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Contribution to the Development of a Simplified LCA Decision-Making Tool Applied to Metal Oil Platforms in Offshore Environments

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Abstract

Life Cycle Assessment (LCA) is a standardised methodology to evaluate environmental impacts associated with a product or service throughout its life cycle. This study develops and validates a simplified LCA decision-making tool tailored for offshore metallic oil platforms (OMPs) in the Gulf of Guinea. The goal is to reduce the data collection burden typically associated with LCA, while maintaining a representative assessment of the environmental footprint. Simplified LCA models have gained increasing attention due to their ability to provide rapid assessments without compromising decision quality [1] [2]. The research involved defining the scope and system boundaries for a reference "PAPA" jacket-deck platform. Key impact categories were selected, including resource depletion, climate change, human toxicity, ecotoxicity, acidification, and eutrophication. A screening and evaluation of various LCIA methods (ReCiPe, CML, USEtox) were conducted. A qualitative sensitivity analysis was performed to prioritize key parameters, and the simplified model was implemented using SimaPro 9.2 (starter version) with Ecoinvent processes. The simplified model's results were compared to a full LCA analysis of the PAPA platform. The analysis revealed that the use phase dominates the environmental impacts across most categories, including climate change, resource depletion, eutrophication, and ecotoxicity. The transport phase was identified as the second most significant contributor. The simplified model demonstrated an efficiency of 85.7% compared to the comprehensive LCA, confirming its potential for rapid environmental assessment. The simplified LCA tool offers a robust and time-efficient approach for environmental decision-making related to offshore platform projects in the Gulf of Guinea. This fills a regional research gap, as most LCAs are conducted in the North Sea or Gulf of Mexico [3]. However, limitations related to data availability for manufacturing and end-of-life stages, and the need for regionalized LCA methods, remain areas for future improvement.

Keywords

LCA, Simplified Method, Environmental Footprint, Offshore Oil Platform, Gulf of Guinea

1. Introduction

The escalating demands of industry, mass consumption, and energy needs are major contributors to global environmental degradation [4] [5]. Offshore oil platforms, in particular, have significant environmental footprints, with emissions of CO_2, CH_4, NO_x, SO_x, and wastewater discharges contributing to climate change, acidification, and marine ecosystem disruption [6] [7].

Life Cycle Assessment (LCA) is a powerful methodology for evaluating and comparing impacts across the life cycle of products or activities, allowing identification of improvement opportunities without shifting burdens [8] [9]. However, full LCAs are often data-intensive, complex, and time-consuming, limiting their adoption in fast-paced industries such as offshore oil and gas [1].

To address this, researchers have proposed simplified LCA models that reduce data requirements while maintaining scientific validity [2]. For instance, streamlined LCAs focusing on key indicators such as energy use and GHG emissions have been successfully applied in infrastructure and industrial sectors. Yet, very few studies focus on offshore metallic platforms in the Gulf of Guinea, despite the region's growing oil activity and ecological sensitivity [5].

This study develops a simplified LCA decision-making tool specifically adapted to OMPs in the Gulf of Guinea, aiming to balance scientific robustness with practical usability for decision-makers.

2. Literature Review: LCA Tools and Specificity of the Proposed Model

In recent years, the complexity and data requirements of conventional Life Cycle Assessment (LCA) have led to the development of streamlined or simplified tools designed to support decision-making while reducing costs and time. These approaches, often referred to as "streamlined LCAs," focus on a reduced set of parameters and impact categories while ensuring a representative evaluation [1].

Several simplified LCA tools have been proposed in the literature:

- The "Envest tool" (BRE, 2010) is used in the construction sector and provides a single aggregated score based on a limited set of environmental indicators.
- The "SURF-LiSET framework" simplifies evaluation through a reduced matrix of indicators, focusing on the most sensitive life cycle stages [10].

- In agrochemicals, a rapid estimation method correlates process mass intensity with CO_2 emissions to provide a proxy for carbon footprint [11].
- For industrial systems, Kiemel *et al.* (2022) proposed simplified approaches focusing on energy and climate indicators as proxies for broader environmental impacts.

While these tools have proven useful, they present significant limitations. Most are highly sector-specific (construction, materials, agrochemicals) and not adapted to the offshore oil industry. Moreover, few incorporate regionalized data suitable for developing contexts such as Africa [3]. Some tools also privilege usability over scientific robustness, providing quick but less representative results.

The model developed in this study addresses these shortcomings by offering:

1) "Sectoral specificity": It is one of the few simplified LCA tools designed explicitly for offshore metallic oil platforms, a sector with substantial environmental impacts yet limited LCA research.

2) "Regional adaptation": It fills a geographic research gap by being tailored to the Gulf of Guinea, where offshore operations are expanding but inventory data remain scarce [3].

3) "Scientific robustness": Unlike many streamlined tools, this model rigorously integrates recognized LCIA methods (ReCiPe, CML, USEtox), ensuring methodological soundness.

4) "High representativity": The model achieves 85.7% accuracy compared to a full LCA, demonstrating that simplification does not compromise reliability.

Therefore, the proposed tool represents an original contribution by combining methodological rigor, sectoral relevance, and regional adaptation, offering decision-makers in the Gulf of Guinea a practical yet scientifically valid means to assess the environmental impacts of offshore oil platforms.

3. Material and Methods

The objective is to develop a generic methodological framework for a simplified LCA model. This model incorporates LCA parameters (life cycle inventory flows and impact indicators), key contributors (materials, products, and processes), and life cycle stages (extraction, transport, manufacturing, use, and end-of-life), the contrary of the full LCA baseline that refers to the comprehensive life cycle model developed in accordance with ISO 14040 and ISO 14044 standards. The full model represents the complete environmental assessment of the offshore metallic platform and serves as the benchmark against which the simplified model is evaluated.

The full LCA includes:

System boundaries (cradle-to-grave):

- Raw material extraction and processing
- Steel production
- Fabrication of platform components
- Transportation and offshore installation
- Operational maintenance during the service life

- End-of-life dismantling and waste treatment

The comprehensive full model includes all relevant processes, material flows, energy inputs, and emissions required to capture the environmental profile of the offshore platform across its entire life cycle.

The aim is to enable future users to efficiently estimate the environmental impacts of Offshore Metallic Platforms (OMPs) using a limited set of parameters.

The methodological approach is based on the following five stages (**Figure 1**) [12]:

1) Definition of Study Framework: Establishing objectives, scope, hypotheses, and system boundaries.

2) Reference Sample Definition: Defining the system's life cycle and relevant environmental impact categories.

3) Identification of Key Parameters: Identifying the parameters that significantly influence the environmental performance of OMPs.

4) Selection of Assessment Methods: Choosing appropriate methods for assessing life cycle impacts.

5) Sensitivity Analysis: Conducting sensitivity analyses of selected methods and indicators.

