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Option: Environment

Coupled modeling of environmental impacts and risks of offshore exploration drilling by Life Cycle Assessment. Case study: Skikda coastline

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Dedication

I dedicate this modest work:

To my family, she who doubted me of a dignified education, her love made me what I am today:

To man, my precious offer of god, who owes my life, my success and all my respect: my dear father Mohammed

To the woman who suffered without letting me suffer, who never said no soul demands and spared no effort to make me happy: my adorable mother Karima

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To all the cousins, neighbors and friends I've known so far

«Thank you for their love and encouragement»

Lairedj Nawal El Batoul

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I dedicate this modest work accompanied by a deep love to her who watered me with tenderness and hope, to the source of love, who taught me supported me and guided me towards glory in my life my mother Mira

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"Thank you for always being there for me"

Rouabhia Hadjer

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1,4-DB eq: 1,4 dichlorobenzene equivalent (Reference substance for human toxicity in the CML method)

DALYs: Disability-Adjusted Life Years

CML: Centrum voor Milieukunde Leiden (Leiden Center for Environmental Sciences)

IFP : French Petroleum Institute

LCA: Life cycle assessment

LCI: Life cycle inventory

PAH: Polycyclic aromatic hydrocarbon

PDF: Potentially Disappeared Fraction of species

TEW: Total emissions in water

TEC: Total emissions in all compartments

WHO: World Health Organization

PAM: Mediterranean Action Plan

INTRODUCTION

The increasingly growing pace of the global economy has led to a rapid increase in energy demand. However, conventional fossil fuels such as coal, oil and natural gas, which have been a key source of energy since the industrial revolution, are not only threatened with depletion; but they have also gradually become a source of concern for their serious adverse effects on our environment.

Since the 1950s, oil and gas extraction from the seabed has grown steadily, despite the recent diversification and expansion of onshore oil and gas operations. It has been estimated that hydrocarbons located deep offshore today concentrate around 30% of the world's conventional resources yet to be discovered. Offshore production corresponds to 30% of world oil production and 27% of gas production. These percentages have remained stable since the beginning of the 21st century, despite the strong onshore development of unconventional hydrocarbons such as bituminous or bituminous sands and shale hydrocarbons. Technological innovation allows oil exploration to discover reserves that are more difficult to access. Today, nearly 2/3 of new discoveries are offshore reserves. Thus, offshore exploitation has been the subject of colossal investments on the part of the States, evaluated in total at 100 billion dollars per year. This is particularly the case of Europe, which today produces 17% of the oil buried in the underwater environment (Planete Energies 2015).

The depletion of stocks now leads oil companies to dig deeper and deeper with the use of extremely expensive and complex advanced technologies, thus increasing the risk of accidents. The offshore industry shows that offshore oil and gas sites have a higher level of risk than any other industrial site on land (Kaasen, K. 2013). For example, the malfunction of an oil platform in the Gulf of Mexico in 2010 caused one of the worst oil spills in history with 780 million liters of oil that spilled into the Atlantic Ocean for 85 days.

In Algeria, the national hydrocarbon company Sonatrach plans to carry out its first offshore oil drilling in 2023. This first drilling will highlight the identified potential on the perimeters on which Sonatrach operates with partners. These are two perimeters, one located in the East between Skikda and Annaba and the second identified in the West basin of the country between Oran and Mostaganem. The Sonatrach had concluded, in October 2018, agreements with the French Total and the Italian ENI, concerning the exploration of offshore hydrocarbons off the Algerian coast. Under the terms of the contract, exploration in the eastern zone at Béjaïa will be conducted by ENI in the eastern Algerian basin, covering an area of 15,000 m2, the objective of which is to identify the sandstone and carbonate reservoirs.

In the Western Area of Interest, in the Western Algerian Basin, the exploration will be conducted by Total, over an area of 10,000 m2, whose objective is also to identify sandstone and carbonate reservoirs. In March 2019, Algeria gave the green light for the exploration and exploitation of offshore hydrocarbons.

In addition to the climate change caused by the combustion of these raw materials, the extraction of offshore hydrocarbons also has direct and indirect consequences on the ocean and coastal areas. Several types of impacts and risks are thus caused by offshore drilling operations such as noise pollution, discharge of solid and microplastic waste, loss of drilling fluids at depth and the drilling mud discharges. This contributes to seriously disrupting marine and coastal ecosystems.

In fact, in oil drilling operations, the drilling mud are complex fluids with several chemical and mineral additives which performs essential and multiple functions, including drilling the well, cooling the drill, transporting cuttings to the surface, and maintaining wall stability. Their type is determined by the continuous section which can be fresh or brackish water (WBM, Water Oil-based mud), or oil (OBM, Oil-based mud). The composition of the mud is precisely adjusted by adding organic and mineral additives such as weighting agents, surfactants and viscose, depending on the mechanical constraints of the drilling as well as the physico-chemical conditions of the formations crossed. The drilling mud composition is precisely adjusted by adding organic and mineral additives such as weighting agents, surfactants and viscose. After use in the various sections of the well, drilling waste composed of residual fluids and contaminated cuttings constitutes the largest part of the drilling discharges (500-3000m3/well), and presents significant potential impacts and risks for the environment throughout their life cycle.

Several researchers and specialists have highlighted different types of damage to ecosystems and human health as well as the risk of serious accidents throughout the life cycle of this industrial activity. This is linked to several causes such as the transport and use of toxic and/or hazardous chemicals, high pressure during drilling and losses of oil-based fluids in aquifers or marine waters and sediments as well as the storage and treatment of drilling rejections (US.EPA. 2000; Gaurina et al. 2005; IOGP 2010).

As part of this work, the Life Cycle Analysis methodology was used as a relevant tool to assess the environmental impacts and risks of the different stages of the life cycle of an exploration well. The system analyzed is an exploration well located in the planned perimeter between

Skikda and Annaba. Three exploration drilling scenarios are simulated taking into account the drilling fluid circuit in all well sections as well as the management of drilling waste on land.

The estimates were based on field data as well as those from international databases and other specialized work. (Pettersen 2007, Perry 2005, Sadiq 2003, Neff and al.2000, Ghazi M. and al. 2008, 2011, Riad and al. 2019, Khodja 2008)

The main objective of this study is to assess the potential environmental impacts and risks of offshore exploration drilling and to compare the environmental benefits of three drilling system scenarios by identifying areas for improvement. This final study project includes the following chapters:

- Chapter 1 is devoted to the state of the art concerning offshore oil and gas drilling with a literature review of the geostrategic, technical, reglementary and environmental aspects of this type of industrial activity in the marine environment.
- Chapter 2 presents the material and the methodology adopted. First, there is the description of the study area, including the physico-chemical and biological characteristics of the marine waters as well as those of the Guerbes-Sanhaja Coastal Ecocomplex, designated as a Ramsar Zone. Next, the LCA methodology and its application to the offshore exploration system in the study area are exposed.
- Chapter 3 presents the essential results of the impact and damage analysis caused by well drilling and the three treatment scenarios of drilling waste.

Finally, a conclusion presents a global and critical vision of the application of LCA to exploration drilling in the marine area of Skikda, emphasizing the relevance of this method with the possibility of exploiting its results as a tool to help the decision, while considering its limits and difficulties.

I. LITERATURE REVIEW OF OFFSHORE OIL AND GAS DRILLING

I.1 Formation of marine hydrocarbon deposits

Oil is a fossil fuel that was formed between 20 and 350 million years ago. It comes from the decomposition of marine organisms. The transformation of organic matter from living organisms into oil takes tens of millions of years, passing through an intermediate substance called kerogen. Kerogen is formed by the action of anaerobic bacteria.

Organic waste is composed of C, N, O which are generally destroyed and digested by bacteria, but some are deposited at the bottom of closed seas, lagoons, lakes which are poor in O2, they are thus protected from the action of bacteria. The organic matter mixes with sediments (sand, clay) and accumulates in successive layers over millions of years, the oldest layers are thus buried under the most recent ones by their own masses and following their coverage by new deposits, the sedimentary layers sink naturally into the earth's crust and solidify into a mother rock, this formation traps the kerogen. As the bedrock is also buried, the kerogen is subjected to increasingly high geothermal pressures and temperatures, and the kerogen undergoes thermal cracking, also known as "pyrolysis". This chemical transformation removes residual nitrogen and oxygen to leave water, CO2 and hydrocarbons, molecules composed exclusively of carbon and hydrogen.

