operations, 2025; The National, 2025).

The estimated Sharara Oil Field reserves and the production lifespan (static) can be analyzed using a ratio of reserves to production (R/P) which indicates that the field will have a life of approximately 27 years when produced at full capacity. But the field is predicted to be fruitful, well beyond this. This extension can be attributed to the ongoing process of developmental drilling, including the initiation of the H-50 well at the end of 2024, and the application of improved oil recovery (EOR) techniques that should reduce the natural decline rates (Libya Herald, 2025).

3.2 The Study Approach

For crude oil, the evaluation of the life cycle stages of production includes the extraction of the resource and the transportation to the refinery gates or to the export terminals. The extraction of crude oil is the first stage of the production process, which is vital to the cradle-to-gate assessment. This stage is identified to contain resource extraction, drilling activities, use of heavy machinery, land erosion and environmental disturbance. The techniques used in the different extraction methods could also produce higher levels of greenhouse gases emission; hence, an in-depth analysis is important for companies that are moving towards sustainability. Karka et al. (2017).

The complex dynamics involved in the Libyan crude oil production can be analyzed by employing a “cradle to gate” approach incorporating numerous visuals and describing the economic and environmental behavior that leads to the production of energy-intensive processes. Such approach offers a new perspective to production processes directed towards meeting both economic objectives and environmental issues. The cradle to gate life cycle of the Libyan crude oil consists of several processes where each one of them includes various operational procedures, technological packages, and numerous logistics and operational problems encountered while moving the extracted crude oil to turn it into a saleable product that can be offloaded to refineries at the "gate". These processes will be highlighted throughout this paper.

A Figure 3.3 shows the main steps in the life of Libyan crude oil is necessary to help comprehend the cradle-to-gate life cycle. It shows how each step in the process is connected and makes the complicated process of making crude oil easier to understand. The graphics show important phases including exploration, drilling, extraction, transportation, storage, and refining of crude oil. This will help readers easily understand the order of activities and how each one fits into the entire life cycle. Every phase shows not just how well the process works, but also the most important places where environmental repercussions are most obvious.

Assessing the factors that influence petroleum output using a cradle-to-gate life cycle approach with the aid of visual tools and flowchart diagrams, to critically assess all processes involved in Libyan crude oil production. The study also sheds light on economic factors and environmental issues associated with such energy intensive processes. In addition, the study aims to illustrate the manufacturing process of turning crude oil into commercial products before it reaches the refinery gate, from the cradle to the gate. Various processes, technologies and logistical problems are involved in the oil manufacturing processes at different stages of the life cycle. All these processes are explained in detail.

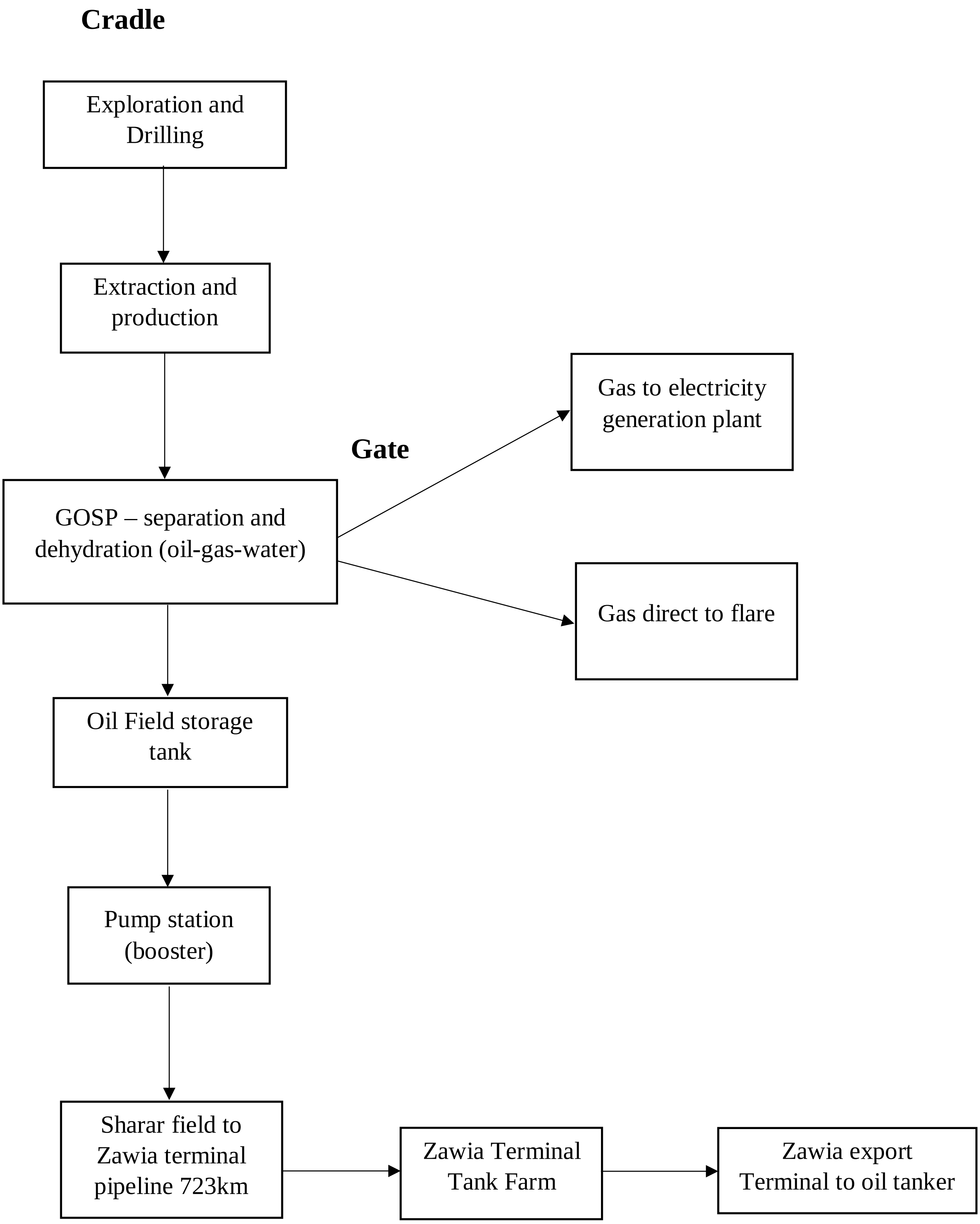

Figure 3.3: Cradle to Gate for Crude Oil in Al Sharara field

3.3 Data Collection

accurate daily and annual production data for significant fields is crucial to both field operators and government agencies in countries such as Libya. To monitor the gathering of crude oil and natural gas production data, flow meters and automated measurement systems can be installed at well heads and production facilities to record oil production. Real time data can be transmitted back to central control rooms, enabling field operators to monitor volumes of oil and liquids produced daily in barrels per day (b/d), as well as identifying trends and issues to enable prompt action to be taken.

Although no daily data is available on Sharara production for natural gas, information on the natural gas associated to the oil production in Libya is available and the majority of it is found in locations where oil and gas are produced from interconnected reservoirs, either fully or partially, whether in subsea or onshore fields, with the bulk of the country's onshore natural gas coming from the Sirte Basin, specifically from onshore areas. However, this information is not included in public field-level data publications.

Data provided by Libya's National Oil Corporation (NOC) indicates that associated gas is one of the components of the 394 billion cubic feet of natural gas it claims the country has been producing in 2023. However, the lack of sufficient infrastructure to handle and process gas associated has seen gas normally be burned off or 'flared' rather than sold commercially. This is different to what is included in daily associated gas production statistics reported for the Sharara field, for example.

3.3.1 The Process of Data Collection

Monitoring daily and annual data for production from major oilfields is a common practice by the field operators, national oil companies, ministries of petroleum and other parties concerned. For instance, Sharara Oil Field for which daily production figures are monitored and reported by operators and national authorities is one of the main oilfields in Libya for which yearly production data are tracked for analytical and planning purposes.

The Sharara Oil Field, which is operated by Akakus Oil Operations together with other foreign operating companies as consortium, has reported production rates which rose to some 300,000 barrels per day in 2025. To arrive at production rates and related information for daily, monthly, quarterly, yearly and five yearly reporting by the field operator to the NOC and other government institutions, production data from the Sharara Oil Field are collected from the real-time measurements obtained from numerous monitoring systems that monitor production rates of each well drilled at the oil field including oil transfer rates from wells and production facilities. Field data are analyzed and ensured for accuracy to update reports which are then communicated via government and private reporting systems for management of production of crude oil for export from Libya.

Annual production is documented and summarized in monitoring reports, used for business planning and other economic measures by National Oil Corporation as the state-owned oil company in charge of oil activities. Production statistics also cover all government licenses and operations monitored by the NOC for official national reporting with international organizations including OPEC for economic and operational planning among member countries.

The importance of tracking and accounting for production and revenue generation for petroleum operators cannot be overemphasized in the business that is crude oil. Reporting oilfield production rates requires ongoing real-time data collection from monitoring of real time data sourced from field level specifically, from various methods and data which are derived from tests on well production and integration of flow and pressure information, along with real time field sensor data.

Industry standard methodologies used by professional petroleum operators in oilfields across the globe rely heavily on the accurate measurement and verification of well-educated oil production which serves as a basic unit of tracking production therefore shaping daily business decisions made by operational managers and served as the analytical backbone for year-end reporting by exploration and production companies globally.

3.3.2 Equipment and machinery emissions

Libya's greenhouse gas (GHG) emissions are mainly derived from the energy sector, accounting for more than 90% of emissions stemming from people vehicles and also as CO_2 and CH_4 fugitive emissions, in addition to the direct emissions emanating from heavy industrial machinery used in the operation of gas turbines, diesel generators, huge oil refining equipment and flaring systems used in the extraction and production processes of oil and gas fields. GHG emissions from the oil and gas sector in Libya derive from energy used by the sector in the operations of Gas and Oil Separation Plants (GOSPs), water injection pumps, gas treatment units and gas compressor units used to maintain pressure in the field to lift and process crude oil. Based on the machinery profile used in the Sharara field, the biggest oil field in Libya operated by Akakus Oil Operations, four A barrels per day are processed with four A flare stacks and crude oil amounting to 5,000 to 6,000 barrels per day is burned in local power generation plants, including the Ubari plant.

However, emissions are decreasing following the installation of several Vapor Recovery Units (VRUs) to capture low-pressure gas emanating from storage tanks destined for flaring, with the main aim of recovering condensate and reducing carbon emissions.

3.3.3 Flaring and venting

Flaring and venting have become essential operational parameters to assess the Sharara field's environmental carbon footprint. In concessions NC-115 and NC-186, associated petroleum gas (APG) management presents a significant challenge in the lift process. Gas that is not exported through the pipelines nor injected into the subsurface is typically burned on high-pressure (HP) and low-pressure (LP) flare headers to prevent potential risks throughout the processing chain. Two 30-meter-high flare stacks, supported by reinforced flare structures, are categorized into primary and auxiliary, respectively. Each flare header has a main Knock-Out (K.O.) drum that removes the liquid fraction of the gas prior to fire, employing this mechanism to prevent the occurrence of burning oil droplets.

Recent efforts by the National Oil Corporation's (NOC), however, discrete instances of flaring do still occur, for example, when problems arise with gas compressor units, in which gas is redirected back diverted to the flare headers (Argus Media, 2024). Conversely, site venting discharges unburned methane directly into the atmosphere via pressure relief valves (PRVs), atmospheric vents on crude oil storage tanks, and through dysfunctional or nonfunctional Vapor Recovery Units (VRUs). Most tank vents are equipped with carbon Bed Filters, whereas the majority of producing crude storage tanks are equipped with VRUs, the functionality of which is often restricted (Al-Sharif, 2024; Nassar and Salem, 2023).

