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Unlocking sustainability: Navigating the vital transition in oil and gas field decommissioning

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Abstract

In today's dynamic oil and gas landscape, effective decommissioning stands as a pivotal challenge. It's a realm where decisions can no longer be deferred, where the stakes are high, and the path forward demands innovation. This paper embarks on an energy transformative exploration offering a Life Cycle analysis approach to estimate emissions entwined with decommissioning efforts. Through a meticulous gate-to-gate lifecycle analysis, this paper traverses the entire lifespan of oil and gas fields, from inception to closure. The model presents a methodological rigor, delves deep into the intricacies of decommissioning processes: from well plugging to plant dismantling, from onsite cutting to offsite fabrication. With a keen eye on sustainability, the study explores avenues for recycling and minimizing environmental impact. The analysis unveils the carbon footprint of decommissioning, with emissions quantified at 2.31x10-2 Kg CO2 Eq. per Mcf of natural gas produced and in this intricate tapestry, one truth emerges: well plug and abandonment, a seemingly mundane task that is part of each field development project, emerges as the primary contributor to emissions, casting a spotlight on areas ripe for improvement. The research charts a course towards a greener, more sustainable future for oil and gas decommissioning through better understanding of each stage of decommissioning through emission lens.

Keywords: Energy Transition; Decarbonization; Sustainability; Decommissioning

1. Introduction

The oil and gas industry operations are largely unfamiliar with large scale decommissioning projects, but much can be learned and transferred from other sectors and industries. Innovation and transformation are underway in the industry and will continue to be important for ultimate success, but more immediate incremental improvements and challenges to traditional approaches can also bring significant results. IHS estimates that USD 2.4 billion will be spent on offshore decommissioning of over 600 installations between now and 2020, over half of that in the North Sea and most of the rest in the Gulf of Mexico (Janeen Judah, 2017).

When a gas installation facility reaches the end of its operational life for commercial or engineering reasons, arrangements must be made for its abandonment and decommissioning. The decommissioning and abandonment process involves a whole range of activities and options open to the owner of the facility to safely removal all the installations, its disposal, reuse or recycle, rehabilitation of the facility area etc. The decommissioning process involves energy intensive operations which includes the utilization of heavy-duty cranes for lifting and loading purpose, lorries, and heavy-duty trucks to transport decommissioned infrastructure to the disposal or recycling sites, temporary fabrication for infrastructure dismantling and the recycling or reuse of the dismantled metal and materials. These energy intensive operations are a critical source of GHG emissions and therefore engineering tools are required to

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estimate their emissions accurately to optimize the decommissioning process. Many authors have studied the emissions during the operational life of gas field, however, have disregarded the carbon footprints during the decommissioning phase of gas facilities (Brown et al.,2016; Horwath et al.,2011; Hultman et al.,2011; Jiang et al.,2011; Burnham et al.,2011; Stephenson et al.,2011). This research aims to develop a model that incorporates several generic, structure and operation specific LCA calculations to estimate the energy used and emissions produced during decommissioning of a gas production facility. The GHG emissions associated with the decommissioning process of a field is calculated by this standard: Guidelines for the Calculation of Estimates of Energy Use and Gaseous Emissions in the Decommissioning of Offshore Structures,Institute of Petroleum., 2002

2. Methodology

LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave).

There are four phases in an LCA study:

- The goal and scope definition phase,
- The inventory analysis phase,
- The impact assessment phase, and
- The interpretation phase

The scope, including the system boundary and level of detail, of an LCA depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA.

The life cycle inventory analysis phase (LCI phase) is the second phase of LCA. It is an inventory of input/output data with regard to the system being studied. It involves collection of the data necessary to meet the goals of the defined study.