The mixture of liquid hydrocarbons is called crude oil, when the bedrock is not sufficiently buried, the kerogen it contains does not undergo pyrolysis, called oil shale, it is a fossil fuel stopped at the pre-oil stage in the kerogen maturation process. The following diagram shows the process of oil formation at sea (Fig.1).

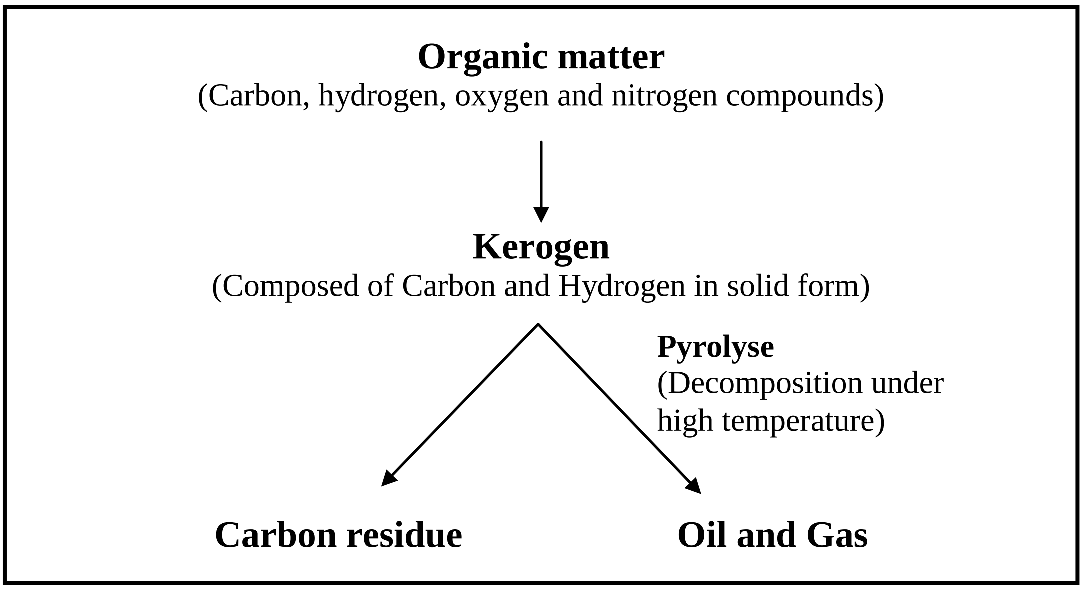


Figure 1: Types of hydrocarbons generated from kerogen as a function of landfill depth (IFP Energies nouvelles)

I.2 Global evolution of offshore oil and gas drilling

I.2.1 Offshore activity around the world

Offshore exploitation in the world is undergoing significant development, with global production in this sector corresponding to 30% of oil and 27% of gas production. Indeed, seabed oil extraction has increased from 10% of global production in 1960 to 30% in 2008.

This offshore trend is expected to remain stable despite the development of no conventional extractive activities such as oil sands and shale oil. Especially since the remaining reserves of oil and gas were estimated at 20% and 28% respectively in 2010 (IFM, 2012). From the year 2012 onwards the number of offshore oil wells increased compared to the number of onshore wells, the number peaked in 2014 (Fig2).

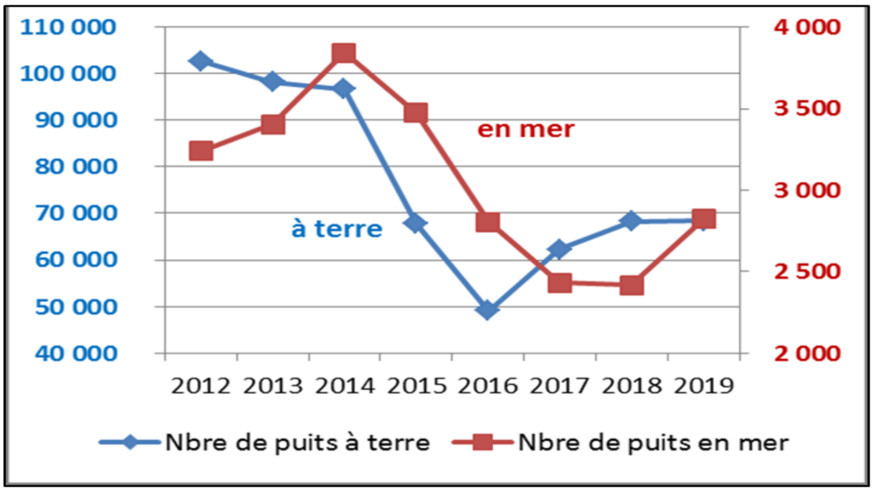


Figure 2: Number of wells drilled onshore and offshore
(IFP Energies nouvelles)

In recent years, significant technological development has enabled oil companies to explore and exploit hydrocarbon deposits in the deep sea in order to meet the rapid growth in global energy needs, thus this industrial activity is closely linked to geopolitical and strategic conditions on a global scale (IFM, 2012).

After the 2008 economic and financial crisis, the decline in global demand for hydrocarbons was followed by a 6% drop in offshore oil production compared to 2010. In 2008, offshore oil production was 25 MMb/d. Two areas account for more than 20% of global offshore oil production: the Middle East (22%), whose production is mainly in shallow waters (less than 200 m), and West Africa (20%) with Nigeria, Angola and now Ghana Europe, with the North Sea and its mature fields, still accounts for 17% of the world's offshore production, as well as South America, with 16% of world production. (Fig. 3) (IFPEN, 2011).

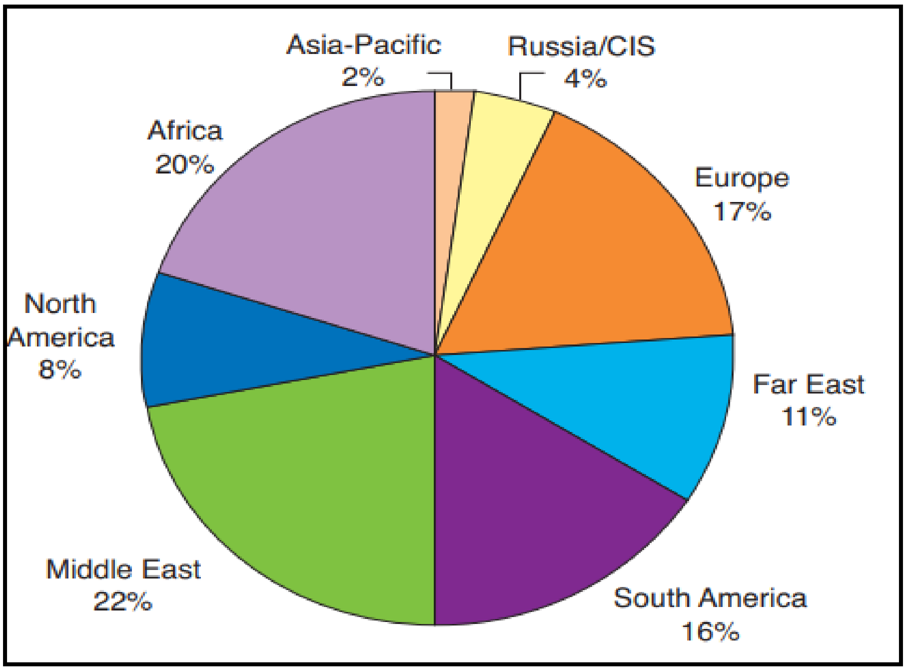


Figure 3: Breakdown of global offshore oil production (IFPEN, 2011)

Technological advances in exploration, in particular, imaging under generally shielded formations (salt, basalt, etc.), or in complex geology, has made it possible to update new offshore reserves (Fig. 4). However, these discoveries are getting smaller and smaller in size and depth. Their development represents both a technological and economic challenge. It is technologically possible to drill wells in 3,000 m of water to reach deeply buried reservoirs (Fig. 5) (IFPEN, 2011).