The onshore field produces about 21 to 25 million cubic feet of associated gas per day. The daily associated gas utilized for power generation is about 6 to 7 million standard cubic feet per day that generates about 30-to-35-megawatt electrical power for the field. However, the majority associated gas, about 15 to 19 million standard cubic feet per day, is being constantly burned or flared. In long run, it would cause significant environmental and health impacts particularly in a densely populated area of the field. Hence, it is desirable to stop gas flaring from the field and utilize the gas for production of petrochemical products or to generate energy for urban and rural areas surrounding the field and it would also be economically beneficial. (Biheri et al., 2022)

3.3.4 Water usage

Oil and gas extraction processes make high water consumption, both in the form of produced water, which naturally occurs in geological reservoirs and is produced when producing hydrocarbons and in injection water that maintain reservoir pressure, normally through reinjection techniques to enhance recovery rates. The Sharara field relies on water use in the production cycle, which is mainly used to achieve secondary recovery to maintain the pressure in the reservoir and enhance the rate at which crude oil is extracted. The Akakus Oil Operations (AOO) manages a well-developed water injection system which is designed to inject large quantities of water into the reservoir by using high-capacity multi-stage centrifugal submersible pumps. Recent drilling of new injection wells has improved this process, which is needed to maintain the output of the field of about 300,000 barrels per day (Libya Monitor, 2024; NS Energy, 2020).

The field infrastructure includes special water treatment facilities that are combined with Gas and Oil Separation Plants (GOSPs). In such plants, the crude oil stream is separated by the produced water that is a by-product with high salinity and heavy metals (Al-Haleem and Al-

Razaq, 2012). To decrease environmental pollution and increase resource utilization, produced water is usually treated to get rid of dispersed hydrocarbons before reinjection into the formation, performing both the functions of eliminating waste and maintaining pressure (AlQalam Journal, 2025; Veolia, 2023).

3.3.5 Chemical input

El Sharara oil field in Libya is using a variety of chemicals in drilling and production operations for ensuring flow assurance, well and surface facility integrity and product quality. In the drilling and completion processes, Akakus Oil Operations (AOO) uses certain weighting agents (barite, and calcium carbonate) and rheology agents (bentonite, etc.) in addition to fluid loss chemicals (Polyanionic Cellulose (PAC) and Carboxymethyl Cellulose (CMC)) to maintain borehole stability.

The refined products contain a variety of chemical additives. For example, diesel fuel contains demulsifies such as alkylphenol ethoxylates, UN 1160. These additives assist in the separation of water from the diesel fuel at the refining stage. The other refined products, unleaded gasoline, jet fuel and natural gas liquids, are colorless and odorless. Naphtha is a solution of petrochemicals that are used as a feedstock and as a product. The chemical additives present in unleaded gasoline include demulsifies, UN 1203, which are like those in diesel fuel. The production of motor fuel from the Sour Sharara crude contains additional chemical additives required to reduce the high viscosity of the feedstock. Drag reducing agents (DRAs) are used to decrease the viscosity of the waxy crude to smoother the flow in export pipelines. The DRA additives include polydimethylsiloxane, UN 2672 and Polystyrene, UN 2661. Corrosion and scale inhibitors as well as biocides are also present. The corrosion inhibitors protect the pipelines, tanks and other related equipment from corrosive agents and acidic environment and contain imidazolines. The scale inhibitors prevent the deposit of scales that may block flow lines. Biocides such as glutaraldehyde and UN 2821 are used to prevent Microbial Induced Corrosion (MIC) in water reinjection networks.

3.3.6 Transportation distances and modes

El Sharara oil field in Libya is utilizing several different chemicals in its drilling and production operations for the purposes of ensuring flow assurance, well and production facility integrity and product quality.
Akakus Oil Operations (AOO) is used in drilling and completion projects with weighting agents as barite and calcium carbonate, rheology agents as bentonite and others chemical agents. Also uses fluid loss agents as Polyanionic Cellulose (PAC) and Carboxymethyl Cellulose (CMC) to maintain the stability of the well bore.

The refined products that are delivered to storage facilities at the Jebel Ali port in addition to containing their usual chemical additives also contain trace amounts of demulsifies which are needed for their separation at the refining stage. These products also include unleaded gasoline, jet fuel and natural gas liquids which are colorless and odorless at delivery. Naphtha which is supplied contains petrochemicals feedstock as well as products. The chemical additives in unleaded gasoline are the same demulsifies UN 1203 like those found in diesel fuel. In addition to the ordinary chemical additives used to produce motor fuel from the Sour Sharara crude, there are additives required to reduce the high viscosity of the feedstock due to the waxy nature of the crude.

The Drag reducing agents (DRAs) are used to smoother the flow in export pipelines including polydimethylsiloxane UN 2672 and Polystyrene UN 2661. Furthermore, there are corrosion and scale inhibitors and biocides which protect pipelines, tanks and other related equipment from the corrosive agents and the acidic environment found therein. The corrosion inhibitors include imidazolines and similar chemicals. The scale inhibitors prevent the deposit of scales in flow lines that may cause blockages thereof. Biocides including glutaraldehyde UN 2821 are used to prevent Microbial Induced Corrosion (MIC) in the water reinjection network.

3.4 Tools for footprint calculating

Measuring and accounting for carbon emissions (carbon accounting) and the greenhouse gas emissions generated by activities, products and organizations (carbon foot printing) have become increasingly important in recent years as concerns around climate change have grown. As a result, many methods and tools have been created and are being used to measure and report the carbon emissions created by organizations. There are many approaches that can be used to carbon account and each have different advantages and disadvantages for both tracking emissions and designing and monitoring sustainability initiatives.

There are many different tools that can be used to calculate the carbon footprint of oil and gas operations. These can range from complex software packages all the way to simple tools like spreadsheets. Also, the Microsoft Excel software can be used for calculating carbon emissions because it is easily accessible, easily modifiable, and sufficient for initial screening and reporting on carbon emissions in the industry. The calculations were performed using emission factors from established databases, such as those found in the Intergovernmental Panel on Climate

Change (IPCC) guidelines (IPCC, 2019) and applied to a variety of activities such as fuel consumption, electricity use, and transportation. Excel provides a platform for calculating direct and indirect greenhouse gas emissions in terms of CO_2 equivalents (CO_2e) based on activity data. It is preferred by industrial practitioners because it allows them to manually verify calculations, change equations to better account for site-specific factors such as the heating values of the fields, and incorporate data from geographically disparate sources such as a remote wellhead and an inline water injection station. Industry groups, such as IPIECA, also provide manual Excel-based reporting templates that ensure compliance with international guidelines for Scope 1, 2, and 3 reporting. Most importantly, calculations performed using Excel can be thoroughly understood by environmental professionals, which is not necessarily the case with black box software.

3.4.1 List of Emission Sources

Emissions from the Sharara oil field come mainly from the burning of associated gas, fuel for power generation and occasional fugitive emissions from processing facilities. Irhoma et al. (2018) identified the major air pollutants emitted by Libyan upstream oil and gas operations, such as Sharara, to be the continuous flaring of associated petroleum gas. The lack of adequate facilities to process, use or dispose of associated gas means that large quantities of greenhouse gas (notably CO2) and short-lived climate pollutants (notably CH4) and particulate (soot) are emitted, as shown in Table 3.1, In addition, there are a lot of fugitive emissions of volatile organic compounds (VOCs) from inadvertent leaks from valves, flanges and storage tanks across the large transmission methanol storage network.

Table 3.1: Category of Emission Sources in Sharara Oil Field

Category	Emission source
Flaring	Associated gas flared
Fuel Combustion	Diesel for engines, generators and rigs
Turbine	Gas turbine for electricity from associated gas
Transportation & Aviation	Jet & gasoline fuel consumed by cars and airplane to joining field
Others	Venting, fugitive and heavy fuel for oil tankers to transfer oil overseas

3.4.2 Estimation of Fuel consumption for transportation and duty logistical support

The surface fleet at the Akakus Oil Operations is split between light-duty transport, used for site inspections and security patrols between wellheads and production facilities, and heavy-duty logistics, responsible for moving water supplies and drilling muds around the site. With a production capability of over 300,000 barrels per day, the operations cover a large area, which requires a strong internal transit logistics capability. According to employees at the Sharara field, the light-duty fleet comprises a fleet of some 150 four-wheel drive vehicles, mainly Toyota Land Cruisers. 'They are all 4x4 vehicles, designed for off-road driving,' an employee explained. This means that on-road fuel economy is not a priority, with a typical four-wheel drive vehicle achieving just 5 kilometers per liter on petrol, equivalent to 20 L/100 km. On the Sharara site, each vehicle will typically travel 100 km per day for site inspections and security patrols. This gives the fleet a potential monthly consumption of 90,000 to 120,000 gallons of diesel. The heavy-duty part of the fleet is made up of around 20 to 25 water tank trucks, typically provided by MAN or Iveco's Trakker heavy truck platform. These are used for drilling operations, to move mud around the site, and to bring water supplies to parts of the site that are too remote for connection to the central water supply. Water tank trucks have high rolling resistance in sandy conditions and so achieve a poor fuel economy on diesel. Typically, heavy-duty vehicle fuel economy is measured in terms of kilometers per liter, with 50–65 L/100 km a more typical figure for the conditions at Sharara. This gives the fleet a potential monthly consumption of 64,000 to 96,000 liters of diesel, with each truck averaging around 80km per day.

The actual fuel consumption varies with several factors such as seasonal variations and idling times etc. Environmental Factors, the climate of Libya, causes big changes in temperature from season to season and from day to day. This causes big changes in the performance of the engines and their fuel consumption. In summer there are high ambient temperatures and in winter there are low ambient temperatures. also, Operational Factor such as Idle Time at Wellheads, Excessive Fuel Consumption: Heavy-duty diesel equipment, Operational Practices. The amount of time heavy machinery or vehicles must wait at wellheads, checkpoints, or maintenance sites. Most people are aware that incomplete Combustion and Engine Wear are issues caused by idling engines. However, most people don’t realize that idling for extended periods can exacerbate these problems, especially at low speeds.

The aviation company associated with the Akakus Oil Operations, which chartered these flights for the employees working on the Sharara oil field, is Petro Air Company, which is a Libyan aviation service company which provides air transport services using a fleet of regional jets, including medium size jets of the type Embraer E-170 series, which seats 70 to 80 passengers plus two flight attendants. Petro Air operates flights from Tripoli and Benghazi cities to the Sharara field using the smaller airstrips, where props are needed for landing. The distance to be flown on the medium size route from Tripoli to Sharara is approximately 700 to 730 kilometers or 380 to 395 nautical miles and 1600 Km from Benghazi to field. Typical fuel consumption for an Embraer E-170 would be 2.6 kg per kilometer for medium size routes, which would be approximately 1,820 to 1,900 liters one way for the flight from Tripoli and 4160 kg of jet fuel to the Sharara field.

This is just an estimate and varies significantly, especially for example, depending on the load factor and various weather and air traffic related factors which may change the routing of the flight. The estimate is based on typical fuel efficiency for regional jets with an average fuel density of 0.8 kg per liter.

There are established emission factors for fuel consumption in the literature, as recommended by the Intergovernmental Panel on Climate Change (IPCC, 2006) for different types of fuel, including gasoline and diesel fuel. In addition to fuel consumption, the environmental impacts of vehicle use can be assessed using a host of other emission factors. For example, the fuel consumption of light four-wheel drive vehicles in harsh desert operating conditions, such as found in the Sharara Oil Field in Libya, can range from 15–25 liters per 100 km for both diesel and gasoline fuel. Heavier four-wheel drive trucks, such as water tankers or supply trucks, may consume 40–60 liters per 100 km, with consumption strongly influenced by load and terrain resistance. Other factors that influence fuel consumption include the vehicle mass, slope gradient, average speed and tires.