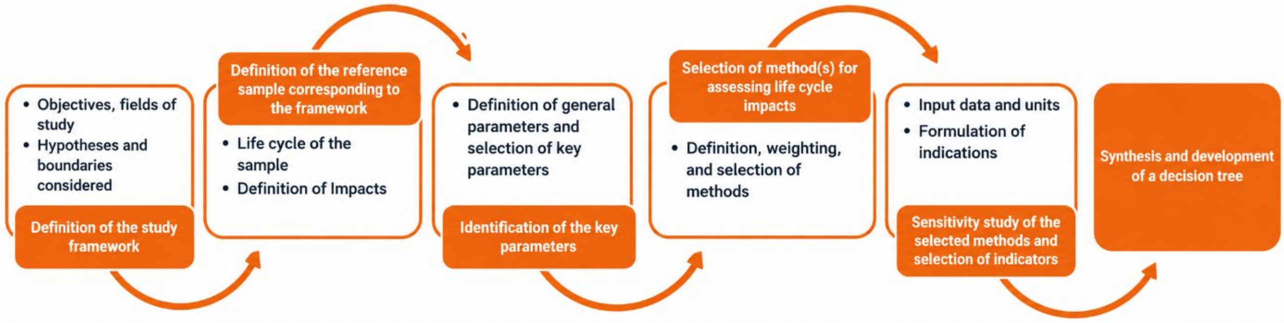

Figure 1. Methodological framework of the study.

3.1. Step 1: Definition of the Study Framework

The study is intended for users, decision-makers, investors, and researchers interested in LCA applications, particularly in the Gulf of Guinea. It provides a simplified, internationally recognized assessment tool that supports environmental considerations in offshore oil exploitation contracts.

The expected result is a simplified LCA model that enables qualitative and quantitative assessment of the environmental impacts of offshore installations, particularly OMPs, throughout their life cycle.

The geographical scope of the study is primarily Cameroon and the Gulf of Guinea, with some impacts considered globally. The Gulf of Guinea is part of the Atlantic Ocean, extending along the west coast of Africa (**Figure 2**).

Working hypotheses

- Hypothesis 1: Impacts will be studied on a global and local scale, guiding the selection of impact assessment methods.

Figure 2. Gulf of Guinea.

- Hypothesis 2: OMPs are prefabricated elsewhere and transported to the installation site.
- Hypothesis 3: Manufacturing duration is estimated at 3 years, representing the maximum duration for large oil platforms [13].
- Hypothesis 4: The lifespan of an offshore platform is assumed to be 30 years [13].
- Hypothesis 5: At the end-of-life stage, the OMP is dismantled and returned to land for overhaul.
- Hypothesis 6: Impacts due to nuisances are neglected due to their subjective nature and lack of a validated evaluation method.

3.2. Step 2: Reference Sample Definition

The purpose of defining the reference sample is to enable the calculation of the environmental performance of the system selected in Step 1. To achieve this, it is necessary to first establish an explicit life cycle model. The system studied here is an offshore metallic platform (OMP) in the Gulf of Guinea, aimed at identifying all potential sources impacting the natural environment—both positively and negatively. Secondly, it is essential to associate the related environmental impacts at each stage in a synthetic and methodical manner, categorizing them according to the approach proposed by ISO 14000 for effective life cycle analysis. The life cycle of OMPs for this study is summarized by **Figure 3** as follows:

The ecological problems that offshore oil and gas projects can cause are mainly linked to the following elements:

- Atmospheric emissions
- Wastewater discharges
- Management of solid and liquid waste
- Nuisances
- Spills

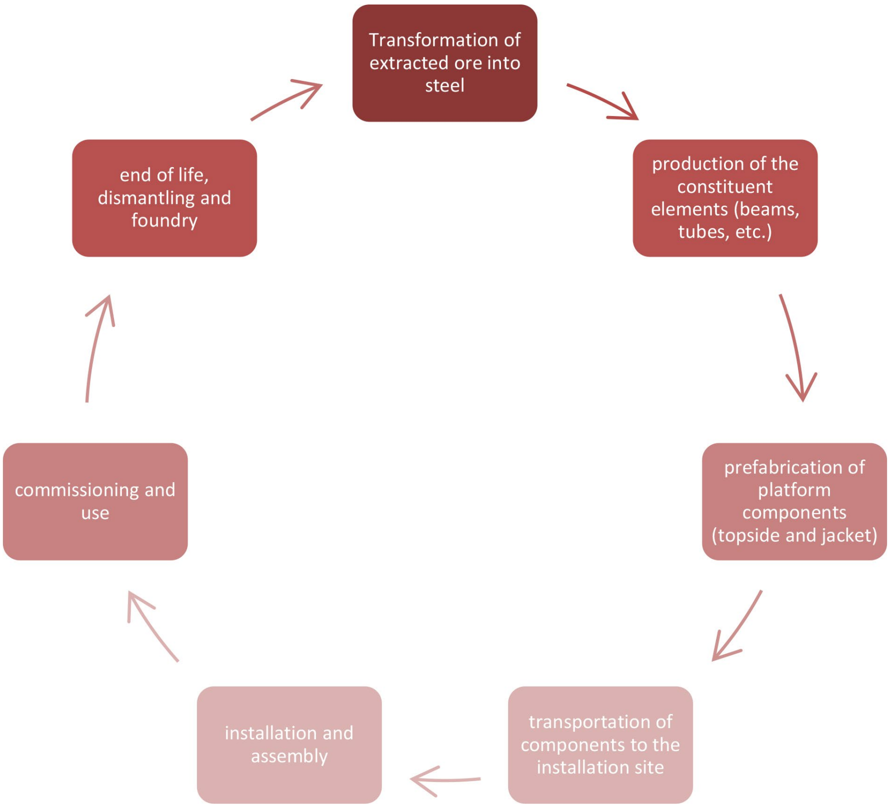

Figure 3. Life cycle of a metal platform.

From the above, the impact categories retained for offshore oil installations are:

- Impact categories relating to incoming flows: The depletion of natural resources.
- Impact categories relating to outgoing flows: The greenhouse effect (climate change), acidification, population health (human toxicity), acidification, population health (human toxicity), pollution of natural environments and ecosystems (Eutrophication of the aquatic environment. Ecotoxicity (aquatic and marine sedimentation)).

3.3. Step 3: Key Parameters Identification

The selection of parameters or indicators requires consideration of their influence on the environmental response of the system. Data and hypotheses collected previously in steps 1 and 2 are analysed through sensitivity studies (Table 1).

Table 1. Main contributing substances to the identified impacts.