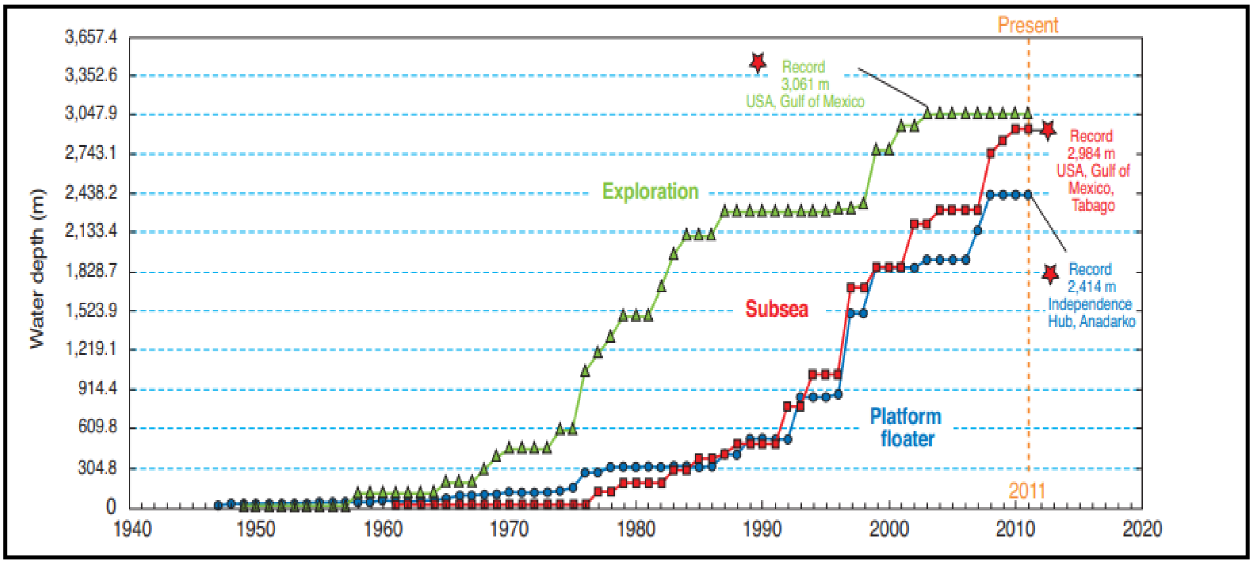


Figure 4: Trend in water depth for exploration and development drilling since 1940 (Offshore Magazine 2011)

Globally, offshore oil production has accounted for about 30% of total oil production over the past decade. In 2015, offshore production accounted for 29% of total global production, down moderately from 32% in 2005 (Fig.5).

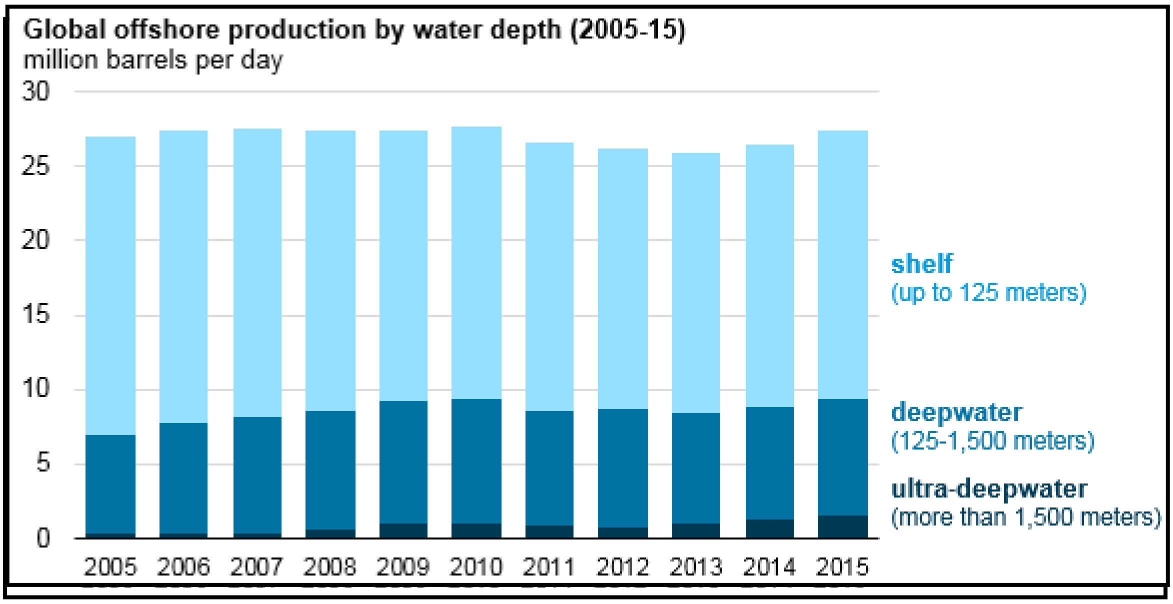


Figure 5: Global offshore production by water depth between 2005 and 2015

(U.S. Energy Information Administration, based on Rystad Energy)

1.2.2 Offshore activity in the Mediterranean and Algeria

There are about 232 hydrocarbon platforms in the Mediterranean, of which one third is for oil. Oil operations are located in the eastern as well as in the western Mediterranean.

In the Eastern Mediterranean, very large gas deposits with reserves estimated at 3,450 billion m³ were discovered in 2001 in the south of Cyprus as well as in the Palestinian and Lebanese territorial waters (Fig. 6). The exploration drilling was carried out by the Texan company Noble Energy in association with the Israeli companies, despite the disputed legitimacy of these reserves due to geopolitics and the Palestinian question. The reserves in these fields, named Tahar and Leviathan, are estimated at 450 and 250 billion m³ respectively (IFM 2012).

There are also environmental issues at stake because the perimeter of the drilling permit in this area of the eastern Mediterranean is framed by twenty or so protected marine and coastal areas as well as the presence of the Pelagos marine sanctuary area, which is located about 40 km downwind. For this reason, French and Italian ecological associations have taken up the cause. Scientists point out that deep drilling techniques are far from being mastered and that the prospecting area is known for its high seismic activity.

In the other countries of the region, the outlook is less optimistic (Fig. 6). In Lebanon, extensive seismic research over 80% of the EEZ (Exclusive Economic Zone) has shown promising prospects, but political chaos and institutional vacuum.

In Syria, despite an exploration agreement signed with the Russian company Soyuz Nefte Gaz, the ongoing war makes it very difficult to develop this activity. Turkey drilled 13 wells in Mediterranean waters between 1966 and 2014 and has recently stepped up its exploration activity, with the acquisition of seismic data, without finding an exploitable deposit so far (IFM, 2012).

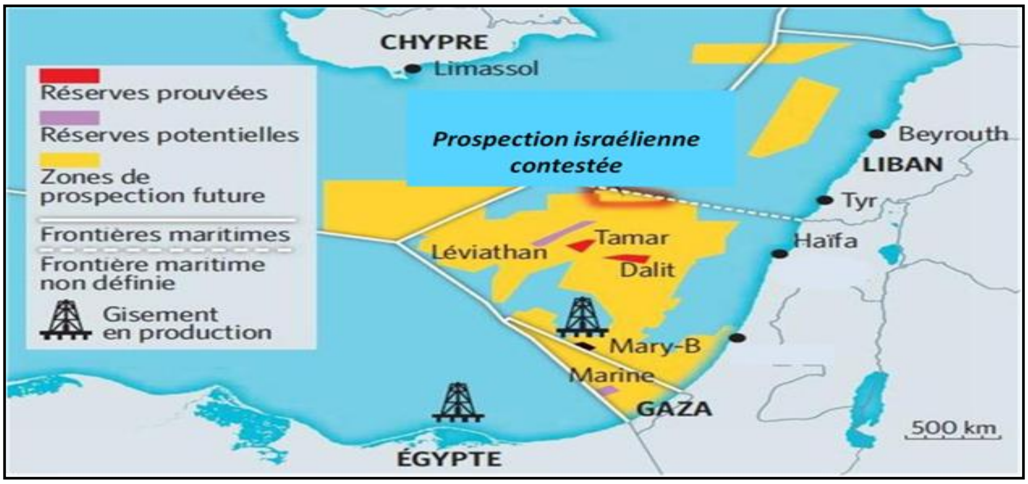


Figure 6: Gas fields and offshore operations in the Eastern Mediterranean

(IFM, 2012)

In the western Mediterranean, hydrocarbon exploration is carried out at great depths, mainly in the Gulf of Lyon (1,500 to 2,000 m) over an area of 25,000 km², south of Marseille and Toulon. The exploration was first carried out by the British company TGS-Nopec in 2001 and then transferred to the Scottish company Melrose in 2006 with an extension until 2010 (IFP 2019).