3.4.3 Estimation of methane fugitive and storage tanks leaks

Cownden et al (2023) report that fugitive leaks and venting emissions represent a substantial fraction of the overall methane emissions from the oil production processes occurring in upstream operations, particularly equipment leaks, valve events and tank vents, particularly storage tank venting (stoichiometric) in the absence of vapor recovery devices

(Rutherford et al, 2021b). Rutherford et al (2021b) reported that tank venting emissions at onshore crude oil facilities were in the range 0.005 to 0.02 scf/bbl. Thus, for tank venting methane of about 1,500 to 6,000 scf CH_4/day storage tanks according to an average daily production of crude oil 300,000 bbl/d. To estimate emission by CH_4/M^3 according to IPCC, meter cubic feet are equal to 0.283168 M^3. This would mean total daily emissions from fugitive leaks and gross leaks for the onshore producing facilities at Sharara of around 425 to 1700 M^3 CH_4/day, as discussed above, assuming a wide range of GORs, onshore infrastructures in good or fair condition and with a range of appropriate mitigation measures having been implemented (Methane emissions from the U.S. petroleum industry, 1996; Stanford et al, 2024).

3.4.4 Impact Analysis and Total Carbon Equivalent Emission in Different Scenario in Terms of kg CO_2e per Barrel of Oil.

Worldwide onshore land oil drilling operations commonly utilize diesel powered rigs for exploration and drilling. Based on rig size and operational nature (i.e. static production support or dynamic drilling) typically a single rig would use between 20 and 45 m^3 of diesel per day. Heavy- duty onshore drilling rigs are deployed to maintain production at approximately 300,000 barrels per day across the Sharara oilfield. The onshore land rigs at Sharara utilize a combination of 1,000 HP and 2,000 HP to complete drilling operations. This would suggest that Sharara utilizes units of a similar nature to those previously commonly hired by companies such as KCA Deutag, famously deploying heavy-duty drilling units of 2,000 HP or higher, comparable to the T-72 class (nsenergybusiness.com). In operation, the power to date there are no public records that have specified the daily consumption of the drilling units at the Sharara oilfield. Sharara's land drilling units create their own power by way of large diesel engine generator sets deployed on-site, likely units of Caterpillar's 3512 type or similar. Data has been compiled in relation to Sharara's historical operational consumption of diesel for drilling purposes. This data typically shows fluctuation largely based on various drilling dynamics. Specifically, the daily drill string consumption is affected by both Rotary Speed (RPM) and Weight on Bit (WOB).

The filed has 6 rigs that are used to dig new wells and keep 70 wells that are not in use. Before that date, drilling was stopped for many reasons. Each rig has a power class of 2,000 HP and is used for active drilling, which uses about 8,000 to 10,000 liters of diesel fuel per day. This includes rigs engine, mud pumps, and Drow works, as well as electricity for the rig camp, which uses two diesel engines that use about 400 to 800 liters of diesel fuel per day. These oil rigs are also accompanied by trucks, including two water tank trucks, two trucks for transporting well pipes and equipment, a bulldozer, and a forklift. According to Sharara staff, these machines use 2,000 to 2,500 liters of diesel fuel per week.

According to that, the monthly consumption for 1 rig with associated generators and heavy machinery is about 172,000 to 266,000 liters of diesel per month, for 6 rigs is about 1,032,000 to 1,596,000 monthly diesel liters. And to take note that the monthly consumption is considered as 20 days, because the rigs work 24 hours once they have finished their duty, the activity stops. The greenhouse gas emissions from exploration and drilling fall under scope 3 because the rigs belong to a third party, some of them are national and international contractors that work with Akakus company.

Total consumption of diesel in exploration and drilling in Sharara field about 1,032,000 to 1,596,000 per month, and emission factor for diesel fuel according to IPCC 2006 is 2.68 kg CO2e/L.

Total 1,032,000 to 1,596,000 × 2.68 = 2,765,760 to 4,277,280 CO_2e/month.

Convert to kg CO_2e per barrel of oil, divide by daily production, since this consumption represent amount of month so divided by 20 days.
Total 2,765,760 to 4,277,280 / 6.000,000 = 0.46 to 0.71 CO_2e / barrel.

The carbon footprint associated with the carbon-free emissions of the Sharara field, which is currently producing around 300,000 barrels per day (bbl/d), lies primarily in tackling the associated gas and in reducing stationary combustion emissions. This analysis further refines the Scope 1 (Direct Emissions) categories, revealing that the primary contribution to the carbon intensity of drilling operations comes from the burning of associated gas (Biheri et al., 2022). The total amount of associated gas produced during drilling averaged 21 to 25 MMSCFD, which compares to emissions from direct flaring of 15 to 17 MSCFD and emissions from burning gas in drilling turbines of 6 to 7 MSCFD.

Fugitive emissions of methane, with its high Global Warming Potential (GWP), are estimated to be in the order of 1425 to 1700 M^3 per day. This emission can result from a variety of factors including environmental degradation, structural damage, failure of equipment, operational failure and flue gas emissions from storage tanks. The use of mobile combustion to support operations requires approximately 46,000 liters of diesel fuel per month across a fleet of 150 vehicles. These vehicles comprise a mixture of 50 production department 4WDs, as well as 70 4WDs distributed amongst the maintenance, safety and health, Corrosion, drilling and exploration and IT support functions, as well as 30 vehicles for use by heads of departments, coordinators and supervisors.

3.5 Quantification of Greenhouse GHGs Gas Emissions Using Global Warming Potential (GWP)

Global warming now is one of the world problems. Oil and Gas industry has significant contribution to global warming by releasing greenhouse gases. Greenhouse gases have Global Warming Potential (GWP) that represent the contribution to Global Warming in comparison with carbon dioxide (CO2).

Global warming potential (GWP) is a way to compare the contributions of different greenhouse gases (GHGs) to global warming over time, typically expressed over a 100-year time frame (GWP_{100}). This allows users to express atmospheric emissions of different GHGs in terms of an equivalent amount of carbon dioxide emissions. Use of Global Warming Potential (GWP) factors allows this comparison, expressing the radiative forcing that would result from a given mass of a particular GHG relative to carbon dioxide over a particular time frame, typically 100 years (GWP100).

Here is a description of how to convert different greenhouse gases into carbon dioxide equivalents. All gases are expressed relative to carbon dioxide which is given a Global Warming Potential (GWP) of 1 over any time. Other gases such as methane (CH_4) and nitrous oxide (N_2O) have larger effects on the radiative forcing caused by carbon dioxide, and their GWPs typically exceed 1 for most time periods. Such as, emissions of methane from landfills and rice paddies might receive a lower GWP than those from the oil and gas industry. To quantify the global warming potential of different emissions, the amounts of all monitored greenhouse gases must first be converted to a common unit, the equivalent mass of carbon dioxide (CO_2e). All emissions from production through to use in the oil and gas industry (including burning, flaring and venting as well as fugitive emissions) are reported in this unit. The equation is:

$$CO_2e = \sum_i (m_i \times GWP_i) \qquad \textbf{\textit{(3.1)}}$$

Where

m_i is the mass of gas emitted kg, tons

GWP_i is a global warming potential to CO_2, kg $CO2_e$ / kg gas.

This equation can then be used to calculate the climate impact of the amount of each gas that the facility is emitting. For example, an oil and gas facility emitting 10 tons of methane can be multiplied by the GWP of methane (currently reported as 28) to give 280 tons of CO2e. By applying this simple formula those working in the industry will for the first time get a realistic view of their true climate impacts.

In addition to providing opportunities for production reduction and utilization, renewable natural gas (RNG) could also reduce the global warming potential (GWP) of greenhouse gases emissions from oil and gas operations. Rai et al. (2022) discuss different methods to produce RNG and their potential to lower GWP. However, they find that even with the use of RNG, a significant reduction in the fossil carbon footprint and overall warming potential can be achieved by shifting to renewable sources of energy.

For describing how to convert different greenhouse gases into carbon dioxide equivalents. All gases are expressed relative to carbon dioxide which is given a Global Warming Potential (GWP) of 1 over any period. Other gases such as methane (CH_4) and nitrous oxide (N_2O) have larger effects on the radiative forcing caused by carbon dioxide, and their GWPs typically exceed 1 for most time periods. GWPs for methane and N_2O typically are close to 28 and 273 respectively as shown in table 3.2 for a 100-year time, but values vary depending on the source used. To quantify the global warming potential of different emissions, the amounts of all monitored greenhouse gases must first be converted to a common unit: the equivalent mass of carbon dioxide (CO_2e). All emissions from production through to use in the oil and gas industry (including burning, flaring and venting as well as fugitive emissions) are reported in this unit.

Table 3.2: The 100-year GWP values for major GHGs, (GHG Protocol's summary of AR6 data).

Greenhouse Gas (GHG)	Chemical Formula	100-Year GWP (AR6 values)
Carbon Dioxide	CO_2	1
Methane	CH_4	28-30
Nitrous Oxide	N_2O	273
Sulphur Hexafluoride	SF_6	25,200
Tetrafluoromethane (PFC-14)	CF_4	6,630
Hexafluoroethane (PFC-116)	C_2F_6	11,100

CHAPTER 4

RESULT AND DISCUSSION

4.1 The Carbon Footprint According to the 3 Scopes of Carbon Emissions (CO_2eq)

The carbon footprint of the Sharara oil field, Libya's largest oil field and the country's greatest oil producer, has become a recent topic of discussion. According to pass studies, the Scope 1 carbon footprint of the Sharara oil field is primarily composed of the direct carbon emissions that originate from the field operations. These emissions include gases that are continuously being either flared or vented into the atmosphere from various locations across the oil field, in addition to vast quantities of carbon emissions that emanate from the heavy use of fuel for energy purposes in the form of power generation to run the fluid handling facilities across the field. The Scope 2 carbon emissions are, however, marginal since majority of the facilities are in remote areas and not connected to the national grid. Sharara's overall carbon footprint is therefore more than just the emissions from the operations of the field. Indeed, exploration and drilling activities fall into Scope 3 due to these activities under third party contractors with Akakus company, the overall carbon emissions that originate from Sharara are largely dependent on the carbon emissions that are generated at gas flaring.

The Table below 4.1 details the carbon-intensive activities at 3 scopes of work at the Sharara field. Associated with gas flaring (450-750 MMSCF per barrel) and gas turbine power generation (11 MW) and fuel for transport (trucks) and air travel (approximately 3 round-trip flights per month) are quantified for 9 million barrels of crude produced per month.

The table includes venting and fugitive emissions of methane where this is a significant contributor to the overall carbon footprint.