Impact categories	Main contributing substances
The depletion of natural resources	Mineral and fossil resources (ore, oil, wood, coal, etc.)
Climate change	CO_2, CH_4, N_2O, NOx SOx H_2S, COV, CO, BTEX, HAP
Human toxicity	Heavy metals, NH_3, CO, SO_x. H_2S

Continued

Ecotoxicity	Heavy metals, NH_3, CO, SO_x.CxHx, sound waves
Acidification	SO_x, NO_x, NH_3, HCl, HF
Eutrophication	Nitrogen compounds (including NOx) and phosphorus compounds (including PO_4^{3-}), x-rays and infrared

As part of this work, the selection of key parameters was conducted through a qualitative analysis of the contributors, based on environmental study reports that relay the contributors' impacts according to their frequency, quantity, and duration of emissions for each impact category studied. Therefore, the following parameters were used:

- The 4th GEIC assessment report of 2007 to determine the key parameters for the impact: climate change.
- Methodological framework for the prioritization of micropollutants in aquatic environments established by the national expert committee for the prioritization of aquatic micropollutants scientific and technical program year 2012 to determine the key parameters of aquatic impacts.

However, it should be remembered that numerous studies on the choice of key parameters relating to the study of sensitivity are underway in the LCA field but are for the most part incomplete [14] (**Table 2**).

Table 2. Main contributing substances selected.

Impact categories	Main contributing substances
The depletion of natural resources	Mineral and fossil resources
Climate change	CO_2, CH_4,
Human toxicity	Heavy metals, NH_3
Ecotoxicity	Heavy metals, NH_3
Acidification	SO_x, NO_x, NH_3
Eutrophication	Nitrogen compounds (including NOx) and phosphorus compounds (including PO_4^{3-}),

3.4. Step 4: Selection of Assessment Methods

The selection of methods for assessing life cycle impacts is crucial for ensuring the scientific validity of the simplified model [7]. In the absence of African-specific methods, the choice of methods must align with the environmental profiles of the geographical area.

After method selection, an evaluation system is established to achieve a quantitative assessment. The objective of this evaluation and then selection is not to determine which method is the best overall, but to define which method(s) it is preferable to use for each given impact category, according to current scientific knowledge. To do this, a comparative evaluation grid comprising 05 criteria was designed.

The evaluation criteria were extracted from three main sources: the ISO 14044:2006 standard (ISO, 2006b), the ILCD Handbook: Framework and requirements for LCIA models and indicators from the JRC and various scientific books and articles dealing with methods of evaluation. impact assessment in LCA, including the Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards. These criteria are as follows:

- Recognized scientific bases in relation to current knowledge.
- Substances considered.
- Geographic spatial differentiation (countries, regions, etc.).
- Methodological manual.
- Internal and external communication.

Recognized scientific bases compared to current knowledge.

This criterion judges whether the methodology used by the impact assessment method is based on scientific bases with consensus in view of current knowledge. The validity of scientific models ensures that potential impacts on the environment will be assessed by reflecting reality as closely as possible. Thus, this criterion favors a method using consensus scientific models. A method using models with a lot of uncertainty, or qualitative bases will be disadvantaged.

Substances considered.

The different impact assessment methods do not make it possible to calculate the potential effects on the environment for the same number of substances. For example, for the impact category "photochemical smog formation", CML 2002 covers 127 substances, while TRACI covers 529. Thus, it could happen that a substance that is in the ICV is covered by TRACI, but not by CML 2002. This criterion therefore evaluates ICV methods based on the number of substances they include. An ICV method covering a high number of substances will be advantageous [15].

Geographic spatial differentiation (countries, regions, etc.)

In the context of the comparative evaluation grid, the expression "geographic spatial differentiation" focuses on the country or continent covered, as well as the levels of differentiation available within that area. For example, the TRACI impact assessment method covers the United States. In addition, for certain impact categories, TRACI makes it possible to specify the geographic area by offering subdivisions by large regions (area east of the Mississippi, etc.), by states or even by county [16]. The finer the spatial differentiation, the closer the assessment of potential environmental impacts will be to reality. This criterion therefore looks at whether the ÉICV method offers several levels of geographical spatial differentiation and favors the one which is closest to the characteristics of the Gulf of Guinea or the one which is global.

Methodological manual

This criterion looks at whether there is a manual (or at least scientific articles) which clearly and completely explains the methodology on which each impact category treated by the ÉICV method is based. Given the complexity of the models used by ICV methods, it is important to have access to such a manual, especially for non-experts. Thus, the more complete, easily understandable, and easily accessible the manual (if there is one), the more advantageous the ICV method will be.

Internal and external communication

The intermediate and damage individual impact categories are not ideal for internal and external communication. This criterion will therefore favor ICV methods which offer both intermediate impact and damage categories.

Evaluation and selection of EIAM methods

There are more than 12 recognized EIAM methods. To conduct an objective evaluation and avoid assessing methods that do not align with the fundamental criteria from the outset, five EIAM methods have been pre-selected based on the following criteria:

- Internal and external communication: methods have been pre-selected, which offer an intermediate and damage-oriented analysis.
- Geographical spatial differentiation: methods corresponding to two types of spatial differentiation have been retained, namely: Europe and/or United States and global because no method specific to the African continent in general and the Gulf of Guinea in particular has seen the day to date.

Based on this preselection, five methods were chosen: CML 2002, EDIP 2003, ReCiPe, TRACI, and USEtox, which specifically addresses two categories of impacts (human toxicity and aquatic ecotoxicity). To enable a quantitative evaluation, a rating scale has been developed (see Table 3).

The evaluation of the selected methods is condensed in Table 4.

Table 3. Legend for quotation.

Evaluation criteria	Quotation	Description
Recognized scientific bases	1	Based on scientific bases with uncertainties
	2	Based on internationally recognized scientific bases but presents certain uncertainties
	3	Based on internationally recognized and consensus scientific bases
Substances considered	1	Number of substances considered much lower (at least 10) than the number of the method with the largest number
	2	Number of substances considered lower (at most 10) than the number of the method with the largest number
	3	Method with the largest number of substances
Geographic spatial differentiation	1	other
	5	Global method
Methodological manual	1	Non-existence of manual or paid access
	2	Existence of manual but not very detailed
	3	Existence of a detailed and free manual
Internal and external communication	1	Problem-oriented or intermediate method exclusively
	3	Damage and problem-oriented method

Table 4. Evaluation of pre-selected EIAM methods.