On the southern shore of the Mediterranean, several North African countries have increased offshore activity in their maritime territories in recent years, with the exception of Morocco where oil and gas exploration has been concentrated in the Atlantic in the Essaouira region and the Gharb basin since 2003 (IFP 2019).

In Egypt, gas production has increased significantly in the Nile delta, where the volumes extracted quadrupled in 10 years between 1995 and 2005. With the giant gas field called Zohr in a deep offshore area and the start of production in 2017, the country has become an exporter by pipeline, notably to Jordan (IFP 2019)

In Tunisia, small offshore deposits have been located in the Gulf of Gabes. Despite a potential for oil and gas production that remains modest at this stage, exploration remains quite active in the country's marine waters (IFP 2019).

In Libya, offshore deposits are estimated to be large and promising, especially in the Sirte basin, which remains under-explored. This explains the great competition from oil companies despite the unstable situation in the country.

In Algeria, the offshore seismic exploration programme started in spring 2011, in an area extending offshore between Mostaganem and Annaba. According to recent information, which was communicated by Sonatrach to several national press media, two exploration drilling programmes are planned on the east and west coasts. The one on the east coast, offshore between Skikda and Annaba, will be started after the acquisition of 2D and 3D seismic data in the first half of 2019. The volume of gas estimated according to the analysis of seismic data is evaluated at nearly 30 trillion cubic meters, suggesting a similarity between the reserves of this coastline with the offshore mega deposit of "Zohr" discovered in Egypt (IFP 2019).

The other exploration programme off the west coast is planned between Mostaganem and Oran. The volumes associated with this first well are estimated at several trillion cubic metres of biogenic gas. According to these initial investigations, it may also contain oil, with an extraction estimated at several million barrels. The exploration of the East and West coasts is led by Sonatrach in partnership with the French Total and the Italian ENI (Algerian-American Energy Forum).

1.2.3 The regulatory condition for offshore drilling

Oil and gas drilling activities have a high potential to pollute the environment. Drilling fluids are subject to licensing in many jurisdictions. These are becoming increasingly restrictive as knowledge of their pollution mechanisms increases. Although minimization of disposal at sea is required, most countries allow marine discharges of cuttings containing water-based fluid residues with the requirement that the additives meet toxicity and persistence limits in the environment (OGP. 2003).

Indeed, in the OSPAR Convention (OSPAR. 1992, 2001), the PLONOR list is the most widely used classification system for additives. PLONOR substances are considered to present little or no risk to the environment.

This is based on the characteristics of the substance or product in terms of persistence in the marine environment, bioaccumulation potential, acute toxicity and possible endocrine effects.

In general, good practice guidelines and best management practices have been developed for onshore and offshore sites (Brandt/EPI, 1996; OGD, 2001; UKOOA, 2002; U.S. EPA, 2001).

Table 1 presents conventions and standards for offshore operations and their discharges:

Regulatory reference	**Discharge into the sea**			
	Water-based sludge (WBF) and cuttings	**Oil-based sludge**	**Oil-polluted spoil**	**Oil limit in the**
OSPAR Convention	Discharges accepted under PARCOM	1 mg/kg	1 mg/kg	40 mg/l current 30
Baltic Sea Convention and	Authorised discharge on the basis of	not determined	Recommendation HELCOM No. 95/1	15 mg/l max
Kuwait Convention and Protocols (Red	Landfill permitted on the basis of UNEP:	not determined	Discharge allowed under the Kuwait	40 mg/l 100 mg/l
Barcelona Convention and	Discharge permitted under the Barcelona	not determined	100 g/kg	40 mg/l 100 mg/l

Table 1: Conventions and standards for offshore drilling operations (Gaurina et al. 2005)

In Algeria, the regulation of offshore oil drilling activities is handled by:

- The legal and institutional framework based on the Algerian Environmental Code, which includes all the laws and conventions signed by the Algerian authorities in terms of respect, protection and improvement of the environment in recent decades.
- The legislative framework which defines the application of several laws and decrees relating to the protection of the environment within the framework of sustainable development such as Law n° 03- 10 of 19 Joumada El Oula 1424 corresponding to 19 July 2003.

Concerning the executive decrees, we can quote the one which determines the field of application, the contents and the methods of approval of the studies and the notices of impact on the environment (Executive decree No. 07-145 of 2 Joumada El Oula 1428 corresponding to

May 19, 2007) and another one which fixes the conditions of approval of the studies of impact on the environment for the activities falling under the field of hydrocarbons (Executive decree No. 08-312 of 5 Chaoual 1429 corresponding to October 5, 2008).

I.3 Characteristics of offshore hydrocarbon drilling

I.3.1 Types and structure of offshore platforms

Offshore oil and/or gas exploitation is carried out using platforms of various types depending on the distance from the coast and the depth of the water column. Platforms mainly support the equipment needed for the drilling or oil extraction stage but may also have facilities to house the operating personnel. Some platforms are the size of a football field (5,000 m²) and there are over 15,000 platforms worldwide. The Gulf of Mexico alone has almost 4,000 active oil platforms (Thomas P.A. 2017).

The platforms differ depending on whether they are used as offshore drilling units (exploratory section) or as production units (operational section). The need to innovate in terms of the platform is due to the technical advances made to exploit oil deposits located under increasing depths of water.

Thus it can be distinguished according to whether the platform is intended for the exploration or exploitation of oil in waters of a depth of less than 1500 meters or in waters of a greater depth.

The structure of the platforms has changed a great deal over the years in order to discover and exploit oil deeper and deeper under the water, the first platforms were fixed to the seabed but other floating and mobile platforms soon appeared.

- Fixed oil platforms:

These platforms are machines built to rest on the seabed: Fixed metal platforms and base platforms weight have dimensions that are sometimes disproportionate; to such an extent that they are built in several elements on sites adapted to land, elements which are then transported separately by floating barges or docks drilling site to be assembled.

These platforms drilling in shallow water but under conditions sometimes extremely this is why it is necessary to create so-called flexible platforms.

- Weight base platforms:

They are also called gravitary platforms; these platforms have the particularity of ensuring their stability thanks to their own weight and are therefore resistant to the effect of swells as well as to difficult climatic conditions.

These platforms are used in waters not exceeding 200 meters in depth because their cost would therefore become prohibitive but have the advantage of being able to be ballasted in order to be moved to another deposit.

The centre of the concrete structure is hollow in order to store oil or water, thereby reinforcing the stability of the structure.

- Flexible platforms:

Called compliant tower or articulated platforms, this type of platform makes it possible to exploit the seabed to a depth of about 1000 meters in difficult conditions, the floating bridges are secured to the bottom by a mechanical hinge, a set of permanently tensioned pipes or by cables anchored to the seafloor.

- Mobile oil platforms: These platforms are characterized by the possibility of being moved according to the deposits to be exploited, we find self-elevating and semi-submersible platforms.

- Self- elevating platforms: These platforms are built for oil operations in shallow water (about 100 meters deep), consist of pillars resting on the seafloor and a hull that can be lifted or lowered by flotation as required by the site on which they are located, primarily used for drilling or exploration platforms not equipped with drilling equipment. They can also serve as a place of life for workers at sea.

- **Semi-submersible platforms:** These oil platforms allow drilling and oil exploitation to a depth of up to 1000 meters, can be towed or self-propelled with pods orientable. They are connected to the seabed by anchors or cables then ballasted in order to immerse them under twenty meters of water. An upper part of the water ensures the operation. This type of platform thus minimizes wave movements and thus adapts more easily to difficult seas.

The various oil platforms mentioned above do not allow exploitation in ultra-deep water but still remain very used since exploitation of shallow water deposits (discovered for the first time by the technologies developed at the time) may continue for several decades.

The following figure shows the different platforms cited (Fig. 7).