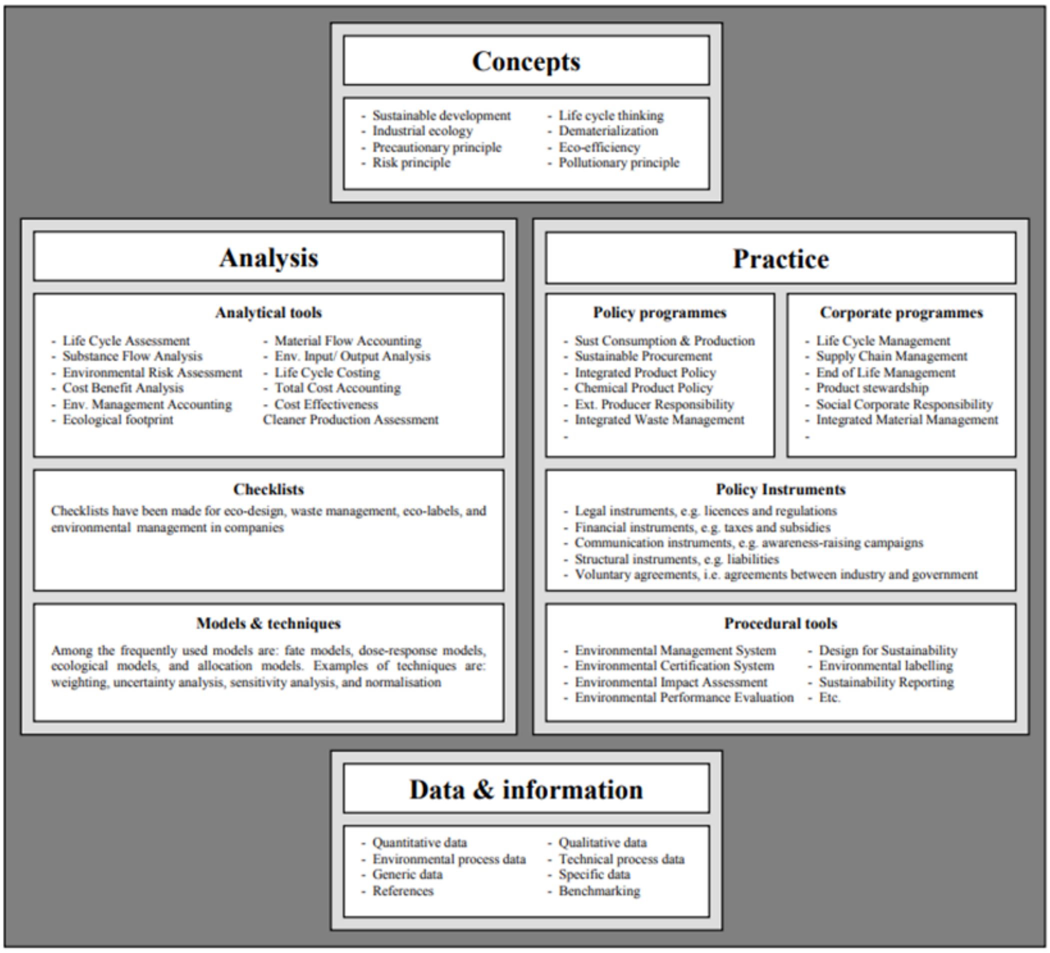
The life cycle impact assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance.

Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

The LCI analysis and modelling involves the data collection and implementation of calculation procedures to quantify relevant inputs and outputs of the product systems. Alternative types of approaches to conduct a life cycle inventory analysis (or modelling) are summarized and compared in Table 1.

An engineering model was built to estimate the emissions during the six distinct operations involved in the decommissioning process i.e. plugging and abandonment of gas wells, dismantling and transportation of plant facility, abandonment, removal and transportation of gas and produced water pipeline surface network, decommissioning of gas wells Christmas trees (wellheads), dismantling steel infrastructure and temporary fabrication during the dismantling operation, new manufacturing from raw material and recycling of dismantled metals. To assess the environmental burdens of decommissioning shale gas production, a life cycle inventory (LCI) model was created using the ISO 14040 standards and used to carry out the assessment. The system boundaries chosen to follow a gate-to-gate approach, with the primary aim to find both the greenhouse gas emissions (GHG) and toxic emissions from decommissioning shale gas production. The calculation of GWP (Global Warming Potential) is based on one hundred years using the IPCC AR5 accounting method (GWP 100 year for CH_4 is 28) to allow comparison with other published studies.

Table 1 Life cycle approaches, consisting of analysis and practice, are directed by concepts ad supported by data and information (modified from Wrisberg et al., 2002).



2.1. Goal of study

The objective of the study is to quantify GHG and toxic emissions of an assumed unconventional shale gas production well in the U.S. This assessment identifies the processes that have significant impacts on emissions, whereby providing the foundation for the development of policy and technology solutions that can then attempt to address these issues. The model also estimates the emissions involved in new manufacturing and recycling from the decommissioned material and metal infrastructure.

2.2. Scope of study

Each individual process in the shale gas field decommissioning associates upstream supply chain (energy, raw materials, product) and a downstream supply chain (emissions in air) that are included in this study to provide a full assessment of GHG and toxic emissions associated with gas installation decommissioning. The sources of emissions considered in the LCA include: emissions from the onsite energy utilization during dismantling, lifting and transporting the gas installations, production of material involved in the well plugging activities and emissions from fuel consumption during onsite and offsite cutting, fabrication, recycling and reuse of the raw materials and metals.