Table 4.1: The Monthly Activity of Al Sharara Field

<table>
<tr><th colspan="2">Category</th><th>Monthly range</th></tr>
<tr><td colspan="2">Crude oil production</td><td>300,000 bpd = 9,000,000 barrels per a month</td></tr>
<tr><td rowspan="3">Associated gas</td><td>Total Daily Gas</td><td>630 MMSCF to 750 MMSCF</td></tr>
<tr><td>Flaring</td><td>450 MMSCF 750 MMSCF</td></tr>
<tr><td>Turbine</td><td>180 to 210 MMSCF</td></tr>
<tr><td colspan="2">Fuel combustion (rigs and generators)</td><td>1,080,000 to 1,404,000 Liters</td></tr>
<tr><td colspan="2">Flights from Cities to The field</td><td>110,240 kg jet fuel</td></tr>
<tr><td colspan="2">Fleets of vehicles</td><td>46,000 L diesel</td></tr>
<tr><td colspan="2">Methane Fugitive and Oil Tank Venting</td><td>45,000 to 180,000 SCF</td></tr>
<tr><td colspan="2">Marine tanker operations</td><td>45,000 to 75,000 kg fuel heavy fuel</td></tr>
<tr><td colspan="2">Supply chain (catering, food supply & warehouse trucks)</td><td>5880 L diesel</td></tr>
</table>

4.1.1 Estimation Carbon Footprint According to Scope 1 of Carbon Emissions (CO_2eq)

To calculate Scope 1 carbon footprint (CO_2e) associated with daily flaring at the Sharara oil field, the daily amount of associated gas produced initially must be first determined. According to Al-Sharif, (2024) and Nassar and Salem, (2023) showed around 21–25 million Standard Cubic Feet per day MMSCFD are produced daily by the Sharara oil field. Out of this amount around 6–7 MMSCFD are utilized for generating power by driving turbines, while the balance of 15–19 MMSCFD is flared daily. First, gas volume in standard cubic feet must be converted to cubic meters (M^3) utilizing IPCC's conversion factor (1 scf = 0.0283168 m^3). The resultant volume in cubic meters is then multiplied by emissions factor of 1.9 kg/CO2e per natural gas (CH_4) under complete combustion. According to IPCC every M^3 complete combustion contains 1.9 kg CO2e. The monthly total from kg CO2e from complete combustion of flaring is about 24,210,840 to 30,667,080 kg CO2e/month.

How to estimate N2O emissions from flaring. Step by step. The total amount of gas that was flared was around 15 to 19 MMSCFD. First, it is converted to cubic meters using the IPCC factor. (1 scf = 0.0283168 M^3). Then we convert the gas volume to energy using a factor (every M3 has 0.038 GJ). Next, it is applied the emission factor for N2O (0.0001 kg/GJ of energy). Finally, it is multiplied by the global warming potential (GWP) of N_2O (273). The result is around 13,104 to 16,653 kg of CO2e per month.

Estimation emission from turbines to generate electricity, the approach is the same but based on fuel use vs. energy output. For the Turbines at Sharara supplying power to the site for residential and working use, there are six turbines in total, five of which are in operation and one on stand-by at any time. Turbines normally run at between 50% and 60% load to optimize operation life. Each turbine under these operating conditions produces approximately 10 MWh/day. In addition to the fuel for electricity generation, the gas also comprises natural gas-associated liquid reject streams which amount to approximately 6 to 7 MMSCF per day. Using the Balanced Daily Junction (BDJ) of 6,220 to 7,260 MMBtu this amounts to 6,220 to 7,260 MMBtu per day of which, according to the IPCC emission factor for natural gas of 53.06 kg CO_2/MMBtu, approximately 330 to 385 tonnes of direct CO_2 emissions per day are generated in addition to very small amounts of CH_4 and N_2O (~1–2% of total emissions). On an annualized basis this amounts to approximately 9,900,996 to 11,556,468 kg CO_2e / month.

Catering, Food supply chain & general services trucks (warehouse) These activities are classified as scope 1 because the operating of these activities are by Al Sharara management direct. The main challenge of these activities is the distance of the Al Sharara field from the capital Tripoli and its remote location in the desert. Two trucks of 10 tons of refrigerated food for catering, food supply chain and general services logistics at the Sharara field facilities. In addition to catering, spare parts, warehouse and inventory materials are also delivered to the field facilities on a weekly trip basis using heavy-duty trucks for the job. Using the drivers for these purposes is efficient and convenient. The consumption of the fuel for the normal food supply chain trucks is about 35 liters for every 100 km driven. So, a round-trip distance would be 490 liters. Sharara operates this activity on a weekly basis, 3 trips per week. So, the monthly consumption would be about 5,880 liters for this activity alone. Using the Intergovernmental Panel on Climate Change (IPCC) emission factor for diesel of 2.68 kg CO_2 per liter, Sharara estimates the activities greenhouse gas emission from this scope to be 15,758 kg CO_2e/ month.

For emission estimation from Fleet of vehicles used in the field, CO2e / month, the fleet of vehicles used across the field was reported by field staff to be approximately 150 four-wheel-drive vehicles with most being Toyota Land Cruisers. These vehicles run 24/7 in extreme desert conditions and are all diesel-powered. These vehicles can be categorized into three groups of work and fuel consuming, namely production, safety and maintenance / technical departments and supervisors / management. The 50 vehicles involved in production activities would collectively consume approximately 24,000 liters of diesel per month. The 70 vehicles involved in safety & maintenance / technical departments would collectively consume approximately 19,600 liters of diesel per month. The remaining 30 vehicles involving supervisors & management would collectively consume approximately 2,400 liters of diesel per month. In total, the fleet would therefore consume approximately 46,000 liters of diesel monthly. The total emissions would then amount to 123,280 kg

CO_2e per month using the IPCC standard emission factor for diesel fuel of 2.68 kg CO_2 per liter.

Estimation of methane fugitive and storage tanks leaks. Adam Rutherford et al. (2021) estimated, for methane emissions from storage and fugitive leaks, that storage tank venting was equivalent to 0.005 to 0.02 standard cubic feet per barrel (scf/barrel) of crude oil, assuming no vapor recovery. Based on production of around 300,000 barrels per day, then multiply by 30 days, this equated to around 45,000 to 180,000 scf/day. Monthly emissions would be 45,000 to 180,000, then transfer this amount to (M^3) multiply by IPCC factor, (0.0283168 M^3), the result will be 1,274 to 5,097 M^3/month, then using the next equation:

Methane Emission = V × d × GWP

Whereas V = methane volume

d = methane density at normal condition 0.717 $kg/m^{3.}$

GWP = global warming potential for methane which is 28.

Emission = 1.274 to 5,097 × 0.717 × 28 = 25,541 to 102,185 CO_2e / month.

4.1.2 Estimation Carbon Footprint based on Scope 3 of Carbon Emissions (CO_2eq)

The estimation of carbon footprint (CO_2e) from oil export at the Zawiya terminal through oil tanker falls in scope 3. The Sharara field produces approximately 300,000 barrels per day of crude oil, which is sent by pipeline to storage tanks at the Zawiya terminal with a capacity of around 2 million barrels, (GlobalData, 2021). Aframax tankers with a capacity of around 600,000 to 800,000 barrels are then loaded over a period of around 12 to 18 hours. In practice, the tankers have an average loading of around 600,000 barrels on Mediterranean routes. Aframax tankers at berth consume around 3 to 5 tons of marine fuel per day. one tanker is loaded at the above field's facilities every two days, which amounts to around 15 loading operations per month. This results in around 45 to 75 tonnes of fuel being consumed per month. This fuel consumption then needs to be multiplied by the relevant IPCC emission factor for heavy marine fuel of 3.16 kg CO_2e per kg of fuel. The above calculation therefore results in emissions of around 142,200 to 237,000 kg CO_2e per month.

For aviation, the calculation follows a similar rule of thumb as with ground transport. Petro Air Company operates regular charter flights carrying staff and equipment from Tripoli and Benghazi to the Sharara oil field this company contracted with Akakus company, the operator of Al Sharara field, to transfer the employees. These flights are operated with regional jets, similar to an Embraer E-170 with a seat capacity of 70-80 seats. For the flights from Tripoli to Sharara, the flight distance is approximately 700-730 km and the flights from Benghazi approximately 1600 km. Operating 3 round trips per week from Tripoli and 2 round trips per week from Benghazi results in a total monthly flight distance of 42,400 km. With an average fuel burn rate of approximately 2.6 kg per kilometers the aviation-related emissions of Petro Air amounts to around 133,984 kg CO_2 equivalent per month.

Carbon footprint (CO_2e) resulting from exploration and drilling operations at the Sharara field, there are approximately 6 rigs in operation; some for exploratory purposes and others for drilling new production wells and enhanced oil recovery wells as well as workovers on existing wells. Each rig has a rated capacity of 2,000 HP plus a mud mixing unit with average daily diesel consumption averaging between 8,000 Liters and 10,000 Liters per day not to mention consumption by generators in the rig gang of approximately 400 Liters to 800 Liters daily. Furthermore, there are water tanker and pipe trucks, large bulldozers, scrapers, and forklifts deployed to move associated tubulars and well equipment to respective drilling locations or offshore facilities. In total, the support vehicle fleet consumes approximately 2,000 Liters to 2,500 Liters of diesel weekly at the onshore drilling sites. Total diesel consumption is approximately 1,080,000 to 1,404,000 Liters monthly. Utilizing IPCC emission factor for diesel of 2.6 kg/L estimated monthly emission would total 2,808,000 to 3,650,400 kg CO2e per month

4.1.2 Estimation Carbon Footprint based on Scope 2 of Carbon Emissions (CO_2eq)

For Al Sharara field this is nil as the field is in a remote area and not connected to the national grid. All the power required is generated on location using a combination of field-run turbines and diesel generators. Therefore, the emissions from this source are reported only based on Scope 1 category.

The study assessed the variety of emissions sources at the operation to identify contribution levels. Emissions from the Sharara oil field operation amount to 75,264,449 kilograms of carbon dioxide equivalent per month. In terms of proportion of emissions, the bulk, eighty-three percent or 62,988,032 kg CO_2e/month, stems from gas flaring, widely recognized as the biggest single largest source of emissions in upstream oil and gas operations. The next largest component is emissions arising from gas turbines used for electricity generation at 15% or 10,728,732 kg CO_2e/month. In contrast, all other emission sources reported in the research contribute a small percentage to the overall carbon footprint of the field, including emissions from diesel combustion for the rigs and generators for power at 1.36% or 1,021,800 kg CO_2e/month, followed by field staff air travel at 0.18% or 133,984 kg CO_2e/month, revealing very low Scope 3 impacts relative to the scope 1 and scope 2 operational emissions. Also, emissions from catering and logistics trucks used for importing consumables and delivery of products between production facilities, as well as field vehicles used by the field operational teams amount to 0.17% or 128,411 kg CO_2e/month and 0.020% or 15,573 kg

CO_2e/month respectively. Moreover, fugitive emissions and tank venting emissions associated with methane and oil losses amount to 0.085% or 65,271 kg CO_2e/month. Most Scope 2 emissions, i.e. emissions arising from consumption of purchased electricity, are stated at zero as Sharara consumes 100% of its required power at the operation, over 99% of emissions at the operation arise due to activities that are inherent to the exploration and production process and that require specific technology. Consequently, for Sharara to reduce its carbon intensity it is critical to explore technological innovations which can further minimize levels of flaring, in addition to maximizing gas recovery in the processing system, as well as adoption of turbine technology which can run on lower power.

Table 4.2: Total percentage of carbon emission based on Scope 1.2. and 3

Emission Source		**CO_{2e} (kg/month)**	**Scope**	**Total %**
Associated gas	Gas Flaring	33,084,504	1	70
	Gas Turbine	10,728,732	1	23
Vehicles of field		123,280	1	0.25
methane fugitive & Oil tanks Venting		63,863	1	0.13
Catering, food supply and warehouse trucks		15,758	1	0.033
Purchased electricity		*NIL*	2	*NIL*
Field Staff travel by aviation		133,984	3	0.28
Diesel combustion (rigs & generators)		3,229,200	3	2.15
Oil Tanker		189,600	3	1.25
The total		47,586,921		

To make Comparison between Scope 1, 2 and 3 activities per a month, the Figure 4.1 shows Scope 1, 2 and 3 emissions in a simple to understand format monthly activities in Al-Sharara field. The chart shows Scope 1 emissions account for approximately 93% of total emissions with Scope 1 emissions amounting to around 47.5 million kg CO_2e per month. These emissions largely come from on-site activities such as flaring, fuel usage and power generation. Scope 2 emissions are reported as zero due to the field not purchasing any electricity and relying on internal power generation. The field's Scope 3 emissions are approximately 1.75 million kg CO_2e per month with these emissions accounting for 3.7% of total emissions. These emissions primarily come from indirect activities such as transportation, logistics and purchases of good and services provided by external parties.