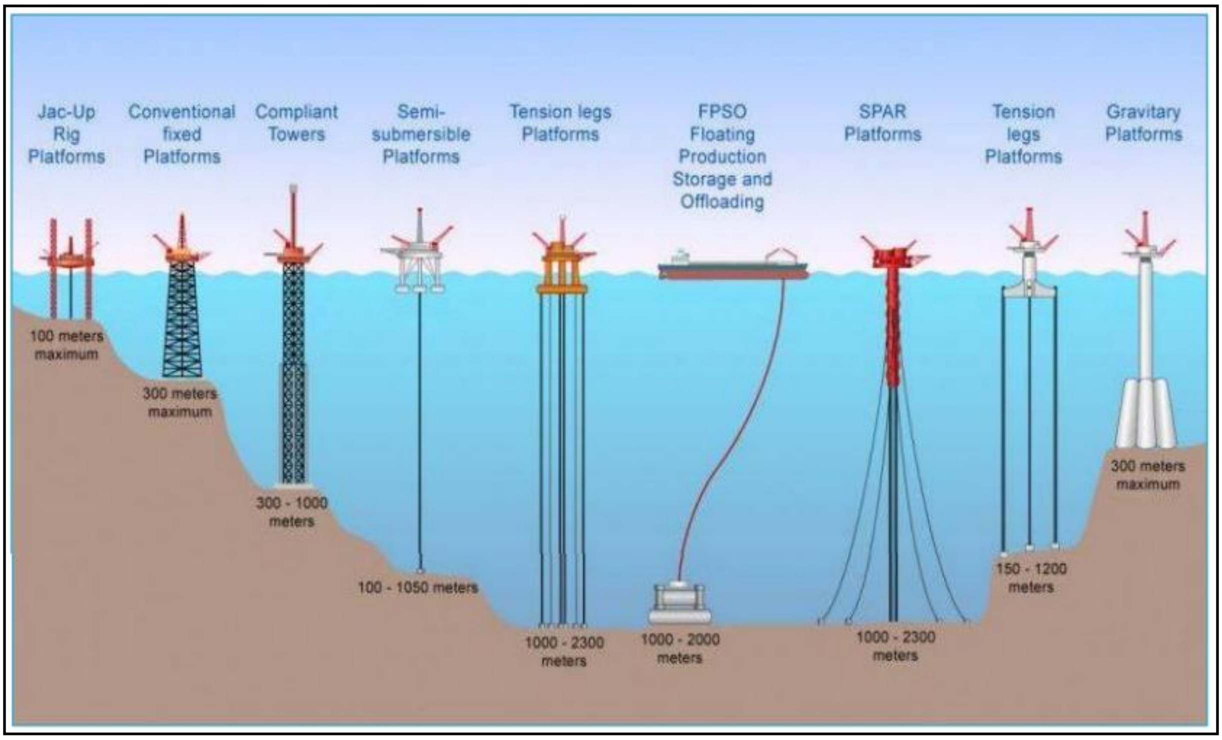


Figure 7: Types of offshore platforms according to the depth of the water column (Thomas P.A. 2017)

I.3.2. Drilling operations and well drilling sections

Three steps are essential in the process of exploiting hydrocarbon deposits:

1- Seismic research of deposits based on preliminary geological studies

Offshore exploration uses the technique of "seismic reflection" from a vessel emitting energy through air guns that move forward driving a line of sensors called a "streamer" (Fig. 8). The initial technique, which used two dimensions (2D) in the vertical plane, had a success rate of 30-40%. With the transition to three dimensions (3D), by gridding with various transmitter-receiver sets, we obtain a success rate of 70%, it is increasingly used because of the quality of the results obtained, by integrating the time factor, we can analyze the evolution of the deposits during exploitation in 4D.

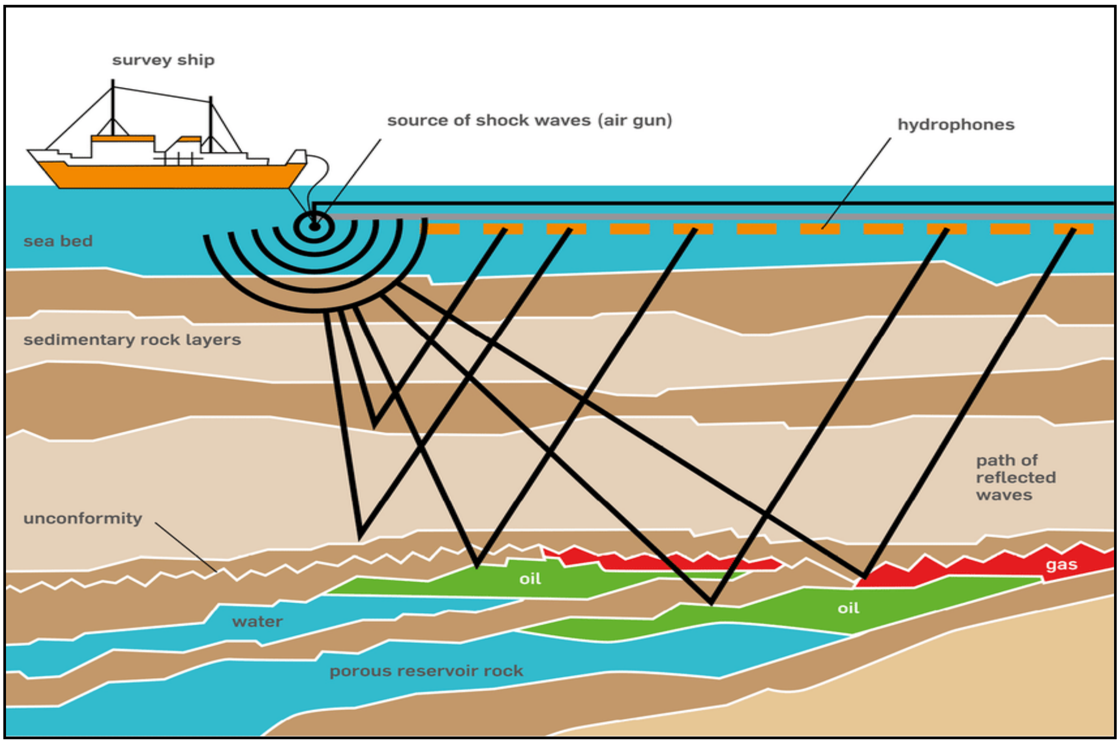


Figure 8: Offshore geophysical survey (Navjot, 2017)

2- Exploration of the deposit by drilling

After prospecting, the drilling exploration is to verify the estimated volumes of hydrocarbons and to validate the decision to develop the field drilling. It is the only method to confirm the presence of hydrocarbons and to define: the quality of the well effluent (gas or water saturated oil); the permeability of the reservoir; the potential production and quantity of oil. When a deposit is detected thanks to the seismic data collected in the previous step, a suitable platform is installed. This platform provides many services and functions during the drilling of the well such as cementing, casing, injection. Other specific weather and diver services are also provided by the platform in addition to power generators, personnel living quarters, including fire safety and gas detection systems to prevent the risk of explosion.

The operation of drilling the well is carried out by powerful tools including the derrick and the drill bit which makes it possible to drill the sea floor and break the rocks of the geological formations crossed. This device makes it possible to inject fluids during the drilling of the different sections of the well to control the pressure, cool the drill bit and raise the cuttings to the surface.

3- Exploitation of the deposit

The entry into in the optimal production of the deposit is validated by the geophysical investigation and the numerical modeling of the previous stage. A development plan is established beforehand which specifies: (i) the number of wells to be drilled to optimize the exploitation of the discovered field; (ii) the type of production platform and the cost of specific equipment according to the conditions of the marine environment; (iii) the optimal management method for solid and liquid discharges from drilling in order to preserve the environment and reduce depollution costs.

The installation of specific equipment is necessary throughout the life of offshore drilling. Thus, the first step is to install tubes or hoses that allow the hydrocarbons to rise, the flow rates of which are controlled by a series of valves and their pressure measured by pressure gauges. The decrease in pressure informs about the advanced age of the well after several years of operation. The lifespan of an oil or gas operation depends on the characteristics of the marine deposit. It is 15 to 30 years on average but can reach more than 50 years in the giant fields. The end of the exploitation of an offshore field is marked by a final stage which is the dismantling of the platform and the routing of its structures towards the ground for a future exploitation, a recycling or an end of life as waste concerning the parts unusable.