Impacts	EIAM method	Scientific bases	Number of substances	Spatial differentiation	Methodological manual	Internal and external communication	TOTAL
Depletion of natural resource	CML 2002	1	1 (88)	5	3	1	11
	EDIP 2003	1	1 (33)	5	1	1	9
	ReCIPE	1	3 (112)	5	2	3	14
	TRACI	1	/	5	1	1	8
	USETox	N/A	N/A	N/A	N/A	N/A	N/A
Climate change	CML 2002	3	1 (56)	5	3	1	12
	EDIP 2003	3	1 (77)	5	1	1	11
	ReCIPE	3	2 (95)	5	2	3	15
	TRACI	3	3 (104)	5	1	1	13
	USETox	N/A	N/A	N/A	N/A	N/A	N/A
Human toxicity	CML 2002	2	1 (859)	1	3	1	7
	EDIP 2003	2	1 (181)	1	1	1	5
	ReCIPE	2	3 (1204)	1	2	3	10
	TRACI	2	1 (1076)	1	1	1	5
	USETox	3	1 (1100)	5	1	3	13
Ecotoxicity	CML 2002	2	1 (892)	5	3	1	12
	EDIP 2003	2	1 (192)	1	1	1	5
	ReCIPE	2	1 (1342)	1	2	3	8
	TRACI	2	1 (380)	1	1	1	5
	USETox	3	3 (2519)	5	1	1	13
Acidification	CML 2002	3	3 (24)	0	3	1	10
	EDIP 2003	3	1 (12)	1	1	1	6
	ReCIPE	3	1 (4)	1	2	3	9
	TRACI	3	2 (17)	1	1	1	7
	USETox	N/A	N/A	N/A	N/A	N/A	N/A
Eutrophication	CML 2002	2	3 (54)	5	3	1	13
	EDIP 2003	3	1 (12)	1	1	1	6
	ReCIPE	3	1 (93)	1	2	3	9
	TRACI	3	1 (18)	1	1	1	6
	USETox	N/A	N/A	N/A	N/A	N/A	N/A

From Table 4, it is retain that:

1) For the impact categories "depletion of natural resources" and "climate

change" the selected method is ReCIPE.

2) For the impact categories "Human toxicity" and "Aquatic eco toxicity" the selected method is USETox.

3) For the impact categories "Acidification" and "Eutrophication" the method used will be CML 2002.

3.5. Step 5: Studies of Selected Methods and Selection of Indicators and Functional Units

Step 5 of the methodology consists of studying the different methods selected according to the degree of impact:

- The input data it needs to characterize the impact and their units.
- The formula of its indicator.
- The output data which makes it possible to obtain.

During this study, it was noted that for each impact, the indicators for its characterization depend on the evaluation method selected.

This paragraph raises the question on how to highlight the characteristics of impact indicators according to the selected EIAM method. The elements presented are taken from the methodological manuals of the selected methods, which will validate the calculations, as these methods are recognized by the scientific community.

ReCIPE method

The ReCIPE method was selected to characterize the impacts of climate change and resource depletion of natural resources. As specified in hypothesis 1, this study will focus on midpoint or intermediate analysis, the ReCIPE method is a hybrid method. However, only the characteristics of midpoint indicators will be presented (Table 5). Therefore, the table below summarizes the characteristics of the indicators used to calculate the impacts of climate change and depletion of natural resources with the ReCIPE method [1].

Table 5. Characteristics of indicators with the ReCIPE method.

Impacts categories	Indicators	Characteristics
	Midpoint indicators	Climate change (CC)
	Substances	Greenhouse gas
Climate change	midpoint indicator unit	kg (CO_2 to air)
	Midpoint characterization factor	GWP
	Midpoint Characterization Factor Unit	- (or kg/kg)
	Midpoint indicators	Mineral depletion (MD)
	Substances	Minerals mined
Depletion of natural resources	midpoint indicator unit	Kg of minerals; MJ of fossil fuel
	Midpoint characterization factor	Mineral depletion potential (MDP)
	Midpoint Characterization Factor Unit	- (ou kg/kg or MJ/MJ)

USETox method

From the above, the USETox method was selected for the "Human toxicity" and "Aquatic eco toxicity" impact categories. Like any EIAM method, USEtox aims to understand the relative importance of individual emissions during the life cycle of the system studied, which is done by a weighted summation of the substances emitted by the system, the impact score in USEtox is given by the following formula:

$$IS = \sum_i \sum_x CF_{x,i} \times m_{x,i}$$

with:

IS The impact score for example for the human toxicity impact IS refers to the disease cases listed.

$CF_{x,i}$ the characterization factor of substance x emitted in region i (disease cases/kg at midpoint level or DALY/kg at endpoint level).

$m_{x,i}$ The mass emitted by substance x in region i (kg).

With the USEtox method, substances that have the potential to increase cases of disease in humans have a "human toxicity factor" which derives from the product of three matrices, namely: the "Fate Factor" (FF), "human exposure factors (XF)" and the "human toxicological effect factor (EF)" so the characterization factor can be written as follows:

$$CF = EF \times XF \times FF \times CF = EF \times iF$$

with

iF The inhaled fraction (the fraction of the mass emitted and inhaled by the population in a specific region).

The table below summarizes the characteristics of the indicators used to calculate these impacts with this method. Similar to ReCIPE, only the characteristics for midpoint evaluation are presented (see Table 6).

CML 2002 method

The CML method is one of the most recognized, proven and regularly updated methods. According to many authors and researchers in the LCA community, it provides the most comprehensive method for characterizing impacts on eutrophication of aquatic environments. As part of this study, it was selected for the

Table 6. Characteristics of indicators with the USETox method.

Impacts categories	Indicators	Characteristics
Human toxicity	Midpoint characterization facto	Human toxicity potential
	Substances	Any substance classified as dangerous for humans
	Midpoint Characterization Factor Unit	CTU_h (Cas/kg_{emited})
Ecotoxicity/aquatic toxicity	Midpoint characterization facto	Ecotoxicity potential
	Substances	Any substance classified as dangerous for humans
	Midpoint Characterization Factor Unit	PAF.m^3/kg_{emited}

characterization of the "Acidification" and "Eutrophication" impacts. The table below summarizes the characteristics of the indicators for calculating Acidification and Eutrophication impacts (Table 7).

Table 7. Characteristics of indicators with the CML method.

Impacts categories	Indicators	Characteristics
Acidification	Impact indicator	Acidifying potential
	Substances	Nitrogen oxides and sulfur products
	Unit	$KgSO_2$ equivalent
Eutrophication	Impact indicator	Concentration of nitrogen and phosphorus Formation of biomass (algae)
	Substances	Nitrogen compounds (including NOx) and phosphorus compounds (including PO_4^{3-})
	Unit	kg PO_4^{3-} kgN equivalent

Synthesis

The execution of the methodology clearly illustrates the various elements that could constitute the stages of the simplified LCA model. To summarize this model and facilitate its rapid implementation, a procedural diagram in the form of a flowchart is presented below (see Figure 4).

Although the impact assessment method used in the study is not region-specific, the regional adaptation of the simplified LCA tool is implemented at the inventory and scenario levels rather than within the impact characterization method.

The regional adaptation for the Gulf of Guinea offshore context includes:

- Case study parameters

  - Platform dimensions and material quantities representative of offshore infrastructure in the Gulf of Guinea.

  - Operational lifetime consistent with regional offshore oil and gas projects.

- Operational conditions

  - Marine transport distances based on regional logistics.

  -Installation procedures typical of offshore developments in West Africa.