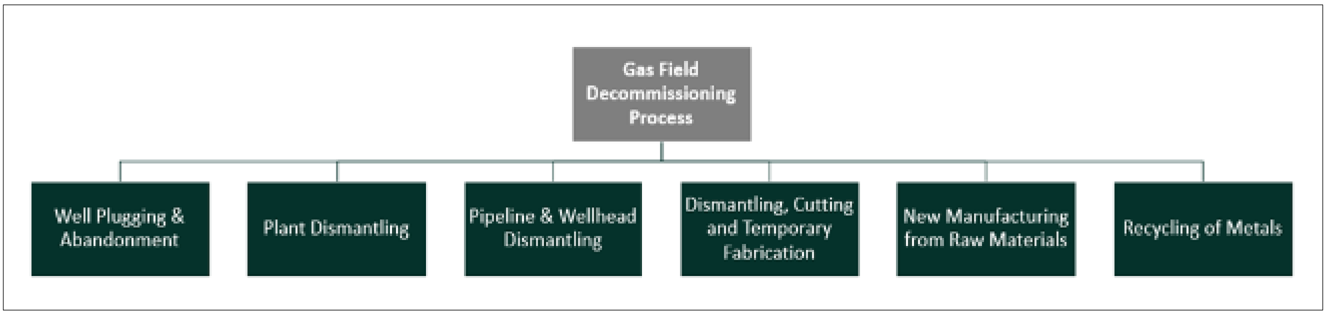


Figure 1 Gas Field Decommissioning Process

2.3. Functional unit

GHG emission estimates are reported in kilograms of carbon dioxide equivalent emission per thousand standard cubic feet of natural gas produced (kg CO_2-Eq./Mcf) and toxic emissions estimation are reported in kilograms of nitrogen oxides per thousand standard cubic feet of natural gas produced (kg NOx/Mcf), kilograms of carbon monoxide per thousand standard cubic feet of natural gas produced (kg CO/Mcf), kilograms of sulphur oxides per thousand standard cubic feet of natural gas produced (kg SOx/Mcf) and kilograms of methane per thousand standard cubic feet of natural gas produced (kg CH_4/Mcf).

2.4. Life Cycle inventory model development

The gas field decommissioning process involves several operations that include the utilization of heavy-duty lifting cranes, transportation means, temporary manufacturing from the raw materials and metals. These energy intensive operations are a large source of GHG emissions. The model splits the gas field decommissioning process into six distinct operations to estimate the GHG emissions during the decommissioning process (see Figure 1). The LCI model work flow is shown in Figure 2.