The drilling of sections of the well is carried out according to a defined technical program and subject to rigorous regulatory application. The well is drilled using a drill bit and derrick with high-pressure injection of drilling fluids whose chemical composition varies according to the depth and the nature of the geological formations crossed.

The sections of the well decrease in diameter as the drilling progresses depending on the depth. In the first section of the well (36"~0.914 mm), a metal casing crosses the water column up to 500 m on average and its diameter shrinks to 26".

The casing continues with the depth to the source rock where the steel tubes, whose diameter is smaller and smaller, are cemented as they go to stabilize the walls of the well and avoid the risk of leakage of fluids called training losses.

Figure 9 below shows the variability of casing diameters and the type of fluids injected into the different sections of the well depending on the depth of the well, which are generally the sections: 26”; 16”; 12"; 8" and 6".

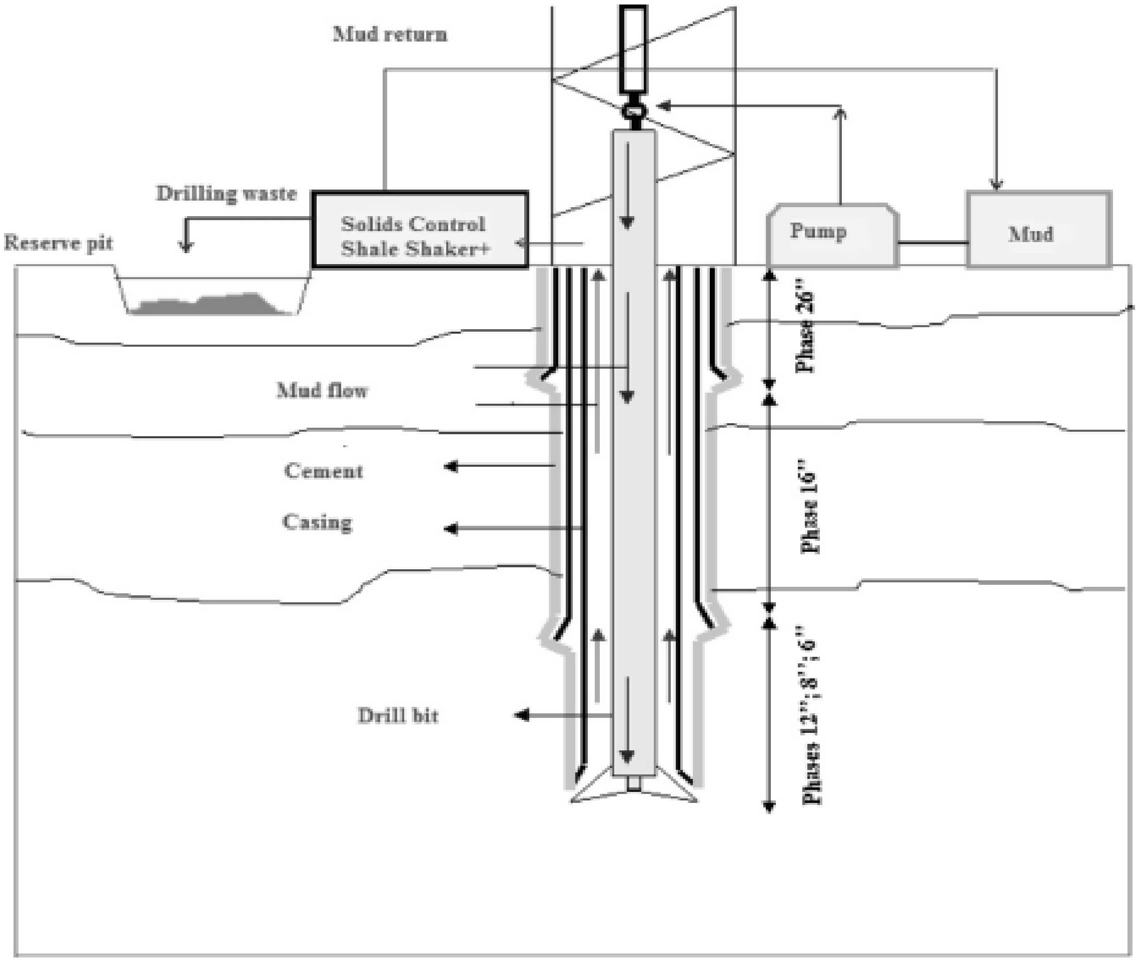


Figure 9: Drilling mud flow during well sections (Ghazi & al.2011)

I.3.3. The drilling fluids and their functions

Drilling fluids, also called mud, have several roles, the most common of which are drilling the well (effect of high-pressure injection), transporting rock cuttings drilled to the surface and cooling the drilling tool.

Their composition varies according to the depth and nature of the formations crossed. It includes a continuous or emulsified section which is water or diesel, in addition to a very large number of chemical additives and auxiliaries which have a specific role and multiple actions.

In general, the first section of the well is drilled with water-based mud or Water-Based Mud (WBM) which is composed of more than 95% water in addition to bentonite or other clay and chemical additives of low percentage. The drilling mud used deeper in the other sections of the well are oil-based, hence their name OBM or Oil-Based Mud. They are composed of up to 94% diesel (for example in 6" section) in addition to many additives and chemical reagents. In Table 2, the components of drilling mud are classified by type.

Main functions	Clay colloids	Organic Colloids or Filtrate Reducers	Thinners or viscosity reducers	Mineral additives	Special organic products	Weighting	Sealants
Examples	- Bentonites - Attapulgites	- Amidons - CMC (Carboxyle Méthyl Cellulose)	- Polyphosphates - Tannins - Lignosulphonates - Chrome lignins	- Caustic soda ($NaOH$) - Soda ash (Na_2CO_3) - Gypsum ($CaSO_4$) - Hydrated lime ($Ca(OH)_2$) - Sodium bicarbonate ($NaHCO_3$)	Anti-ferments - Defoamers - Anti-jamming - Anti-corrosion - Anti-fillings	- Barite or barium sulphate ($BaSO_4$) - Calcium carbonate ($CaCO_3$) - Galena (PbS) - Hematite (Fe_2O_3)	-Organic sealants - fibrous sealants - Lamellar sealants - Swelling sealants - Sealing agents (hydraulic binders).

Table 2: Chemical sets and functions of drilling fluid components

I.4. Environmental risks and impacts of offshore hydrocarbon drilling

I.4.1 Accidental risks of drilling in the marine environment

Due to the sometimes extreme conditions of the marine environment and difficult climatic conditions, the risk of accidents related to offshore drilling is significant and its management must be rigorous for the safety of workers on site as well as to avoid colossal economic losses (Baram 2010).

For example, the wells are subjected to very high pressure of 300 to 1150 bars and sometimes temperatures above 180°C, hence the requirement for proper operation of the specific safety equipment on the platform. Figure 10 below gives a summary of the accident risks at several sites around the world, which differ according to their occurrence and severity over the period 1970-2007 (OGP, mars 2010).

It can be seen that the most frequent accidental risks are those related to transport, in particular the helicopter, as well as explosion and fire which are due to the pressure of the well and the chemicals.