- End-of-life scenarios

  - Recycling assumptions reflecting the limited local recycling infrastructure and typical export of scrap steel.

- Energy context

  -Electricity mix assumptions reflecting regional energy supply conditions where applicable.

In addition, due to limited availability of primary industrial data for certain life cycle stages, particularly manufacturing and end-of-life operations, proxy data and assumptions were used to complete the inventory model.

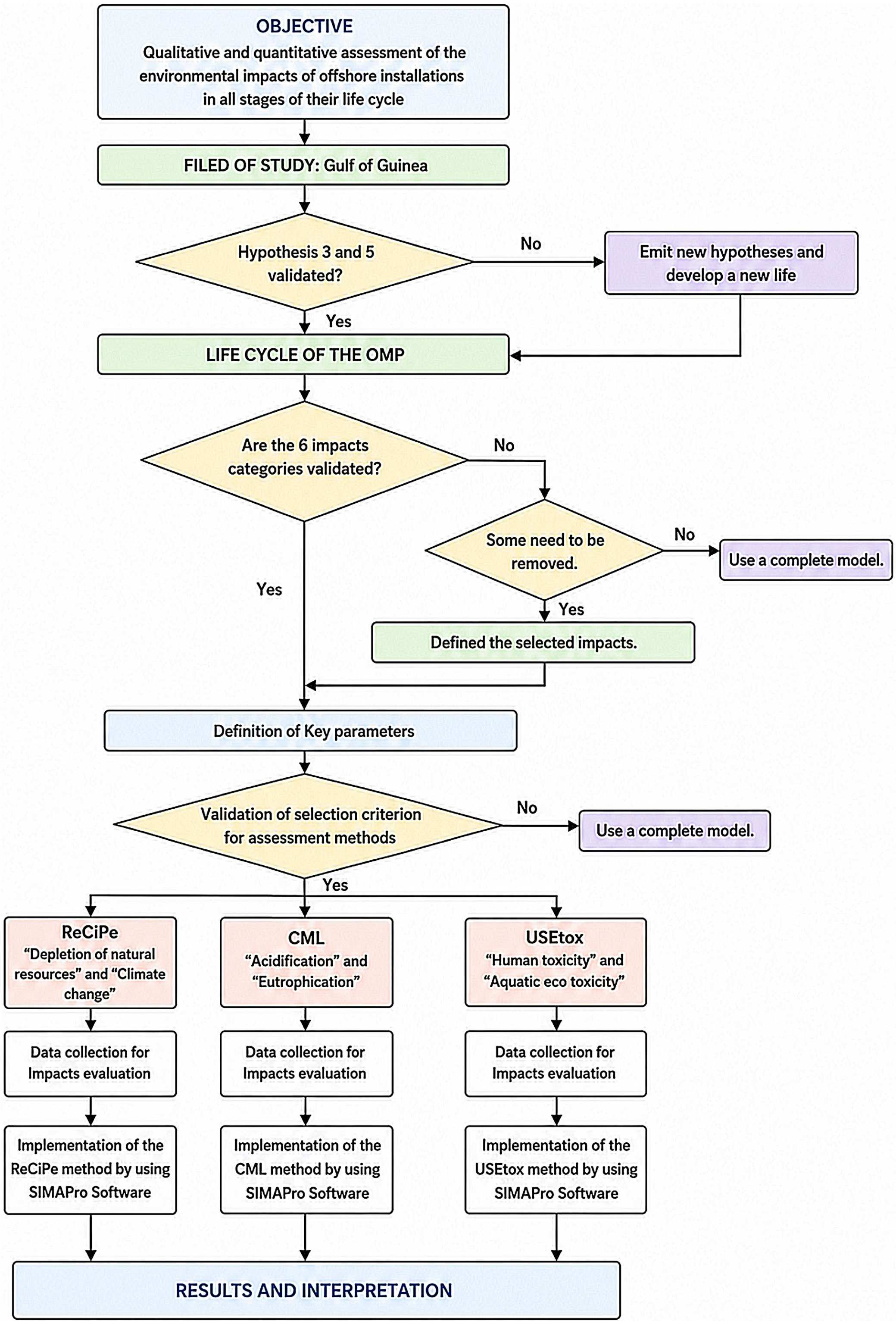

Figure 4. Procedure for implementing the proposed simplified LCA model.

Specifically:

- Manufacturing processes were modeled using proxy datasets from the Ecoinvent database, including generic datasets for steel plate rolling, welding operations, and industrial electricity consumption.

- End-of-life scenarios were modeled using representative steel recycling datasets, assuming typical industrial recycling rates based on literature values for offshore structures.
- When specific regional data were unavailable, global or European datasets from Ecoinvent were used as approximations, while maintaining consistency with the material and energy flows of the system.

4. Tool Implementation

After having developed a simplified model and set up a procedure for its execution, it is appropriate for us, to validate the model, to apply it in an appropriate context on an offshore metallic platform "PAPA" in offshore Cameroon.

4.1. Definition of the Objectives and Boundaries of the Study

The aim of this study is to determine the environmental impacts associated with each stage of the life cycle of the "PAPA" metal oil platform, utilizing the simplified LCA model developed in the previous chapter. This will help validate the simplified model and demonstrate its effectiveness, flexibility, and quality as an environmental assessment method. Additionally, the study will highlight the robustness of this method in assessing environmental impacts, employing scientifically validated tools recognized by a large scientific community.

- Hypotheses and boundaries of the study

  The elements considered are the following:

  - Regarding the stages of the life cycle of the "PAPA" platform to calculate the effects.
  - The construction of the platform including the manufacturing of components (steel beams, tanks, tubes, gratings, etc.) and the assembly of the topside and jacket elements.
  - Transport of the topside and jacket from the manufacturing sites to the installation site.
  - Use.
  - End of life, dismantling and recycling.
  - Concerning the stages of the life cycle of the "PAPA" platform not taken into account during the calculations due to insufficient or even inaccessible data.
  - Processing of raw materials.
  - Extraction of raw materials.
  - Transportation of materials from raw material extraction.
  - Design and exploration phase.

4.2. Impact Categories and EIAM Methods

- Impact categories

  Using the development carried out in the previous paragraph, the impact categories retained for the oil installation are as follows:

✓ Categories of impacts relating to incoming flows
- The depletion of natural resources

✓ Categories of impacts relating to outgoing flows
- Climate change
- Acidification
- Population health (human toxicity)
- Eutrophication of the aquatic environment
- Ecotoxicity (aquatic and marine sedimentation)

Despite the influence of the nuisance category (noise and odours), in the context of this work, these impacts were neglected.

- EIAM methods

The EIAM methods are selected according to the methodology defined and developed in paragraph **2.4**. The following methods are identified as EIAM methods:

- For the impact categories "depletion of natural resources" and "climate change" the method used will be ReCIPE.
- For the impact categories "Human toxicity" and "Aquatic eco toxicity" the method used will be USETox.
- For the "Acidification" and "Eutrophication" impact categories, the method used will be CML 2002.