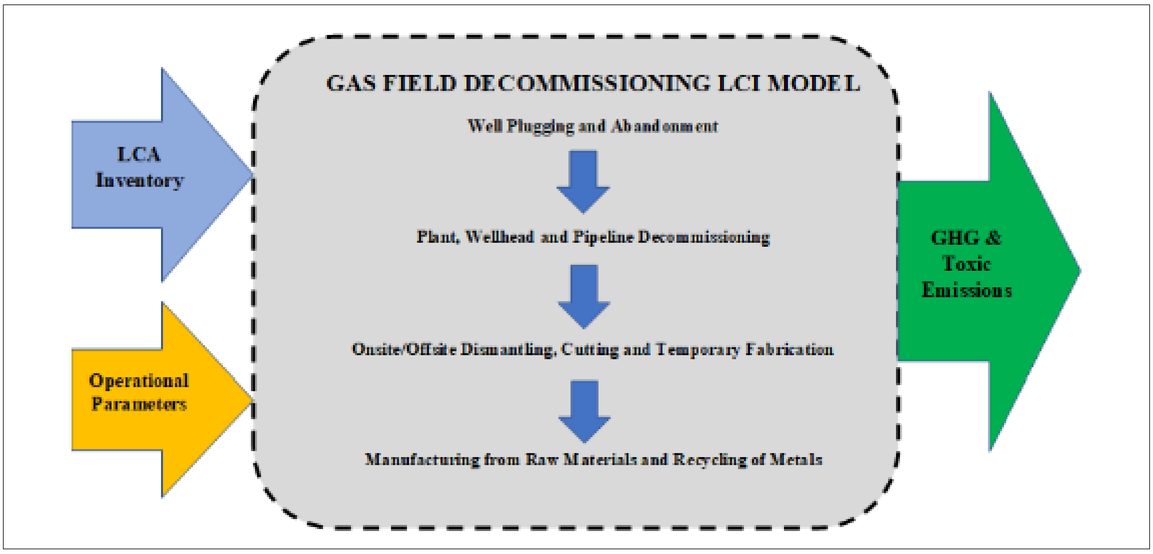


Figure 2 Workflow of LCI Model

2.5. Well Plugging and Abandonment

Wells are designed with multiple layers of casings to prevent pollutants from entering the environment. When a well is no longer required, it undergoes a decommissioning process called “plugging and abandonment”. This involves filling cement plugs in the wellbore to seal the wellbore against leaks, addition to the casing and cement that is already present. The well is then cut off several meters below ground, and the land remediated. Essentially well plugging restricts the pathway of reservoir fluids to leak into the atmosphere or contaminate fresh water reservoirs (at 150-300 feet) (Mary Kanga, 2014). This research work calculates the amount of cement at is needed for plugging 4,741 wells using inputs including number of plugs to be placed, plug volumes and casing specifications. The calculated amount of cement is linked with the emission factors for industrial manufacturing of cement to estimate the overall operation emissions (Figure 3).

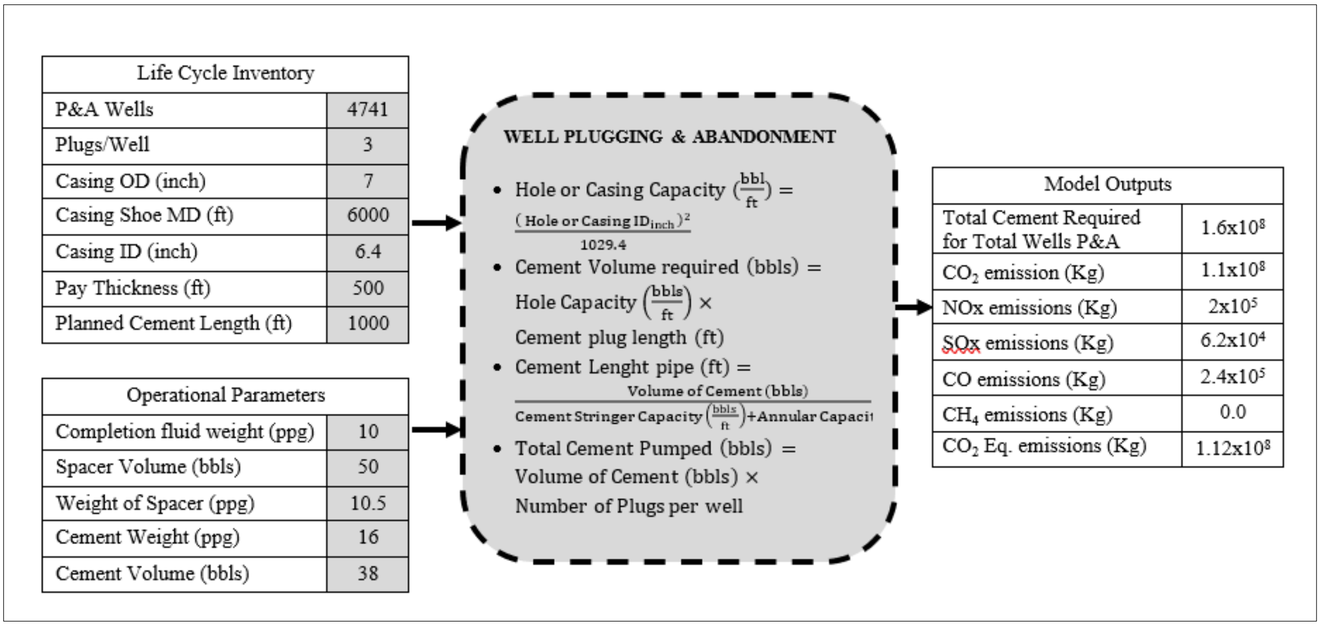


Figure 3 Workflow of well plugging and abandonment model

2.6. Plant, Wellhead and Pipeline Decommissioning Operations

Most air pollution emissions from plant decommissioning stem from the combustion of fuel by diesel engines of the heavy-duty cranes, which are used in virtually all phases and activities of the decommissioning process (Peter Cantley, 2014). The amount of engine fuel required is large, the engine horse power and likely age range is broad, the number of applications for which the engines are used is also considerable, and therefore the potential for air pollution emissions is correspondingly large (Brown, 1997). The emissions arising from the use of these cranes (heavy/light duty lifting cranes, Jib Tower cranes and site boom cranes) depends on the fuel efficiency of the combustion process (Institute of Petroleum, 2000). The model calculates diesel consumed by the cranes with the inputs including engine power, machine uptime, machine load and operational days etc. and links it with the emission factors to calculate the GHG emissions.