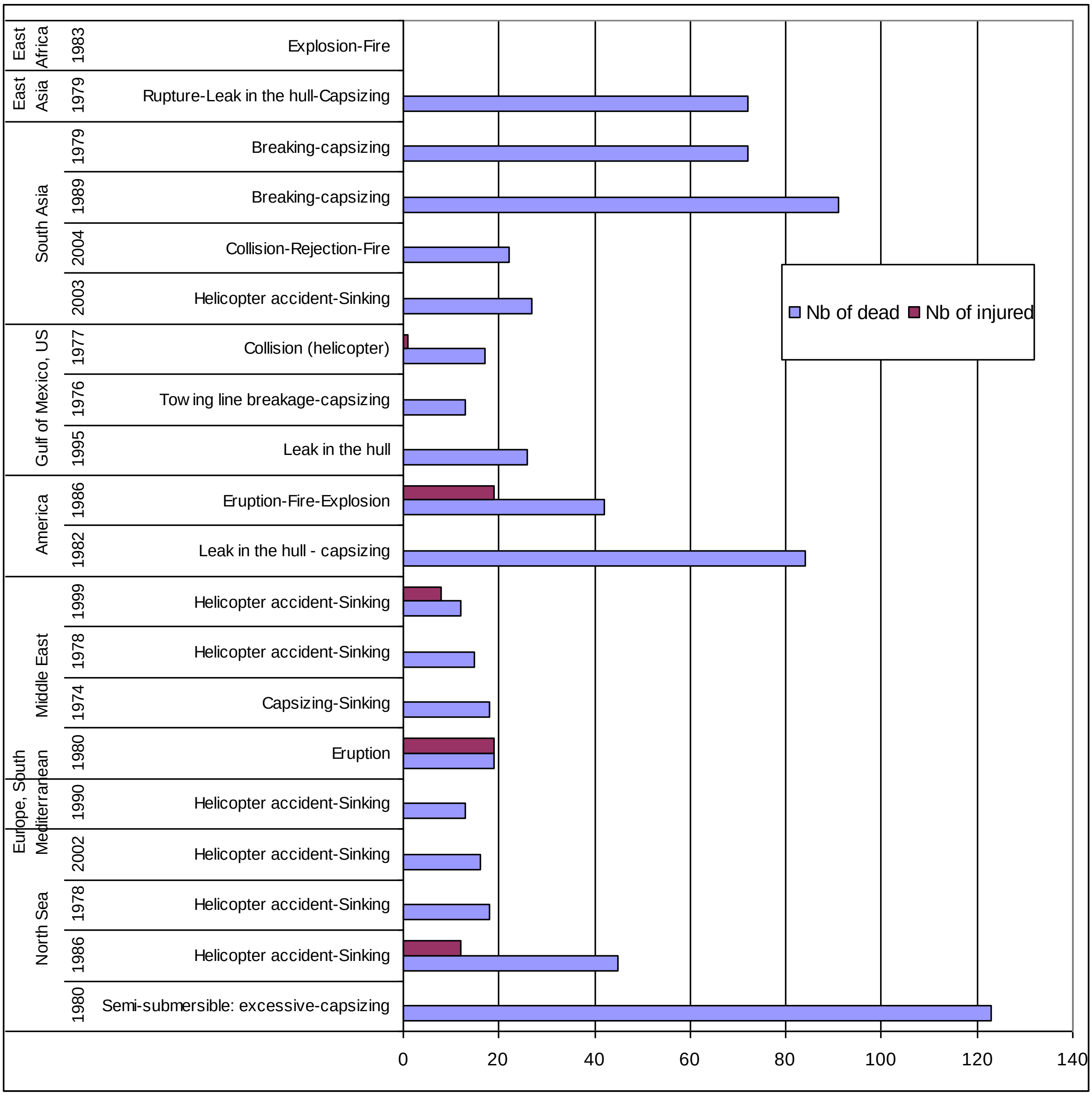


Figure 10: Accidental risks of drilling offshore at several sites around the world (From OGP, mars 2010)

The accidentology analysis reveals that a well blowout is the type of accident most damaging to the environment in the case of offshore hydrocarbon exploration-production (EP) activities. A "blowout" is an uncontrolled release of effluent from a well. The effluent exit point can be at the wellhead or along the well, in line with vulnerable underground formations.

This imbalance can be linked to a set of reasons, of which the most frequently encountered in accidents are below.

- Shallow gas: located in geological layers at shallow depths (between a few dozen and a few hundred meters below the seabed, in the form of hydrates (shallow gas). When drilling through these layers, the gas is released, leading to a gassing of the mud. Gas blowout is then almost inevitable and difficult to control, as the well does not have a blowout preventer (BOP). This scenario is one of the most common causes of blowouts in the offshore.
- Insufficient mud density: due to human or instrumental error in the formulation, manufacture or testing of the mud before it is pumped into the well.
- A too rapid manoeuvre of the packer: a lightening of the mud column and an imbalance of pressure at the bottom of the well is due to a too rapid rise of the drill packer during a manoeuvre can lead, by piston effect, to a loss of pressure.
- Unexpected encounter with an over pressured formation: a formation containing fluids under pressure was not identified and taken into account in the drilling programme.
- A loss of mud circulation, i.e. a decrease in the height of the mud column in the well due to losses in the ground.
- Uncontrolled emptying or tearing of the extension tube (only in deep water): the extension tube is a particularly stressed element during drilling, particularly due to marine currents or swell. It can therefore be weakened, in particular by fatigue effects, and be subject to the rupture of one of its elements. In the event of a rupture, the extension tube can be partially emptied of its mud, which leads to a pressure imbalance at the bottom of the well.
- The intersection of an adjacent well: a pressure imbalance at the bottom of the well caused by human or instrumental error in the control of the drilling direction.

I.4.2 Pollution from well drilling and drilling waste

The development of offshore drilling must be accompanied by an increase in support vessel and tanker traffic. In general, the impacts associated with this industrial activity are of several types:

- Construction noise causes marine wildlife such as fish and marine mammals to avoid the area.
- Vibrations and the presence of erected equipment: noise pollution.

- Liquid and solid production waste.
- Increased turbidity of the water due to dredging, thus less photosynthesis.
- Seabed disturbance.
- Invasions of certain alien species carried in the ballast water of support vessels. (Steiner, 2003; Wills, 2002; Patin, 1999).

The risk of pollution linked to the multiple activities of offshore drilling and therefore the various potential environmental impacts is considerable but at the same time depends on the overall mode of management of this pollution on the platform. Management must take regulatory requirements into account but must be adapted to the type of pollution and the specific behavior of the pollutants. Thus, in the case of accidental pollution, there is urgency and the solutions provided must be faster. This is the case, for example, of accidental spills linked to the loss of control of certain operations in the overcooking of sludge on the surface on the platform or at depth. This risk also exists in the event of uncontrolled discharge of drilling waste into the sea as well as during their transport to land.

I.4.2.1 Emissions to water and marine sediments

Potential emissions of pollutants into the marine environment can occur throughout the life cycle of this industrial activity but are greatest during these stages:
- Emissions to water and marine sediments that are related to circulation losses during well drilling. It is a mixture of pollutants including hydrocarbons, metals, salts and other toxic substances due to the composition of drilling fluids. The metals may be of natural origin since they were initially found in the cuttings of rocks drilled from the different geological layers crossed. The highest total contents in the cuttings are therefore linked to the local geochemical background. The total contents of these pollutants depend both on the volumes of loss, on the variable composition of the fluids for each section or section of the well and finally on the depth of the well. The local physico-chemical and bathymetric conditions play a key role in the behavior of these pollutants by promoting their transfer and/or certain biogeochemical processes such as bioturbation, biodegradation (aerobic or anaerobic), chemical speciation, bioavailability and bioaccumulation.
- Emissions to the air and their atmospheric deposition, either in the area of the offshore platform on the surface of the water or further offshore or on land depending on the winds and the size of the particles emitted.

These emissions are mainly linked to the continuous circuit of sludge brought up from the well in the mechanical device for oil removal and centrifugation operations by vibrating screens and centrifuges. These emissions are essentially volatile organic compounds (VOCs) which are light hydrocarbon fractions such as carbon oxides, methane and benzene as well as certain metals such as mercury (Mey M. 2013; Ghazi M. et al 2019).

I.4.2.2 Drilling mud discharges and their management

The solid and liquid wastes that are generated during the exploration, operation and decommissioning stages vary in volume and nature depending on the type of oil or gas platform and drilling.

The management of these wastes must be done according to local and international legislation to minimize the risks and environmental impacts on the marine environment and maritime life in general, and even on human health.

The risk of pollution linked to the multiple activities of offshore drilling and therefore the various potential environmental impacts is considerable but at the same time depends on the overall mode of management of this pollution on the platform. Management must be adapted to the type of pollution and the specific behavior of the pollutants. Thus, in the case of accidental pollution, there is urgency and the solutions provided must be faster. This is the case, for example, of accidental spills linked to the loss of control of certain operations in the overcooking of sludge on the surface on the platform or at depth. This risk also exists in the event of uncontrolled discharge of drilling waste into the sea as well as during their transport to land.