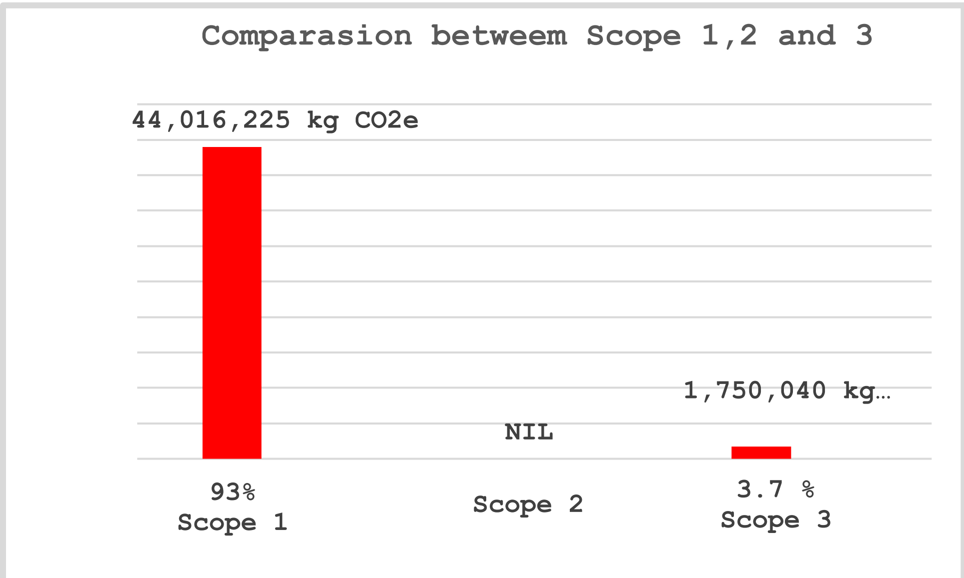

Figure 4.1: The comparison among Scopes 1,2 and 3 of Monthly Carbon Emission.

To facilitate easier comparison, the total emissions from the entire production site were standardized using the site's oil production as the activity basis. This is achieved by dividing the total carbon footprint in kg per day by the oil production rate in barrels per day, giving kg CO_2e per bbl. As shown in equation (4.1), the resulting value states the emission intensity per barrel of oil produced. This facilitates comparison on an absolute scale with similar measurements from other or previous periods of production.

kg CO_2e per bbl = $\frac{total\ CO2e\ (kg/day)}{oil\ production\ bbl/day}$ = kg CO2e per barrel ***(4.1)***

Whereas the calculation is done by monthly term, so calculate and transfer the values into monthly term.

kg CO_2e per bbl = $\frac{total\ CO2e\ (kg/month)}{oil\ production\ bbl/month} = \frac{47{,}586{,}921}{9{,}000{,}000}$ = 5.28 kg CO2e per barrel

From a professional oil and gas perspective, the upstream carbon intensity result of 5.28 kg CO_2e/bbl from Sharara oil field is technically plausible and very competitive. The carbon intensity of upstream oil production varies significantly around the world. While on average, it falls between 15 and 60 kg CO_2e/bbl, there are significant variations among different reservoirs, modes of energy usage, and flaring practices. The Oil and Gas Climate Initiative has identified an industry average intensity of 17–23 kg CO_2e/bbl based on best practices among the largest operators globally. Assessments performed using Stanford's OPGEE tool have identified some of the best performing low-emission fields globally with intensities to have intensities lower than 20 kg CO_2e/bbl.

The result of 5.28 kg CO_2e/bbl is indeed far lower than the global average and clearly indicates that the upstream carbon intensity of Sharara's oil is low carbon and environmentally competitive as shown in Table 4.3. The results are comparable to other assets globally that recover gas instead of flaring it, which use best-practice lifting methods and have low levels of methane leakage. Importantly, Sharara oil's carbon intensity is on par with the best-in-class performance of international operators.

Table 4.3 Carbon intensity comparison for Sharara field with some countries

Country / field	Carbon intensity kg CO2e / bbl.	Key characteristics
Libya/Sharara field	5	Moderate flaring in an onshore conventional field
Norway	6 – 8	Strict rules and electrified offshore platforms
Saudi Arabia	8 – 12	Massive, normal reservoirs with little flaring
Kuwait	10 – 15	Higher energy uses onshore fields
Global average (OGCI)	17 - 18	Mixed assets, which comprise fields with a lot of energy

The standardized and benchmarked results show that the Sharara oil field has competitive carbon performance globally, on par with best practice for upstream oil production, if considered all Libya production which is about 1,300,000 million barrel per day and Al Sharara consider about the quarter of Libya production, this mean this CO2e will increase dramatically. The findings indicate that it is possible to sustain oil production while meeting global decarbonization goals. But there is also considerable room for additional reductions through flaring prevention and operational efficiency improvements.

4.2 The key challenges in calculating carbon emissions associated with crude oil production

The challenges in precisely measuring carbon emissions from crude oil extraction make it hard to get the right numbers. Because crude oil is made up of several types of oil that change a lot depending on where it comes from and what kind of rock they are found in, emissions data might be inconsistent. For example, Masnadi et al. (2018) showed that the carbon intensity of crude oil production is greatly affected by the conditions of the extraction site and the methods used to extract it. This heterogeneity makes it harder to standardize things since different areas may use different production methods that leave varied carbon footprints. Additionally, the variations in crude oil content, from light to heavy grades, complicate emissions assessments, since each kind requires specific methodology to effectively measure associated emissions.

Another problem is that oil producers also need to report their emissions, which can reduce the reliability and accuracy of emissions data because of any inherent bias or variability. In practice, companies may have a vested interest in downplaying emissions to highlight their environmental credentials, or to avoid detection by regulators. The paper also points out that self-reported data on emissions can have significant variability, which presents challenges for verifying reported figures, and for designing and implementing effective curbs on carbon emissions from the oil industry. As a result, the challenge of creating a complete emissions inventory for the oil industry is greatly increased.

Emissions from oil and gas development operations have been studied from several perspectives with special attention focused on fugitive methane emissions and efficiency of combustion when gas is flared. Emissions from stationary combustion including diesel powered generators, can be reasonably accurately predicted based on knowledge of fuel consumption. Fugitive emissions, however, are composed of many emission points, each having a different emission rate over time and some of these being very difficult to detect and measure. As a result, emissions from this category of petroleum operations are generally estimated using multiple accepted emissions factors rather than real-time measurements. Gas flare combustion efficiency is generally estimated to be about 93%. However, there are a host of variables including crosswind, liquid in the flare stream, and field operating and maintenance practices that can cause actual combustion efficiency to be significantly lower. This in turn results in emissions of unburned methane, a greenhouse gas having a global warming potential that is several times greater than carbon dioxide. Several uncertainties exist regarding accurate assessment of the carbon impact of petroleum operations to which much work remains to be done (IEA, 2011).

The system boundary and organizational control are key and, in many cases, contentious elements in carbon accounting for oil and gas. This is not always an easy task. For many fields, the joint venture or production sharing contracts involve multiple parties that share ownership and control. This can result in different emissions figures being reported depending on the accounting method used. An ownership approach allocates emissions based on financial stake, while an operational control method allocates emissions to the party that controls the day-to-day operations. Both approaches are correct, but can lead to different results, making comparisons challenging and potentially hiding responsibility. These complexities underline the need for well-defined boundaries and transparency in reporting to ensure reliable and comparable life cycle assessments.

The inability to accurately assess crude oil extraction emissions, along with the recently revealed issues with the data, exposes the complexities involved in determining emissions from oil extraction. The challenges that extraction methods face when it comes to accurately assessing environmental impacts include both temporal and spatial considerations and have long required innovative thinking. However, improved regulatory frameworks, a culture of compliance with measurement standards, and increasingly sophisticated measuring technology could allow for a combined assessment of the oil industry's environmental impacts.

4.3 Carbon Reduction Strategies, Towards to Net Zero Emission

Oil and gas operations account for around 15% of all energy-related emissions globally, amounting to 5.1 billion tons of greenhouse gases. The International Energy Agency (IEA) believes that oil and gas must reach net-zero emissions by 2050 to meet its target. Emissions intensity of these activities falls by half by the end of the decade. Including the cuts to oil and gas production, emissions from oil and gas activities fall by 60% by 2030. The net zero emissions (NZE) Scenario outlines a path to meet the goal of no more than a 1.5°C global temperature rise, while at the same time meeting the access goal to modern energy services by 2030. The scenario suggests that the demand for oil and gas could fall rapidly enough to be met from existing fields alone.

As shown in Figure 4.2 the strategic plan of transition to zero emissions in the power and industry sectors is dramatically transition emission in future, the oil and gas industry is also making an urgent transition to reduce emissions from its own operations. With the implementation of the NZE Scenario, the average rates of reduction in emissions from oil and gas supply globally exceed 50% from 2022 to 2030. The plans also include cuts in oil and gas use, meaning emissions from oil and gas activities would fall by 60% by 2030.

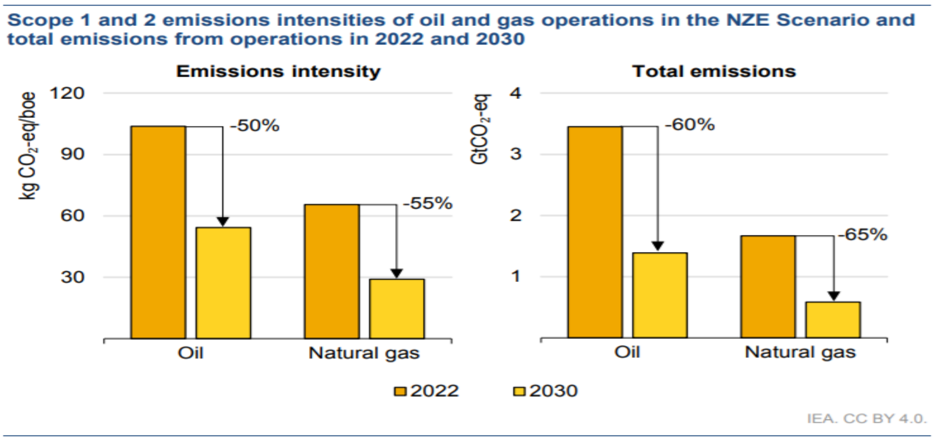

Figure 4.2: the scenario of GHGs emissions reduction in 2030 (IEA,2022).

In addition to the methods mentioned above to reduce emissions from the perspective of oil and gas operations, there are also other ways to decrease Scope 1,2 and 3 emissions, as five main levers are available to reduce emissions intensities as illustrated in Figure 4.3, including reducing methane emissions, stopping all flaring that isn't necessary, electrifying upstream facilities using low-emissions electricity, adding carbon capture utilization and storage (CCUS) to oil and gas production and processing, and use of more low-emissions electrolysis hydrogen in refineries.