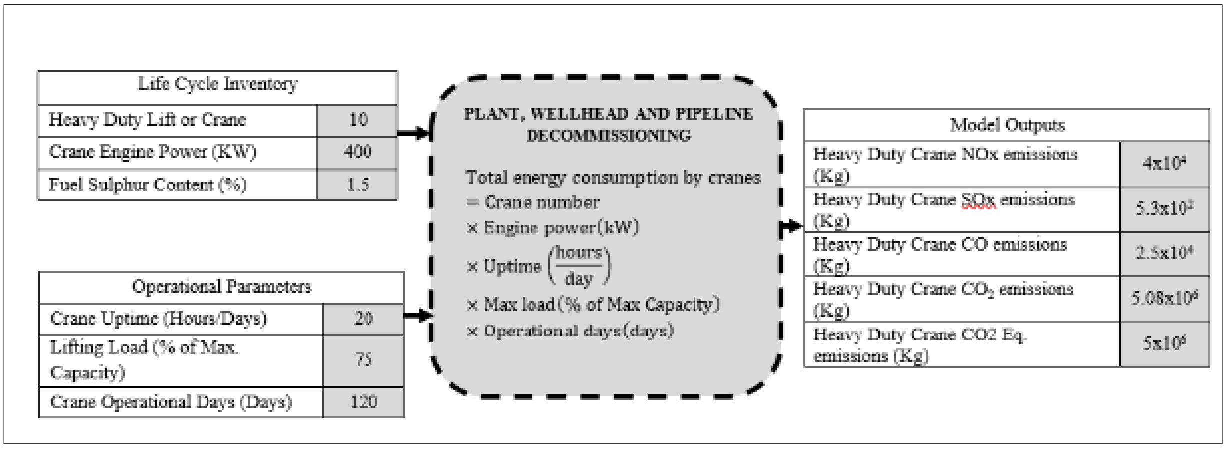


Figure 4 Workflow of Plant, Wellhead and Pipeline Decommissioning Model

2.7. Dismantling, Cutting and Temporary Fabrication

For the decommissioning process, some fundamental activities require metal cutting and dismantling (hot and hydraulic cutting), others require fabrication of temporary tools or frameworks for the dismantling operations (Institute of Petroleum, 2000). To estimate the GHG emissions from these operations, the model first calculates the energy consumption from cutting, dismantling and temporary fabrication per ton of steel by combining the amount of steel to be cut, fabricated and dismantled. The energy consumed is then linked with GHG emission factors for the above-mentioned operations to calculate the total GHG emissions.