4.3. Data Collection

The "PAPA" oil platform is a metallic platform classified in the category of "JACKET-DECK" platforms because it has a 6-foot supporting structure and a "topside" including production equipment (pretreatment equipment of crude oil) and living quarters. It was prefabricated in the United States in the HOUSTON region, transported and assembled offshore Cameroon in 1990 when it was put into service; its oil pretreatment equipment allows pretreatment of more than thirty thousand barrels of crude oil per day (30,000 Barrels/day) and its living quarters have a capacity for more than 120 employees.

- Date of commissioning: 1990
- Lifespan: 30 years+
- Leg length: 126 m under the sea and 30 m above
- Production: 30,000 barrels of oil per day

The image (**Figure 5**) below is a photo of the "PAPA" platform.

- Life cycle inventory

An inventory of the total mass of steel used in the platform and its manufacturing process was conducted (**Table 8** and **Table 9**).

Transport and assembly.

The transportation of components (topside and jacket) from the "PAPA" platform to the final assembly location (offshore Cameroon) was done by sea using barges.

Table 10 below condenses the data collected on the ships which transported

Figure 5. PAPA offshore metallic platform.

Table 8. Total mass of steel of the "PAPA" platform.

	Mass (t)	Mass (%)
Steel	43 000	96%
Other	/	4%

Table 9. Manufacturing processes for the constituent elements of the platform.

Material	Processesused	Element	Mass
Iron-ore	Reduction	Metal/iron	/
Metal	Refining	Steel	43,000 t
Steel	Hot rolling + cutting	Beams	23,650 t
Steel	Hot rolling + cutting	Unwelded hollow tubes	10,750 t
Steel	Cold rolling + cutting + bending + welding	Tanks	2150 t
Steel	Electroforging + cutting	Grating	6450 t
Element	Welding	Assembled platform	43,000 t

Table 10. Characteristics of barges and vessels carrying PAPA platform.

	Characteristics		Distance travelled (km)
Num. of barges = 2	Type 1: convoy pushes medium formation for the jacket	Capacity = 18,000 t Length = 172 m Width = 34.2 m	11,664
	Type 2: convoy pushes long formation for the topside	Capacity = 27,000 t Length = 270 m Width = 22.80 m	
Num. of barges = 2	Length = 40 m Width = 11.40 m Motor Power = 6000 CV		11,664

the elements of the platform and the distance travelled by them.

Use

After its installation and commissioning, the oil platform is operated and used for the objectives of its construction, namely the production or pretreatment of oil and for the case in point; the "PAPA" platform is pretreatment. crude oil and on-site employee accommodation.

The main sources of pollution based on activities on the "PAPA" platform are therefore summarized in the table below (see Table 11).

Table 11. Polluting activities and contributor data.

Impacts categories	Activities/processes	Contributors	Characteristics
The depletion of natural resources	Operation of mechanical equipment	Diesel and engine oil consumption by equipment	146 gal/day
	Crude oil pretreatment	Petroleum-derived chemicals for crude oil processing	400 gal/day
Climate change	Atmospheric emissions (exhaust fumes, flaring, tank purging, etc.)	Emission of CH_4	30 mscf/month during 30 years
		Emission of CO_2	10,000 mscf/day during 30 years
Human toxicity	Solid and liquid waste management Spills Wastewater discharges	Heavy metals, H2S	500 barils/day
Ecotoxicity (aquatic and marine sedimentation)	Solid and liquid waste management Spills Wastewater discharges	Heavy metals	500 barel/day
Acidification	Solid and liquid waste management Spills Wastewater discharges	HCl	140 barel/day
Eutrophication of the aquatic environment	Solid and liquid waste management Spills Wastewater discharges	Nitrogen compounds (including NO_x) and phosphorus compounds (including PO_4^{3-})	1000 barel/day

4.4. Modeling and Calculating Impacts with SimaPro

Using the software, a simulation was conducted under the conditions mentioned above, employing the Ecoinvent database. The first step involves building the process tree, which includes selecting materials from the software database and creating the processes relevant to the system in question. Table 12 lists the elements selected for this case study and their correspondences in the chosen database.

The software offers several impact calculation methods, allowing the user to select the method that best fits their case study. In accordance with the simplified model proposed above and the starter version of the SimaPro software, impact calculations were performed using two EIAM methods, resulting in two models, each calculating the related impacts. Once the method is selected, the software performs the calculations and presents the results ingraphs.

Table 12. Main selected processes and their correspondences in SimaPro.

	Materials/Processes	Name in SimaPro's Ecoinvent database
Raw material	Steel	Steel, chromium steel 18/8 {RER}| steel production, converter, chromium steel 18/8 | Alloc Def, S
Production of the components	Hot rolling	N/A
	Cold rolling	N/A
	Cutting	N/A
	Folding	N/A
	Electroforging	N/A
	Welding	N/A
Assembly	Welding	Electricity, high voltage {ASCC}| market for | Alloc Def, S
Transport	Boat	Transport, ocean freighter, diesel powered/tkm/RNA

- Modeling of "climate change" and "depletion of natural resources" impacts and Interpretation

The calculation and modeling of these impacts were carried out using the ReC-IPE method, Figure 6 illustrates the results obtained after calculating the impacts of climate change and depletion of natural resources of the "PAPA" oil platform.

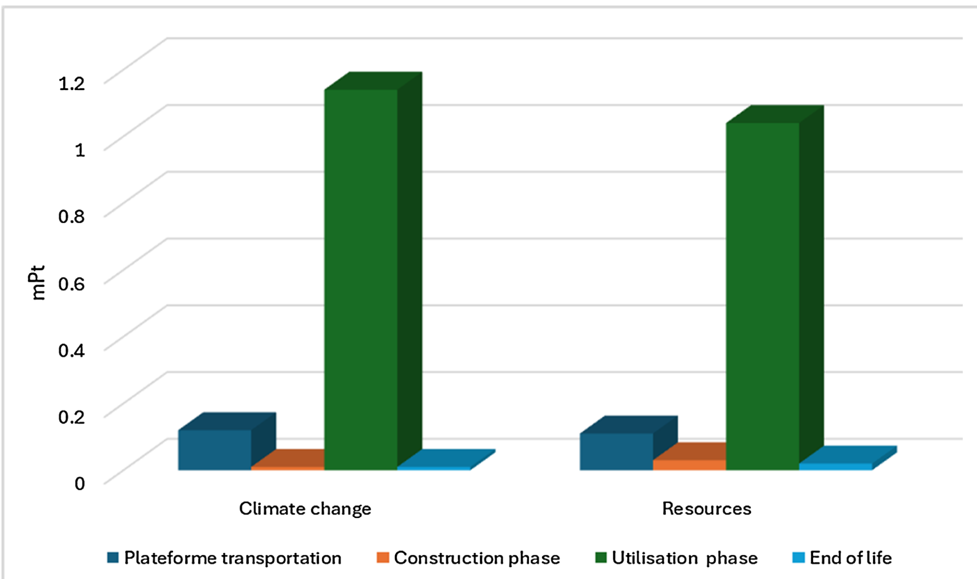

Figure 6. Impacts of climate change and depletion of natural resources.