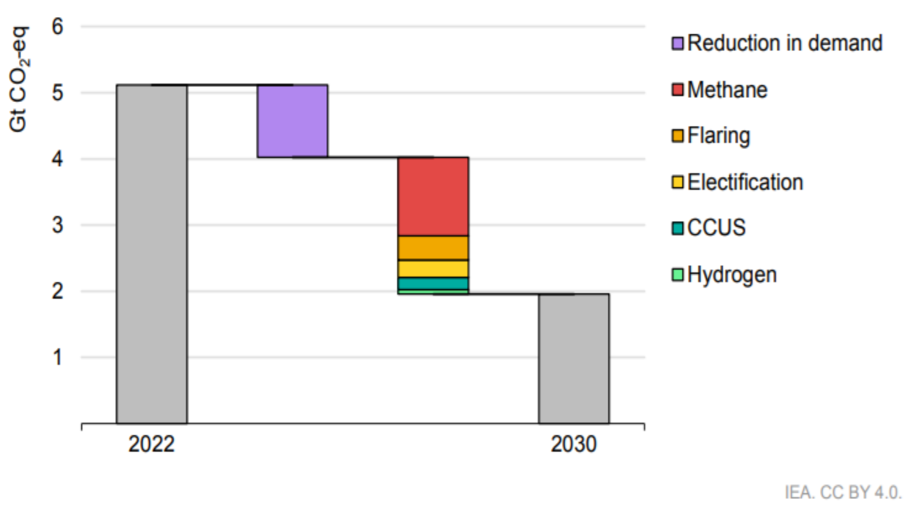

Figure 4.3: Reductions in total oil and gas emissions in the NZE Scenario by 2030
(IEA,2023)

The global oil and gas industry is undergoing a major transformation as it moves in line with the Paris Agreement goals and Net Zero aspirations. For Libya, this transition offers a great opportunity for the economy, which is heavily reliant on oil, to upgrade and enhance its petroleum operations. The Sharara field, with a production capacity of 300,000 barrels per day (b/d), operated by Akakus Oil Operations in the Murzuq Basin, provides an apt example of how the decarbonization process can be structured. This report outlines a multi-pronged approach for the Sharara field, spanning the reduction of gas and vapor emissions, leveraging Gas-to-Power and vapor recovery unit (VRU) to boost power generation, integration of solar-hybrid systems to supply upstream operations, and the utilization of digital twins to enhance oil recovery and thereby lower the carbon intensity of the oil produced. The Sharara field acts as a case study that seeks to evaluate the viability of the field as a model for operations in Libya, integrating the National Oil Corporation's (NOC) strategic objectives for 2026 with local-level environmental analysis.

4.4.1 Gas to Liquid (GTL) Alternative to Flaring natural gas

The gas-to-liquid (GTL) process is considered a technological breakthrough for transforming naturally occurring gaseous hydrocarbons into liquid fuels. With the increased global attention towards reduction of greenhouse gases and shift towards renewable energy sources, GTL technology offers a potentially cleaner alternative to the current fossil fuel extraction methods. Gas-to-liquid technology offers a viable means for energy diversification by chemically converting natural gas into liquid hydrocarbons, thereby producing a cleaner environment. The process employs Fischer-Tropsch (FT) synthesis which is a catalytic reaction that transforms syngas, comprising carbon monoxide (CO) and hydrogen (H2), into long chain liquid hydrocarbons primarily useable as diesel, middle distillate stocks, naphtha and gasoline.

The Gas-to-Liquid (GTL) technology is a strategic breakthrough in the energy industry; it is a practical solution for the problem of gas burning (flaring). Such practice is currently used for many reasons, not least because it releases a large amount of carbon into the atmosphere and squanders a tremendous amount of energy (Wood et al., 2020). GTL technology chemically transforms natural gas (methane) into high-value, long-chain hydrocarbons such as synthetic diesel, kerosene and naphtha. Such products are much easier to transport and have superior burn characteristics when compared with conventional petroleum-derived products (Bozzano and Vendante, 2016).

Figure 4.4 Typical Gas to Liquid (GTL) Process. The Gas-to-Liquids (GTL) process consists of a thermally driven process train consisting of three sections that produce liquid fuels from natural gas. The sections consist of syngas generation, the Fischer-Tropsch (FT) synthesis reaction, and product upgrading (the cracking and reformation of the heavy wax streams into the desired refined liquid fuels, kerosine and high-quality diesel fuel).

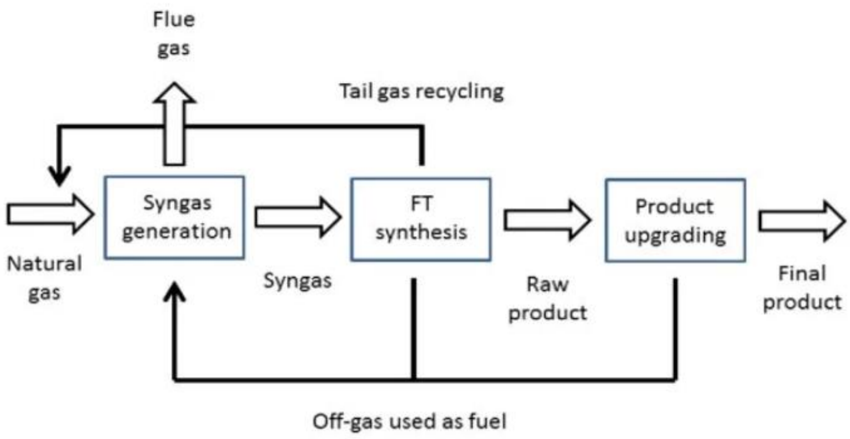

Figure 4.4: Process of Gas-to-Liquids (GTL) Process (Höök et al., 2013)

Catalytic performance in Fischer-Tropsch (FT) synthesis directly affects the yield and quality of the resulting liquid fuels. Iron and cobalt based catalysts, and ruthenium, have been widely investigated due to their catalytic features and selective reactiveness to some hydrocarbon species. In this book, the work presented by Santos (2021) defends the techno-economic viability of FT synthesis using modular GTL (Gas to Liquid) reactors, where improvement in performance of FT catalysts and FT reactor configurations can make GTL process competitive for investors in energy market and for environmental government policies.

GTL methods provide potential for improving both economy and environment by converting associated gas to useable liquid fuels. In addressing energy needs in developing countries, the use of natural gas offers a means to utilize energy while at the same time reducing carbon emission into the atmosphere. Natural gas is one of the world's fastest growing energy resources. Currently natural gas is consumed mainly as combusted fuel thus failing to realize its full potential. Effective Fischer-Tropsch synthesis provides a means to utilize natural gas to produce a variety of liquid fuels affording true diversity of energy supplies. The synthesized liquid fuel has the potential of upgrading the energy economy to be more efficient and environmentally benign. With GTL on the horizon, much attention will be devoted to both improving performance of catalysts and extending their durability and stability. The development of FT catalysts will become an essential component of the future energy mix.

The Fischer-Tropsch synthesis (FTS) is a section of the gas-to-liquid (GTL) process, used to convert natural gas to fuel. The reaction transforms a syngas feedstock, consisting of a mixture of hydrogen and one-third carbon monoxide, into liquid hydrocarbon fuel. The liquid products consist of a broad distribution of alkanes ranging from naphtha to middle distillate (diesel) fractions, capable of directly blending into existing petrol (gasoline) and diesel fuel streams. To achieve desired products properties, appropriate catalysts and reaction conditions must be established. A variety of transition metals have been assessed, with iron and cobalt being the most common employed in FTS. This is due primarily to the unique features of these two metals that render them optimal for this type of reaction.

While iron-based catalysts are not as suitable to produce long-chain hydrocarbons they are well suited for the conversion of syngas to lighter hydrocarbons such as gasoline and naphtha. Iron is the most abundant transition metal in the Earth's crust and has the lowest cost relative to other transition metals. While iron-based catalysts are less active than those containing cobalt and require specific conditions to maintain activity through long-term runs, they can lose activity by producing unwanted by-products such as methane (Matsumura et al., 2016). A recent multi-objective optimization approach by Panahi et al. (2018) underlines the significance of the interrelation between the catalyst performance and reactor and operational conditions influencing the product selectivity and process performance.

Finding a cleaner and more sustainable way to transition to renewable energy is increasingly a future focus, and new GTL technology and fisher trpopsch synthesis (FTS) catalysts are no longer of interest only for long-term thinking. The development of FTS catalysis and resulting hydrocarbon synthesis has provided a means to economically produce liquid fuels from gaseous feedstocks in a sustainable fashion. Advances in catalyst and process technology provide the potential for continued improvements in clean fuel technologies and thereby postpone the complete transition to renewable energy sources and a decrease in our reliance on the vast reservoirs of fossil fuels.

Using Gas-to-Liquids (GTL) technology rather than conventional gas flaring in the Sharara oil field is a sound technical approach to reduce greenhouse gas (GHG) emissions and improve resource utilization. Recent production figures indicate that every day, 15-19 million scf of associated gas is flared. The World Bank estimates that flaring each cubic meter of gas results in 2.6 kg of CO_2e emissions, or 0.0736 kg of CO_2e per standard cubic foot (scf). That means that the Sharara field is flaring about 1,104 -1,398 tons of CO_2e per day. The typical GTL process converts around 10,000 scf of natural gas to 1 barrel of synthetic liquid fuel (called synfuel) using the Fischer–Tropsch process. The flaring gas could produce approximately 1,500-1,900 barrels / day (bbl/day) or 0.55-0.69 million barrels / year. According to the International Energy Agency's global data, there are huge contributions to greenhouse gas emissions from gas flaring, about 500 Mt CO_2e per year globally.

Using associated gas to make GTL can eliminate flaring emissions. But emissions from the GTL process (including converting the gas to syngas and synthesizing fuel) typically have a 20-40% loss of carbon as CO_2, depending on the efficiency of the process and energy source. So, the net emission reduction possible at Sharara is estimated to be 40-60% less than flaring alone (which will be a reduction of 450-750 tons CO_2e/day). Finally, since the primary component of natural gas, methane (CH_4), has a global warming potential of 28 times that of CO_2 over a 100-

year timeframe, using GTL to capture and convert associated gas also results in a significant reduction in CO_2 and fugitive CH_4 emissions. So, the use of GTL in the Sharara field helps reduce carbon intensity (kg CO_2e/bbl) and produces valuable low-sulfur fuels.

4.4.2 Assessing Solar Panel as Renewable Energy Integration for GHGs Reduction

Using solar power in Libya's oil and gas industry is crucial for cutting greenhouse gas (GHG) emissions and enhancing the sustainability of energy generation. Despite abundant hydrocarbon resources, Libya tends to burn fossil fuels for energy production. But it has many environmental issues such as gas-fired turbines emit carbon dioxide (CO2).

One of the main benefits of solar power is that it reduces greenhouse emissions. Fossil fuel combustion creates a lot of carbon dioxide (CO2), which contributes to global warming. The oil and gas industry is a big part of this. Using more solar energy can reduce these emissions. Akroot et al. (2024) highlight that renewable energy, such as solar, can support conventional energy systems of oil and gas producing nations. Their case study demonstrates that incorporating solar into existing systems can help reduce CO_2 emissions, making the oil and gas sector more sustainable.

In addition, using solar energy can improve energy security and sustainability. It could be risky to only have one source of energy, such as oil, due to supply disruptions and geopolitical reasons. By diversifying its energy sources, such as using solar energy, Libya's energy supply can be more secure and less dependent on fossil fuels. These make Libya's plan to "green" its energy portfolio by tapping into renewable energy sources, like solar energy, a good idea because it can improve energy diversification and sustainability.

But there are some issues with the use of solar energy for the Sharara oil field. The upfront cost of installing solar power is a concern. The cost of installing solar panels, inverters and energy storage may be an issue, particularly for places like Libya, where the government may be facing economic difficulties. The investment is very significant because it may deter oil companies from investing in solar. The initial costs can be frightening, despite the benefits of saving money over time on electricity bills, which are reported in the paper by Aboukra and Lekhmaisi (2024).