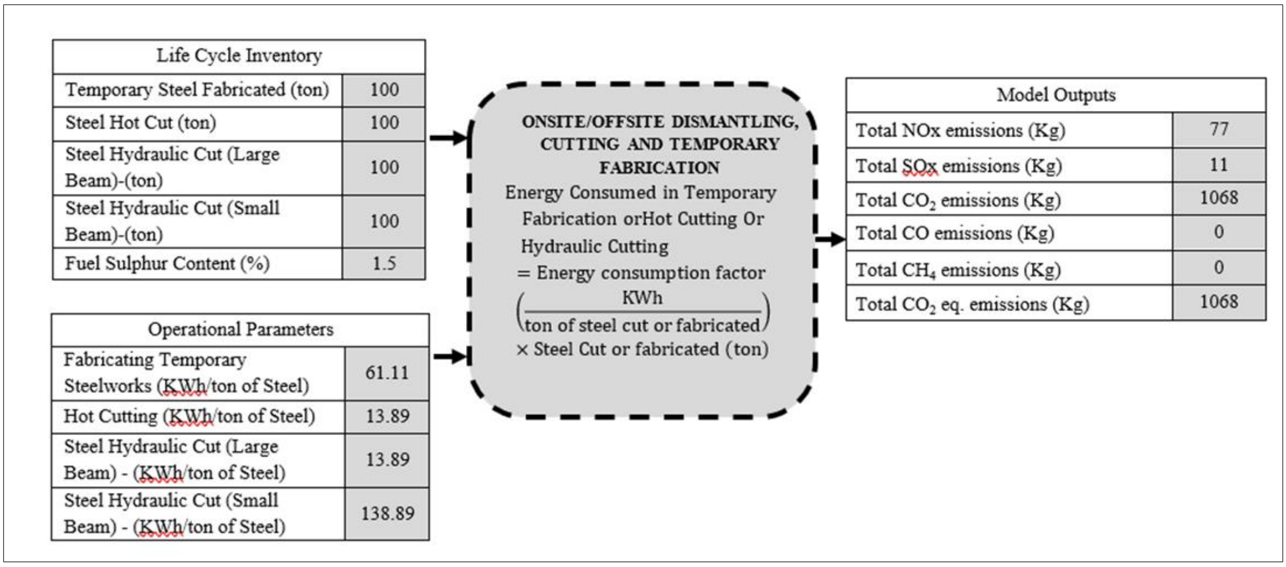


Figure 5 Workflow of Dismantling, Cutting and Temporary Fabrication Model

2.8. Manufacturing from Raw Material and Recycling of Metals

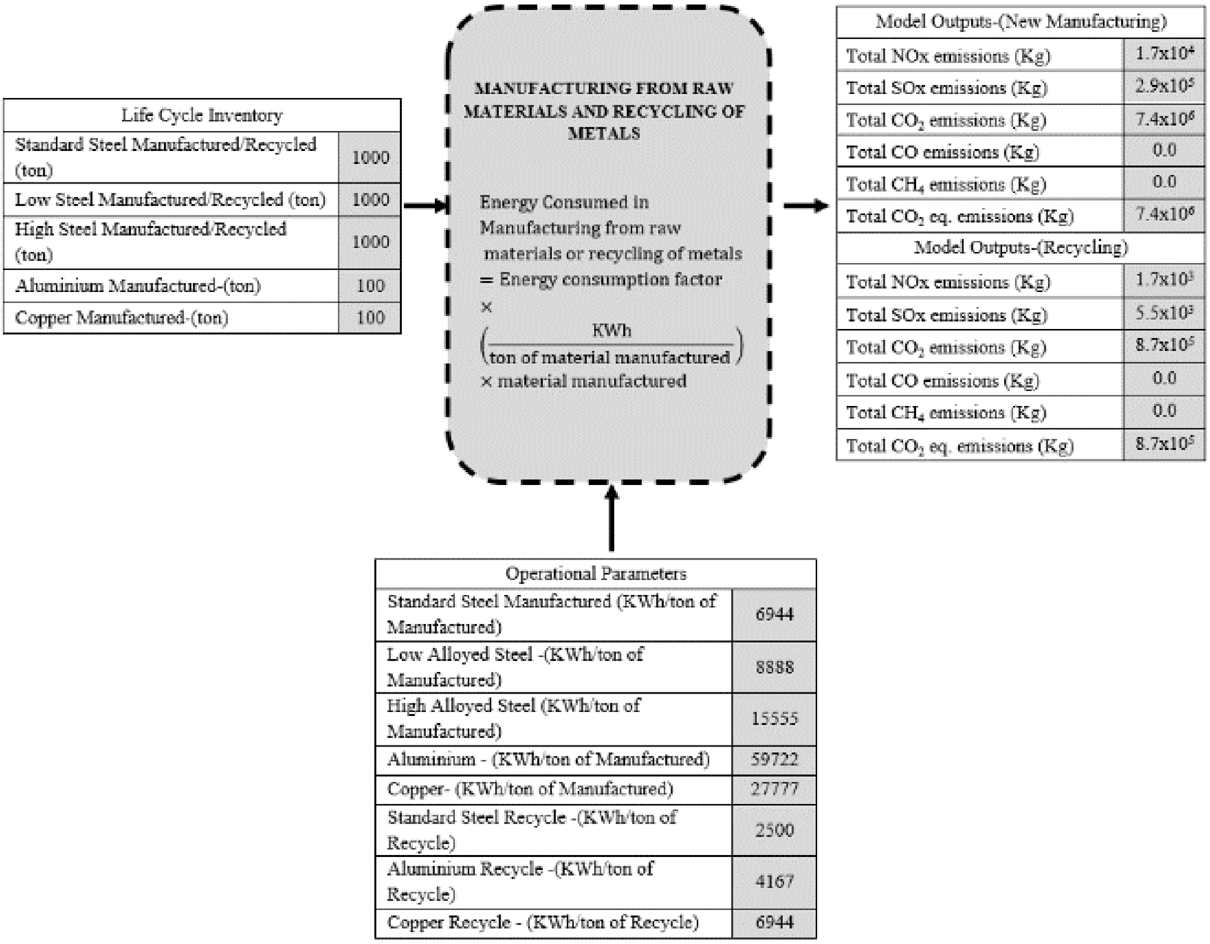


Figure 6 Workflow of Manufacturing from Raw Material and Recycling of Metals

It is important to estimate accurately all types of materials that are manufactured or recycled from raw material and metals as these operations require intensive use of energy. Such materials might include for example (a) recyclable materials in which there a great difference between energy needed to reprocess or manufacture it (b) materials that, because of their nature of toxicity, require special consideration and treatment during removal, dismantling transportation, storage and reprocessing or ultimately, disposal (Institute of Petroleum, 2000)

The model first calculates the energy consumption from the new manufacturing from raw materials and recycling of metal operations by combining energy consumption per ton materials manufacturing or recycling including Standard Steel, Alloyed Steel, Aluminum, Copper, Zinc, Concrete, Rock Wool and Explosives with the amount manufactured. The energy consumed is then linked with the emission factor to estimate the GHG emissions.