The results obtained after calculating the impacts of climate change and depletion of natural resources represented by Figure 6 show us that:

The phase of the life cycle of the "PAPA" platform which generates the most impacts both in the climate change category (with a score of 1.14 mPt) and in the resource depletion category (with a score of 1.04) is the use phase; the transport phase follows with scores of 0.0919 mPt for resources and 0.102 for climate change.

The dismantling and construction phases have the least impact on the climate and resources with scores less than 0.09 mPt.

- Modeling of "human toxicity", "aquatic ecotoxicity" "Acidification" and "eutrophication" impacts

The calculation of these impacts was carried out using the CML 2002/WORLD method available in the SimaPro software; Figure 7 illustrates the results obtained from the impact assessment after calculation.

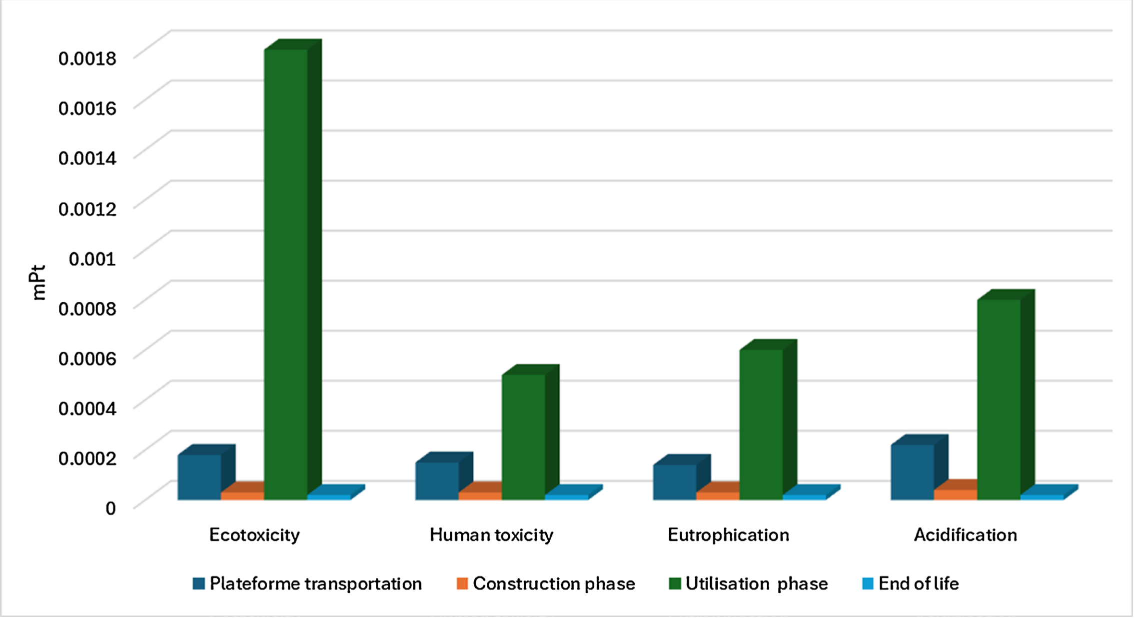

Figure 7. Impacts of human and aquatic ecotoxicity, eutrophication and acidification.

Examining this graph, it clearly appears that:

- The use phase of the platform has the most significant impact on human health and the environment, particularly in the categories of eutrophication, acidification, and ecotoxicity, achieving a notably high score of 0.0018 Pt compared to other phases and categories.
- The transport phase also has considerable effects, primarily in the acidification and ecotoxicity categories.
- The dismantling and recycling phase presents the lowest scores across all impact categories, indicating a minimal effect.
- Additionally, Figure 7 illustrates that the construction phase has negligible effects on the aquatic environment, which can be attributed to the platform being constructed on dry land.

4.5. Modeling of All Impacts

This paragraph proposes to model all environmental impacts, including those not included in the simplified model, using the CML 2002/WORLD method. The choice of the CML 2002/WORLD method is based on its high weighted averages across nearly all impact categories during the evaluation and selection of methods (see Table 4). Additionally, this method is available in the starter version of SimaPro.

The results of this calculation are represented in the graph below (Figure 8).

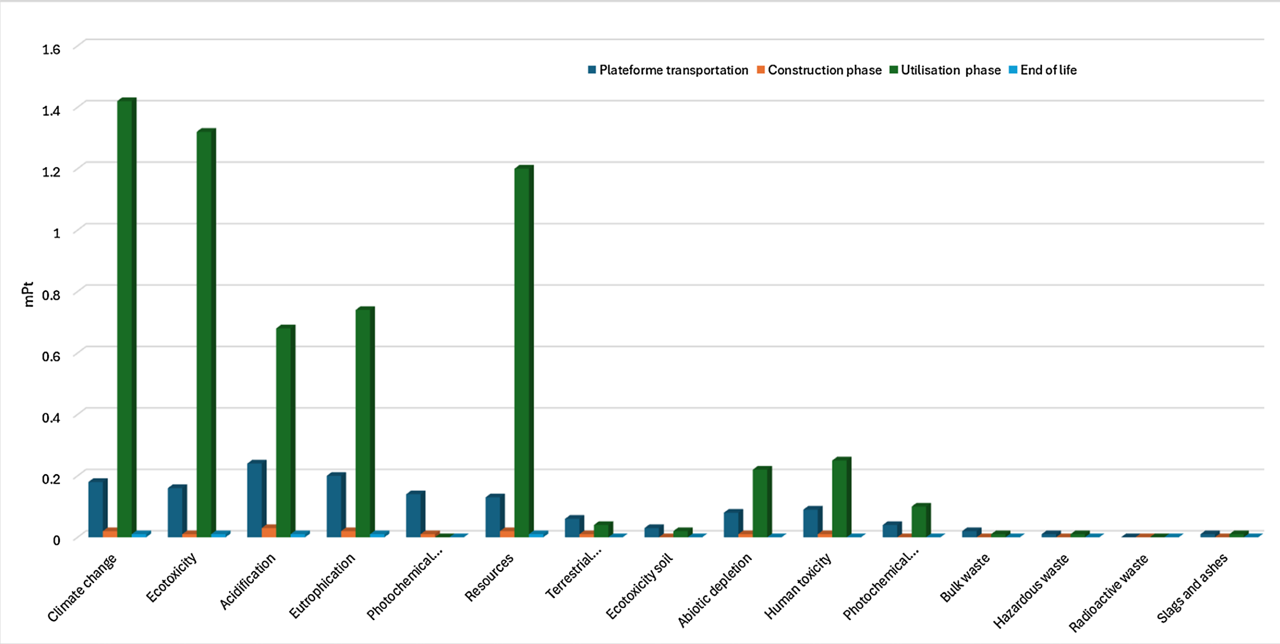

Figure 8. Modelling all platform impacts using SimaPro.