Solar energy can be tricky to work with. The oil industry has mechanisms that may be difficult to work with renewable energy. Solar technology might not be compatible with oil field operations. This needs to be addressed by people with special expertise. People must be trained to operate hybrid systems, making it difficult to transition. As Akroot et al. (2024) note, integrating solar energy into existing power generation systems needs to be planned and technologically skilled to avoid these issues. Also, Libya's policies make it difficult to use solar energy. Renewable energy policies are still under revision across the country, also considering the environment. Solar energy has a lot of potential in Libya, but it can be less effective with poor weather. Hot weather, dust storms and sand accumulation on solar panels can cause them to be less efficient and more costly to operate. This needs to be considered, and solar systems must be cleaned and maintained to ensure they operate efficiently, which can be an additional burden. Rawesat et al. (2024) discuss these environmental issues and stress the need for the right maintenance programs to ensure the efficient operation of solar energy systems.

In summary, the potential benefits and drawbacks of renewable energy use in Sharara oil field need to be considered. Using renewable and non-renewable resources can make Libya's oil and gas industry more sustainable.

4.4.3 Applying Methane Leak Detection and Repair Integration for GHGs Reduction

From a purely efficiency perspective the best way to reduce greenhouse gas emissions in the petroleum and natural gas industry is by implementing a robust methane leak detection and repair (LDAR) program. Methane (CH_4) has a global warming potential of 28–34 above CO_2 over a 100-year time frame (IPCC, 2021). In the upstream oil and gas industry, fugitive emissions typically originate from a range of sources including valves and flanges, as well as from compressors, large bulk storage tanks and gas handling processes. Remote and challenging working conditions, age of equipment and inconsistent levels of maintenance can all impede the effectiveness of such a program. At the Sharara oil field, one of the largest upstream operations world-wide, Advanced Remote Survey Technologies have been deployed to underpin improvements to LDAR efficiency:

I. Optical Gas Imaging (OGI): Leaks in natural gas pipelines can be seen as smoke using special infrared cameras that facilitate fast identification of sources such as valves and flanges. The technology also enables continuous monitoring as well as pipe leak detection from space via satellite. Fast leak detection and measurement are also capabilities of this technology.

II. Laser-based detection: High precision methane concentration measurement can be performed by Laser-based Detection techniques such as TDLAS (Tunable Diode Laser Absorption Spectroscopy) and LiDAR. Several devices have been developed for such measurement e.g. drone-based, or simply portable, like Laser Methane Smart (LMS) or RMLD-CS.

III. Airborne/Drone Surveys: Drones and airborne sensors like those used in the airborne portion of the airborne/drone portion of the Bridger program make it easier to monitor and access wider areas of land that are remote and/or difficult to access.

IV. Ground-based Sensors: Additional information can be gathered by using ground-based sensors to supplement aerial surveys.

Good Leak Detection and Repair (LDAR) programs can reduce methane emissions from oil and gas operations by up to 75%, the International Energy Agency (IEA) has found. A significant 40–50% of this reduction could be achieved at no additional cost as the saved gas has value as illustrate in figure 4.5 The combined application of LDAR with gas recovery and use strategies, such as gas-to-liquids or re-injection, has the potential to significantly reduce the GHG intensity of the operations at the Sharara field, saving several kg CO_2e per barrel of oil produced.

However, infrastructure, operational, regulatory and enforcement challenges, including the harsh desert environment of the field, need to be addressed. Furthermore, adherence to internationally recognized best practices, such as the emissions reporting standards of the Oil and Gas Methane Partnership (OGMP 2.0) and the World Bank's Zero Routine Flaring by 2030 initiative, would increase transparency of emissions as well as the effectiveness of mitigating measures currently in place at the field. The environment and the bottom line of the operation would be the winners.

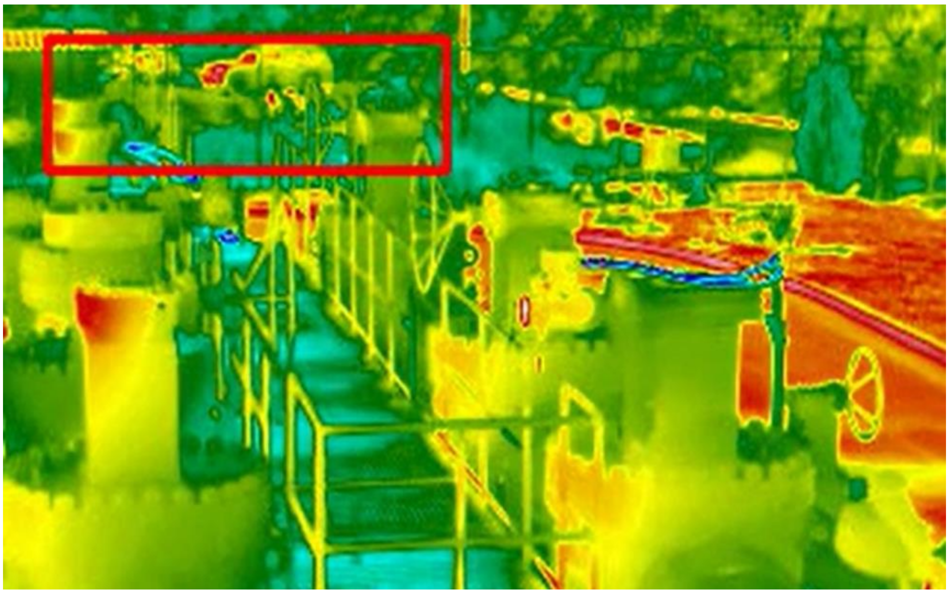

Figure 4.5: Methane Leak Detection by OGI Camera - (Pandey et al., 2019)

The leak and repair industry has evolved significantly in recent years, experiencing a steady increase in its market value. The Leaks and Repair Market is projected to grow from $20.89 billion in 2025 to $22.17 billion in 2026 as shown in figure 4.6 specialized for industry analysis on the leak ddetection and repair (LDAR) global Market, representing a 6.1% Compound Annual Growth Rate (CAGR). Past growth trends may be attributed to increased industrial concerns regarding leaks, industrial safety mandates, emission controls mandates, oil and gas activities, and growing awareness of the harm caused by hazardous leaks.

The global ambient air quality monitoring systems market is projected to grow from $14.74 billion in 2018 to $27.75 billion by 2023, achieving a Compound Annual Growth Rate (CAGR) of 5.8% from 2018 to 2023. Factors such as an increasing focus on sustainability, adoption of automated detection systems, rising spending on industrial safety, growing environmental compliance regulations, and monitoring systems with precise capabilities will all drive market growth.

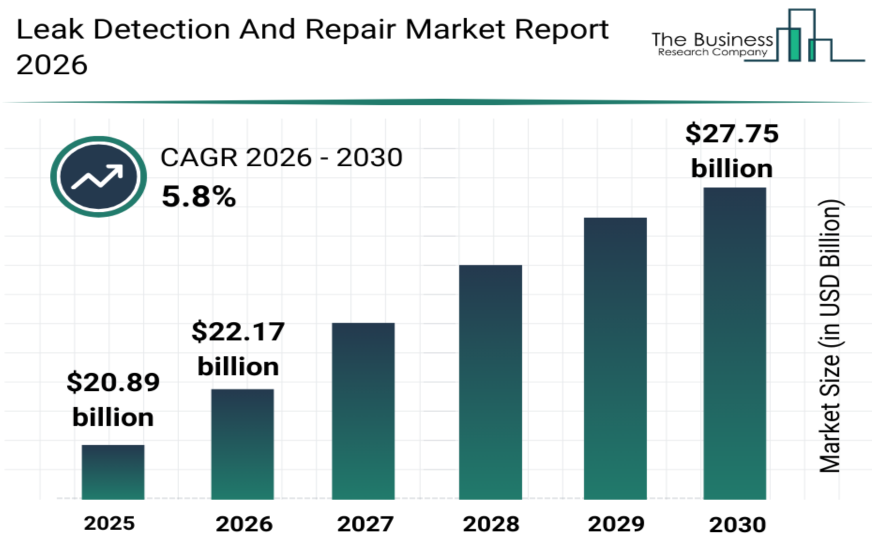

Figure 4.6: Projection of Leak Detection and Repair Market Report for industry Analysis. (IEA,2023)

CHAPTER 5

CONCLUSIONS

5.1 Summary

Findings from a research project applying carbon accounting methods to the Al-Sharara crude oil field show a good but slow development in understanding of the various greenhouse gas (GHG) emissions associated with the crude oil life cycle. A carbon accounting framework, which is convinced to be in line with global practices, has been developed following the Greenhouse Gas Protocol (Scope 1, 2 and 3). Employing a novel approach, a cradle-to-gate Life Cycle Assessment (LCA) technique has been applied in measuring emissions and environmental impacts associated with crude oil extraction, processing and distribution. The research study found that gas flaring, diesel-powered production and issues related to gas management practices constitute the bulk of the GHG emissions at the Al-Sharara field. Logistical operations associated with crude oil distribution through pipelines also generate significant emissions, albeit lower than the operational emissions. Findings from the research demonstrate that carbon intensity at the Sharara field is affected greatly by a combination of infrastructure, operational, institutional and environmental factors.

The study stresses the relevance of developing methods that integrate carbon accounting with life cycle assessment (LCA) to identify sources of emissions and corresponding mitigation measures. Utilization of gas (GTL or reinjection), implementation of Leak Detection and Repair (LDAR) programs and improving efficiency in energy use are recommended as critical actions to reduce the substantial emissions associated with crude oil production. Nevertheless, the study identifies significant challenges, especially related to data uncertainties, the use of default factors and poor information availability because of the situation in Libya. Overall, the research demonstrates the importance of carbon accounting as a tool for measuring and comparison; however, sustainable reductions in GHG emissions associated with oil production require technology as well as institutional developments. In this sense, carbon accounting has a potential to go beyond emissions measurement and can be a fundamental tool for strategic sustainable planning of oil production in Libya.

5.2 Recommendations for Future Studies

As we tackle climate change, carbon accounting and footprints need to be understood and mitigated. As the world moves towards carbon neutrality, innovative methods and technology to achieve this are paramount. The Sharara oil field in Libya is one of the largest producing fields worldwide and poses challenges to carbon emissions management. Methods and technologies for optimizing carbon accounting for high volume resources extraction need to be explored in detail.

Carbon accounting has traditionally relied on the use of standardized emissions factors for accounting for greenhouse gas emissions associated with different activities. However, such generic approaches may not be sufficient, particularly for the oil industry, where emissions can vary significantly based on several factors including production methods, degradation and performance of equipment and geo-physical conditions specific to a given oil field. For the Sharara oil field, a more advanced, data-driven approach is required, leveraging modern measurement technologies. As part of this approach, a continuous emissions monitoring system (CEMS) can be installed at the various emission sources, providing real-time measurements that allow for a highly accurate assessment of greenhouse gas emissions, helping to support informed operational decisions.

Combining different remote sensing technologies may also enhance carbon accounting. Satellite-based data may be used to generate emissions information as well as to monitor surface dynamics. In this context, a new app has been developed that can identify diffuse sources of pollution that cannot be detected by conventional measurements on the ground. This makes it possible to adjust emissions reduction measures precisely. The monitoring of the Sharara oil field by drones and aerial images provides stakeholders with valuable environmental information, and always up-to-date assessments of the current situation.

Technological advancements also must improve when it comes to carbon accounting and footprint methods as well as their application in carbon management using data. For instance, the use of AI and machine learning in the analysis of big data can transform the field and enable the creation of prediction models that can forecast future emissions under different operational scenarios. The prediction functions that these technologies offer will in turn be able to boost methods for sustainable resource extraction and enable reductions in carbon emissions while meeting production targets.

Blockchain technology can also make carbon accounting transparent and accountable. Carbon footprints can be tracked and reported in supply chains through a reliable record of emissions data. This is an innovative idea that can be applied in the oil and gas sector, which requires strict compliance with reporting criteria to meet international commitments to reduce emissions. For instance, application of blockchain technology in Sharara oil field can not only ensure compliance with local and global reporting standards but also can build trust locally and globally among stakeholders.