3. Results

3.1. Well Plugging and Abandonment

It is estimated that to plug 4,741 wells with three plugs per well each of 1000 feet length, 1.96×10^{-02} Kg CO2 eq. per Mscf of GHG emissions are produced.

3.2. Plant, Wellhead and Pipeline Decommissioning Operations

The plant, wellhead and pipeline decommissioning operations contribute 1.07×10^{-03} kg CO_2 eq. per Mscf of gas produced.

3.3. Dismantling, Cutting and Temporary Fabrication

These operations contribute 1.86×10^{-07} kg CO_2 eq. per Mscf of gas produced.

3.4. Manufacturing from Raw Material and Recycling of Metals

The new manufacturing from raw material operation contributes 1.28×10^{-03} kg CO_2 eq. per Mscf of gas produced while recycling of metal operation contributes 1.51×10^{-04} kg CO_2 eq. per Mscf of gas produced.

The GHG emissions from all the operations are shown in the Figures 7.

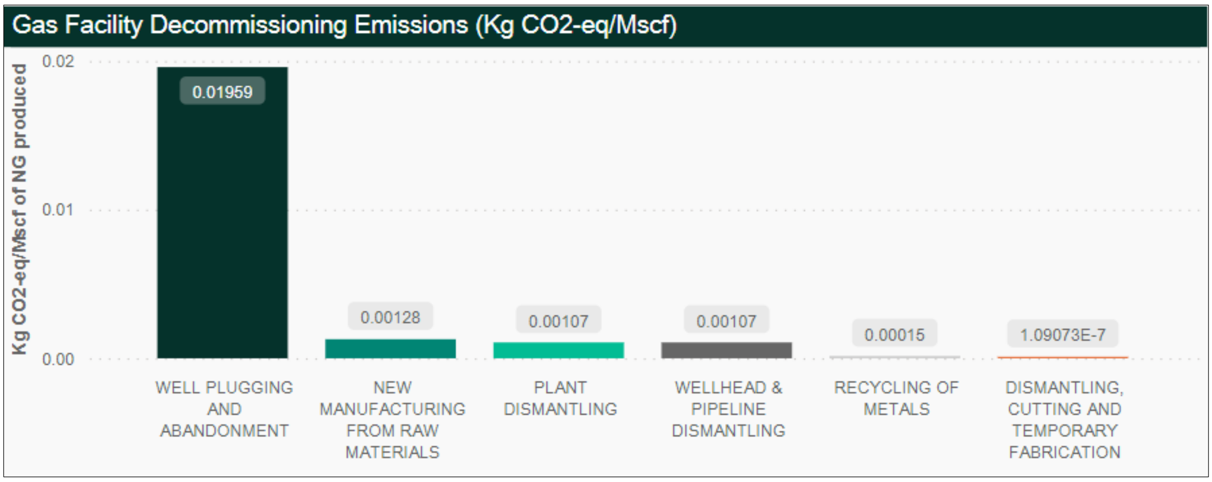


Figure 7 Gas Facility Decommissioning Emissions (Kg CO_2 eq. per Mscf)

4. Discussion

Considering the results reported here in comparison with other LCA studies, the GHG emission estimates by the model is around 2.31×10^{-2} Kg CO_2 Eq. per Mcf of the produced natural gas (total $132\times10^{+3}$ ton of CO_2 eq.) which is in line with the range available in published literature which ranges between 1.9 $\times10^{+3}$ to $4.6\times10^{+3}$ ton of CO_2 emissions during the decommissioning process of wellhead and pipeline decommissioning neglecting well plug and abandonment, plant dismantling, onsite and offsite cutting and temporary fabrication, new manufacturing from dismantled raw material and recycling of metals (Centrica Energy: Rose Field Decommissioning Environmental Impact Assessment, 2015). The GHG emissions from all the operations are shown in the Figures 8.