4.6. Results

The analysis confirmed that:

- Use phase dominates environmental impacts, particularly GHG emissions and resource depletion, aligning with global studies on offshore platforms [6].
- Transport phase is the second contributor, due to long-distance barge operations.
- Construction and dismantling phases show lower impacts, though this may reflect data gaps rather than negligible impacts [17].
- The simplified model achieved 85.7% accuracy relative to a full LCA. The comparison was performed across the selected impact categories using the following equation:

$$Accuracy = \left(1 - \left(\left| Result_{simplified} - Result_{full} \right|\right) / \left(Result_{full}\right)\right) \times 100$$

where:

- $Result_{simplified}$ represents the number of selected environmental impact calculated using the simplified model

- $Result_{full}$ represents the number of significant environmental impacts calculated obtained from the complete LCA model.

The comparison was performed for the major impact categories including Climate Change, Acidification, Eutrophication, Human Toxicity, Fossil Resource Depletion and Ecotoxicity. The average deviation between both models was calculated, resulting in an overall mean accuracy of 85.7%, indicating that the simplified model reproduces the majority of the environmental impact trends captured by the full LCA while significantly reducing modelling complexity, confirming that a reduced parameter set can provide reliable decision support while saving significant resources.

5. Discussion

The simplification of the LCA model has been a recurring theme in sustainability research since the seminal work of Todd *et al.* (1999), which established the foundations for streamlined approaches within SETAC. Recent studies continue to emphasize that full LCAs, while comprehensive, are often impractical in industrial settings due to their substantial data requirements and high costs [1] [2]. The findings of this study align with this literature, demonstrating that simplification can be achieved without compromising representativity, provided that key impact categories and phases are carefully selected.

A key outcome of this study is the confirmation that the use phase overwhelmingly dominates the environmental impacts of offshore metallic platforms. This observation aligns with global evidence from offshore oil and gas operations, where operational emissions of CO_2, CH_4, and NO_x—primarily from flaring, venting, and fuel combustion—are consistently identified as critical contributors to climate change and air pollution [6] [7]. In the Gulf of Guinea, where oil exploitation is expanding rapidly, this result underscores the urgent need for operational improvements such as flaring reduction technologies, methane leak detection systems, and stricter wastewater management [3].

The transport phase emerged as the second most impactful stage, largely due to the long-distance maritime transport of prefabricated platform components. This finding is consistent with recent assessments of supply chains for large industrial infrastructures, where heavy transport and logistics account for a substantial share of life cycle emissions [17]. However, the results for the construction and dismantling phases showed relatively minor impacts, which may be partly attributed to data limitations. Similar challenges have been reported in the literature; dismantling data for offshore platforms remain scarce, and construction inventories are often underestimated due to a lack of transparency from fabrication companies [18]. This suggests that the model, while robust, may still underestimate impacts during these phases.

An important contribution of this work is the demonstration that a simplified LCA model can achieve 85.7% accuracy compared to a full LCA. Few streamlined tools report such validation rates, and this level of reliability enhances confidence in the tool's applicability for decision support. In contrast, some simplified models in other sectors—such as construction (Envest tool) or agrochemicals [10]—tend to sacrifice representativity in favor of usability. This model avoids that trade-off by rigorously integrating well-established LCIA methods (ReCiPe, CML), However, due to software compatibility limitations within the open LCA modelling environment, the USEtox method could not be consistently applied across all modelled processes. Consequently, the CML 2002 midpoint method was used to assess toxicity-related impact categories.

While CML 2002 provides established characterization factors, it should be noted that it does not incorporate the same level of fate, exposure, and effect modelling as USEtox. As a result, toxicity impact results presented in this study should be interpreted with caution.

Future work should aim to incorporate USEtox-based characterization to improve the robustness and representativeness of toxicity assessments.

Moreover, the originality of this contribution lies in addressing a regional research gap. While most offshore LCA studies have focused on the North Sea or Gulf of Mexico [2], very few exist for West Africa. By tailoring the tool to the Gulf of Guinea, this study provides a rare and much-needed regional perspective. This is critical, as environmental conditions, regulatory frameworks, and operational practices in African contexts differ significantly from those in industrialized regions.

Nonetheless, some limitations must be acknowledged. The absence of African-specific characterization factors in LCIA methods constrains the precision of impact assessments. Regionalized models capturing local ecotoxicity, water scarcity, and social-environmental dynamics would enhance accuracy [5]. Additionally, while this tool is validated for jacket-deck platforms, its applicability to floating production systems or hybrid offshore structures remains to be tested.

Most importantly, this study addresses a regional gap: while LCAs for offshore installations are well-documented in the North Sea and Gulf of Mexico, very limited data exist for West Africa. This work provides a foundation for region-specific tools, supporting more sustainable oil operations in the Gulf of Guinea. It is also important to point out avenues for methodological and data improvements in future research.

6. Conclusions

This research developed and validated a simplified LCA decision-making tool for offshore metallic platforms in the Gulf of Guinea. The tool provides an efficient way to assess environmental impacts with reduced data requirements, achieving 85.7% accuracy compared to full LCA.

By addressing a methodological and geographical gap, this study supports decision-makers and oil companies in integrating environmental considerations into planning and operations. It provides a replicable framework for simplified LCAs in data-scarce contexts and highlights the urgent need for regionalized LCIA methods tailored to African environmental conditions.

In conclusion, this tool has the potential to enhance sustainability in offshore oil projects by enabling faster, more accessible, and scientifically robust environmental assessments.

Author Contributions

Jesus Assaguina Bodiong: Conceived study, designed methodology, analyzed data, edited manuscript.

Aime Elime Bouboama: Designed methodology, drafted the manuscript, validated the results, provided resources, final editing, supervised.

Deodonne Kunwufine: drafted and reviewed the literature, developed the system boundary/scope; selected the impact assessment method, implemented the software/model, reviewed the manuscript.

Giscard Desting Nimpa: Implemented the inventory modelling (life cycle inventory); validated the scenario assumptions, reviewed and edited the manuscript.

Jacques Rémy Minane: interpreted results (LCA outcomes); drafted the discussion, reviewed and edited the manuscript.

Joyce Ursula Merveille Pettang Nana: drafted the manuscript(abstract/intro/methods); reviewed and edited the manuscript.

All authors contributed significantly, approved final manuscript, agreed on journal, and take full responsibility for the work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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