Intersectoral collaboration is another area where improvement can occur to strengthen carbon accounting globally. Collaboration and partnerships among stakeholders, such as industry players, research institutions and government agencies, are necessary and will likely require process changes to stimulate research and innovation. By fostering such partnerships, organizations can benefit from knowledge-sharing, access to tools and best practices on carbon accounting and carbon accounting systems, and establishment of a strong foundation that can be flexible and adaptable to address specific situations.

Complementing the implementation of new approaches and technologies to support carbon footprint assessment, effort will be also dedicated to building capacity for sustainable carbon accounting through training. By providing a professional team with continued training and education using the latest and greatest in technology and data management systems, FODAG can support comprehensive and long-lasting carbon accounting. In countries with large oil reserves such as Libya.

Governance frameworks at the national level must be strengthened to ensure that carbon accounting systems are tracking towards international climate goals. Strong rules and regulations need to be developed and enforced by governments to encourage the adoption of new carbon accounting methods and technologies. To ensure compliance and proper management of carbon emissions, the industry needs governments to establish a culture of accountability. By developing and implementing rules that mandate proper tracking and strict reporting of greenhouse gas emissions, governments can also ensure that industry is implementing best practices to reduce these emissions.

Carbon accounting and measurement of the carbon footprint globally, and especially for the Sharara oil field, is a highly complex process. Industry players can greatly benefit from emphasizing the need for new methods and new technologies to manage carbon, fostering collaboration, training and regulation for good carbon management. These solutions will be crucial to the oil and gas industry’s drive towards carbon neutrality and achieving climate resilience and sustainability.

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APPENDIX

APPENDIX A - MONTHLY ESTIMATION KG OF CO_2 FROM COMPLETE COMPASTION INTO FLARING

The field produces about 21 to 25 million standard cubic feet (MMSFD) of associated gas every day, 6 to 7 MMSFD consumed into turbines for power generation and flaring the rest which is about 15 to 19 MMSFD.

To calculate kg CO_2e from complete combustion into flaring, need to transfer standard cubic feet to meter cubic:
Then 1 scf = 0.0283168 m^3 according to IPCC.
The average of flaring is 15 to 19 MMSFD per day.
15 & 19 MMSFD × 0.0283168 = 424,752 & 538,020 M^3/d.
According to IPCC, CO_2 = 1.9 kg CO_2 per M^3 of gas burned.
1.9 × 424,752 & 1.9 × 538,019 = **807,029 to 1.022,236 kg CO2 / day.**

Monthly total = 807,029 to 1.022,236 × 30 days = 24,210,840 to 30,667,080 kg CO2e/month

APPENDIX B – ESTIMATION METHANE SLIP (UNBURNED CH_4)

According to IPCC default flare combustion efficiency is 98% and 2% methane slip.

Whereas methane density at standard conditions is 0.716 kg/m³.

Unburned volume = 424,752 to 538,019 M^3/d × 0.02 =

8,495 to 10,760 M^3/Day.

8,495 to 10,760 M^3/Day × 0.717 kg/m³ = 6,090 to 7,715 kg CH_4 / day.

Global warming potential pf methane 27.2

6,090 to 7,715 kg CH_4 / day × 27.2 = **165,648 to 209,848 kg CO2e / day.**

Total month of complete and methane slip: 4,969,440 to 6,295,440 kg CO2e / month

APPENDIX C – MONTHLY ESTIMATION OF N_2O FROM FLARING

To estimate nitrous oxide (N_2O) emissions from natural gas flaring, firstly convert the volume of gas into energy content, according to IPCC the approximation $1M^3$ NG ≈ 0.038 GJ.

First determine GJ into gas flaring**:**

424,752 to 538,020 $M^3/d \times 0.038$ GJ = 16,140 to 20,444 GJ / day.

According to IPCC AR6 every GJ contains 0.0001 kg N_2O.

Then 16,140 to 20,444 GJ / day × 0.0001 = 1.614 to 2.04 kg N_2O / day

Monthly computing of N2O = 1.614 to 2.04 kg N_2O / day × 30 days =

48 to 61 kg N_2O / month

Finally applying the GWP of N_2O according to IPCC which is 273

48 to 61 kg N_2O / month c 273 = **13,104 to 16,653 kg CO_2e / month**

The Total of N_2O as CO_2e from flaring per month **13,104 to 16,653 kg**

APPENDIX D – ESTIMATE EMISSION FROM TURBINES TO GENERATE ELECTROCITY

Daily gas burned for power about 6 to 7 MMSCF.

1 MMSCF = 1,000,000 standard cubic feet.

Convert gas volume to energy using IPCC 2019 standard,

1 scf = 1,037 BTU

Then 6 to 7 MMSCF × 1037 = 6.22×10^6 to 7.25×10^6 BTU

Convert to million Britch thermal unit (MMBtu)

The total is 6,220 to 7,260 MMBtu / day

6,220 to 7,260 MMBtu / day × 30 days = 186,600 to 217,800 MMBTU / Month

According to IPCC 2019, Natural gas combustion EF = 53.06 kg CO_2/MMBtu

186,600 to 726.023 MMBtu × 53.06 = 9,900,996 to 11,556,468 kg CO_2e / month

The total estimation emission from turbines per month 9,900,996 to 11,556,468 kg CO_2e / month

APPENDIX E – ESTIMATION OF METHANE FEGUTIVE AND STORAGE TANKS LEAKES

According to the International assessment methodologies, storage tank venting alone can release between 0.005 and 0.02 standard cubic feet (scf) of methane for every barrel of crude oil produced without vapor recovery devices (Rutherford et al., 2021b).

0.005 to 0.02 × 300,000 bpd × 30 days = 45,000 to 180,000 scf / month.

Convert scf to M^3 **:** = 45,000 to 180,000 scf / month × 0.0283168 =

1,274 to 5,097 M^3/month

To computing methane vegetive:

Emission = V × d × GWP

Whereas V methane volume

d methane density at normal condition 0.717 kg/m^3

GWP is global warming potential for methane which is 28.

Emission = 1,274 to 5,097 × 0.717 × 28 =

25,576 to 102,327 kg CO_2e / month

The total emission from fugitive methane per month

25,576 to 102,327 kg CO_2e / month

APPENDIX F – ESTIMATION OF EMISSION FROM FLEET OF VECHICLES USED IN THE FIELD

According to Sharara staff, the field has about 150 four-wheel drive (4WD) vehicles, mostly Toyota Land Cruisers, all of them consuming diesel fuel because the desert atmosphere requires that. This Vehicles have Classified into 3 parts from diesel combustion side, according to the duty of the departments.

- 50 vehicles belong to production management. This management is responsible for keeping the level and increasing oil production, according to field staff, these 50 vehicles consume 120L / week for each vehicle.
  50 vehicles × 120 liter × 4 = 24,000 Liter of diesel per a month
- 70 Vehicles belong to safety & health, security, maintenance, corrosion and IT department, consuming 70L/week per each
  70 vehicles × 70 liters × 4 = 19,600 Liter of diesel per a month.
- 30 Vehicles belongs to head of department, head of sections, coordinators and supervisors which are Consume 20L/week.
  30 vehicles × 20 Liter × 4 = 2,400 Liter of diesel per a month.
  The total diesel fuel per a month 24,000 + 19,600 + 2.400 =
  46,000 liters / month.
  According to IPCC, emission factor for diesel fuel, every liter from diesel contains 2.68 kg CO_2.

The Total Emission Estimation from Fleet of vehicles,

46,000 × 2.68 = 123,280 kg CO_2e / month

APPENDIX G – ESTIMATION OF EMISSION FROM EXPLORATION AND DRILLING ACTIVITY

According to field staff, the field has 6 rigs that are used to dig new wells and keep 70 wells that are not in use.
Each rig has a power class of 2,000 HP and is used for active drilling, which uses about 8,000 to 10,000 liters of diesel fuel per day.
Average working days in month is about 20 days per month.
Every rig consumed 8,000 to 10,000 × 20 days = 960,000 to 1,200,000 liters per month.

Every rig has two generators for electricity generation, consuming about 400 to 800 liters of diesel fuel per day.
400 to 800 × 30 days × 6 rigs = 72,000 to 144,000 liters monthly.

Every rig is accompanied by trucks, including two water tank trucks, truck pipes, bulldozer, and a forklift. According to Sharara staff, these trucks use 2,000 to 2,500 liters of diesel fuel per week.
6 rigs × 8,000 to 10,000 liter /day = 48,000 to 60,000 liter / day for each**.**
8,000 to 10,000 liters /day × 20 = 160,000 to 200,000 liters / month.
Every rig has 2 power generators; it operates on a 12-hours shift system.
2,000 to 2,500 liters × 4 × 6 rigs = 48,000 to 60,000 liters / month.
According to EF for diesel fuel is 2.6 kg CO2e for each liter from Diesel.
The total fuel consuming monthly = 1,080,000 to 1,404,000 Liters per month

The Total Emission Estimation from exploration and drilling activities,
1,080,000 to 1,404,000 Liters × 2.6
= 2,808,000 to 3,650,400 kg CO2e per month

APPENDIX H – ESTIMATION EMISSION FROM AVIATION

Petro Air Company (service company), an aviation company associated with Akakus Oil Operations, the aircraft used is An Embraer E-170, which could fly with average fuel burn rate about 2.6 kg/km.
(based on regional jet fuel efficiency of 2.6 kg/km and jet fuel density of ~ 0.8 kg/l).

The distance between Tripoli and Sharara is about 700 - 730 km, three round-trip flights per week, and from Benghazi to field about 1600 km two round-trip flights a week.
From Tripoli to the field, total distance per month is 16,800 km and 25,600 km for Benghazi to field.

Total Km per month is about 42,400 km/month

According to IPCC emission factor and IATA and the US. EPA, the emission factor for jet fuel 3.16 kg CO_2 / kg fuel

Estimation of emissions from aviation

Total Distance (km) = 42,400 × 3.16 = 133,984 kg CO_2e / month

APPENDIX I – ESTIMATION EMISSION FROM OIL TANKER AT AL ZAWIA TERMINAL FOR OIL EXPORT

Aframax tankers typically have a capacity of 600,000 to 800,000 barrels, takes about 12 to 18 hours to load the tanker.
According to the capacity and daily production, aframax loading every two days from zawiya terminal in total 15 days per a month.
According to the IPCC and the journal Marine Science and Engineering, a typical Aframax tanker at dock uses about 3 to 5 tons of marine fuel per day.

According to IPCC, emission factor for heavy fuel oil is 3.15 kg CO_2 per kg of heavy fuel.
3000 to 5000 kg heavy fuel × 15 days = 45,000 to 75,000 kg fuel / month.
45,000 to 75,000 kg fuel × 3.15 = 141,750 to 236,250 kg CO2e / month

Monthly Total Emission from Oil Tanker
141,750 to 236,250 kg CO2e / month

APPENDIX J – ESTIMATION EMISSION FROM CATERRING, FOOD SUPPLY CHAIN GENERAL SERVICES TRUCKS (WAREHOUSE)

According to Al Sharara field stuff, two 10-ton trucks with built-in cooling systems are founded for catering logistics, this is done with two trips per week.

One trip per week for spare parts and warehousing products.

Total Distances traveled by trucks per month 11,200 km / month.

These heavy-duty trucks get about 35 liters of fuel every 100 kilometers.

Every round trip consists of 490 liters of diesel fuel.

3 trips / week × 490 L × 4 weeks = 5880 liters of diesel per month

According to IPCC emission factor of diesel is 2.68 kg CO_2

Catering, Food supply chain & general services trucks **5880 liters of diesel per a month × 2.68 = 15,758 kg CO2e / month**