The comparative results shown above indicates that well plugging and abandonment operations appears to be the most important activity contributing 84.6% of the total field decommissioning operational emissions. Oil and Gas companies should design projects knowing that eventually they will be removed. By including eventual decommissioning and removal into initial project design it will make future clean-ups easier by reducing footprint of onshore fields and better life cycle waste stream management. While comparing the decommissioning emissions (in our case 2.31×10^{-2} Kg CO_2 Eq. per Mcf) with the available literature values for the emissions during the operational life of the field ranging between 7.1 to 68 Kg CO_2 Eq. per Mcf of gas produced (Brown et al., 2016; Jiang., 2011), it can be concluded that decommissioning contribution will be less than 1% as compared to the total emission from operational life of the field.

Our industry has a history of innovation through desperation and with the looming overhang of decommissioning costs, it's looking desperate. The high cost of decommissioning creates business opportunities for technology to cut costs while still protecting people and the environment. Innovative lift equipment can change the offshore decommissioning picture. New cementing and well monitoring can better ensure that groundwater and the environment are protected. Better project management can streamline operations. Using tanks instead of pits keeps contamination contained and forces better waste management. Offshore projects should keep better records and design platforms with a consideration for decommissioning. A little time and money spent upfront can save many millions in the future. New remediation techniques help soil impacted by crude oil or salt water recover faster. Cheaper can be better, especially when it incentivizes operators to clean up more and faster.

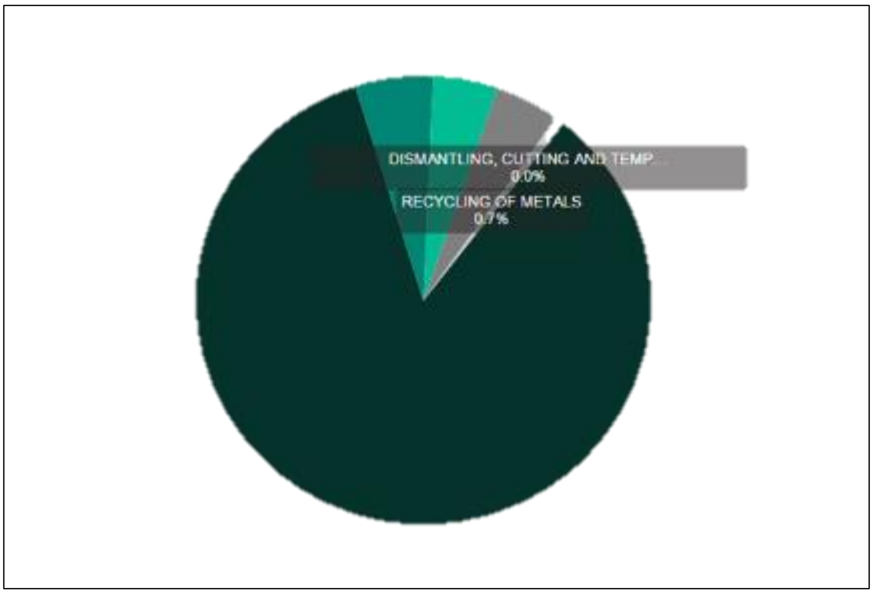


Figure 8 Gas Facility Decommissioning Emissions (% contribution)

5. Conclusions

- The GHG emissions from the considered gas field decommissioning operation estimated to be 2.31×10^{-2} kg-CO_2 eq. per Mcf of natural gas produced for total field production of 5.7 Tcf.
- Well plugging and abandonment operation contributes up to 1.96×10^{-02} kg-CO_2 eq. per Mcf of natural gas produced, 84.7% of total field decommissioning operational emissions.
- Plant dismantling operation contributes up to 1.07×10^{-03} kg-CO_2 eq. per Mcf of natural gas produced, 4.6% of total field decommissioning operational emissions.
- Wellhead and pipeline dismantling operation contributes upto 1.05×10^{-03} kg-CO_2 eq. per Mcf of natural gas produced, 4.5% of total field decommissioning operational emissions.
- Infrastructure dismantling, cutting and temporary fabrication contribution percentage is insignificant, with an emission of 1.86×10^{-07} kg-CO_2 eq. per Mcf of natural gas produced.
- New manufacturing from raw materials contributes up to 1.28×10^{-03} kg-CO_2 eq. per Mcf of natural gas produced, 5.5% of total field decommissioning operational emissions.

- Recycling of metals contributes up to $1.51x10^{-04}$ kg-CO_2 eq. per Mcf of natural gas produced, 0.7% of total field decommissioning operational emissions.

Compliance with ethical standards

Disclosure of conflict of interest

There is no conflict of interest.

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