During the drilling of the well, there are significant volumes of contaminated cuttings (cuttings) by hydrocarbons and non-reusable fluids which contain toxic substances. Efforts to minimize these releases are undertaken using a solids control system installed on the surface which allows the de-oiling of the cuttings after their continuous passage through vibrating screens and centrifuges, during the drilling of all sections of the well. At the end of the drilling, the waste generated can be treated on site or sent to storage and/or treatment units on land. The treatment processes are often stabilization-solidification (inerting) or thermal desorption, which are also applied to onshore oil drilling discharges.

I.4.3.3 Behaviour of drilling emissions in the marine environment

Exposure to marine pollution linked to offshore drilling activities concerns various targets depending on the levels of pollutants and their behaviour: aquatic species living in different levels of the water column; aquatic species living near marine sediments or in their interstitial waters; humans through the consumption of contaminated seafood.

Drilling fluids, particularly oil-based (WBM) fluids with a high hydrocarbon content, have a complex chemical fate that depends on the physico-chemical and bathymetric conditions of the marine environment.

Several processes characterize this fate, such as surface evaporation of light hydrocarbon fractions, dispersion in the water column, persistence of emulsions formed with seawater and the possibility of being transformed into polymers that are difficult to degrade.

Some research is taking a more ecosystem-based approach to measuring the effects of chronic contamination from offshore drilling. This research is increasingly revealing the existence of cumulative and long-term consequences. New evidence indicates that the composition of species of marine microorganisms can change dramatically; bacteria that feed on hydrocarbons develop particularly rapidly, to the detriment of other microorganisms (Kloff and al.2004; Al-Hadhrami and al., 1995; Vik and al., 1996).

Other studies show high mortality and morphological abnormalities for fish eggs and larvae (NERC, 1994; MacGarvin, 1995). A Norwegian study has recently shown that exposing fish to very small amounts of polycyclic aromatic hydrocarbons (HAPs), present in production waters, results in the feminization of male fish, this significantly reduces fertility and delays the spawning period by several weeks (Meier and al., 2002). Cancers in fish and especially in benthic organisms have been directly related to pollution from offshore production facilities (Anderson, 1990; Klekowski and al., 1994).

The degradation of organic molecules in drilling wastes by microorganisms can lead to anoxic zones that are problematic for local communities. In this respect, the risk arises from the combination of an anoxic zone and the inherent toxicity of the drilling waste and possibly the degradation products.

On other hand, metals can also be found in concentrations of concern in drilling waste due to the chemical composition of diesel fuel as well as that of certain additives and reagents. For example, the worrying concentrations of lead, barium and other metals in drilling effluents as well as rock cuttings are due to the initial high levels in the chemical composition of gas oil and barite produced in Algeria (Ghazi M.2010).

The chemical fate of metal emissions from the various offshore drilling activities also depends on the physico-chemical and bathymetric conditions of the marine environment. Indeed, according to several characteristics of this environment such as redox conditions, marine currents and type of sediments; the behavior of each trace or major metallic element is variable. There is competition between several biogeochemical processes that govern the mobility and transfer, biodegradation and chemical speciation, toxicity and bioavailability of these elements in the marine environement.

The main metals present in the aqueous sludge, in terms of quantities and environmental impact, are arsenic, barium, mercury, zinc, chromium, cadmium, copper, iron, nickel and lead present in the barite ($BaSO_4$; additive) or in the material removed from the geological formations through which the borehole was drilled. The bioavailability and toxicity of barium to marine organisms is low due to its low solubility in the water column and in sediments.

Thus, the different organic pollutants as aromatic hydrocarbons and inorganic as metals (trace or major), depending on their concentrations and their toxicity thresholds, can cause acute toxic effects to certain less resistant species in the ecosystem. They can also have long-term toxic effects due to their bioaccumulation and biomagnification in the food chain up to humans via the consumption of seafood products. This mechanism leads to marine and terrestrial Ecotoxicity as well as that of Human Toxicity, which are two categories of impacts analyzed within the framework of the Life Cycle Assessment applied to offshore drilling in the following chapters.

II. ENVIRONMENTAL IMPACTS AND RISKS EVALUATION OF OFFSHORE DRILLING BY LIFE CYCLE ASSESSMENT

II.1 Presentation of the study area

II.1.1 Location of the drilling zone

In the southern part of the algerian-provençal basin, at the level of the marine zone which extends from the wilaya of Skikda to the wilaya of Annaba, the perimeter of offshore oil drilling is located 20km from the coast on average. This area is characterized by important urban, industrial and port activities. According to the oil drilling program, the exploration block is located in coastal waters about 42km from the mainland where the depth of the water column is on average 130 to 500 m, this perimeter is presented below as well as the delimitation of the monitoring area with seismic data (Fig 11).

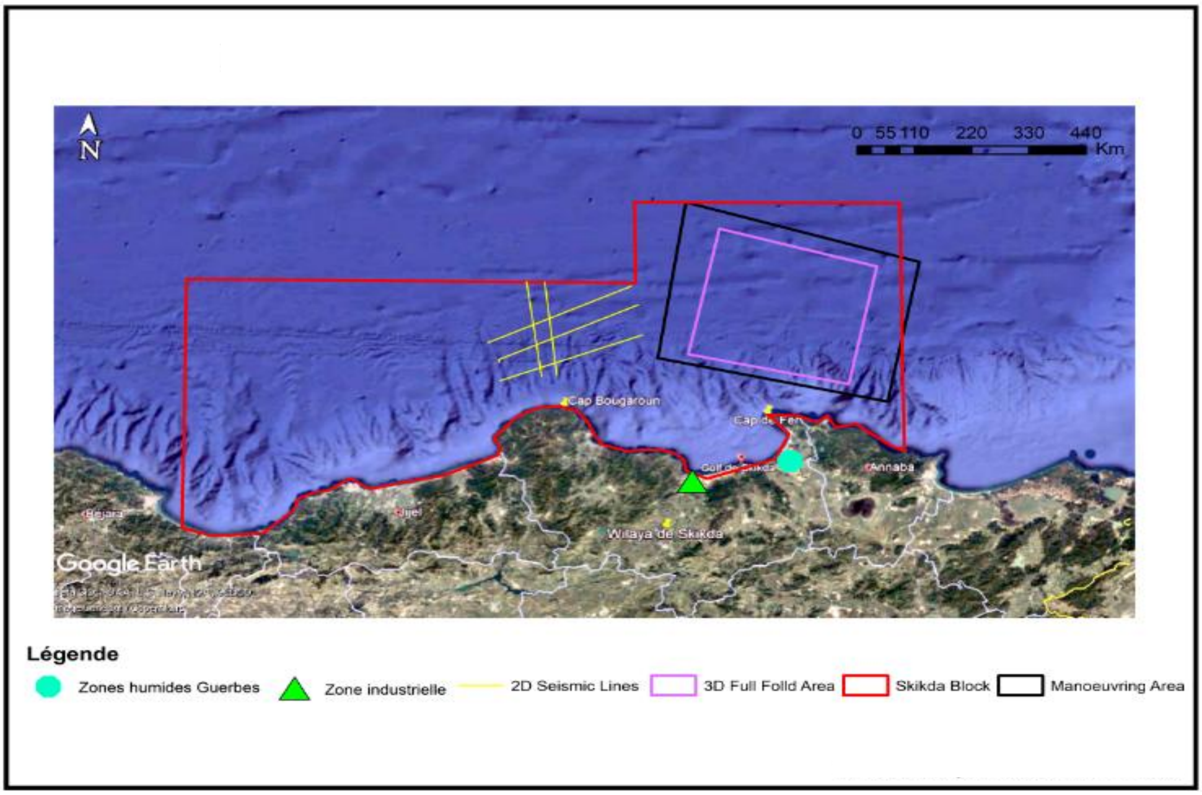


Figure 11: Location of the offshore drilling perimeter

II.1.2 Characteristics of Skikda's coastline

The wilaya of Skikda is located in the northeast of Algeria between 36°05' and 36°15'N latitude and 7°15' and 7°30'E longitude, covering a total area of 4137.68 km² , between the Tell Atlas and the Mediterranean Sea to the North. It is bounded to the east by the wilaya of Annaba, to the west by the wilaya of Jijel, to the south by Constantine and Guelma, and to the southwest by Mila.

The Gulf of Skikda, also called "Stora", is located between Cape Bougaroun to the west and Cape Fer to the east over a length of 146.7 km (Fig 12).

There are both rocky shores, sandy beaches and a large field of dunes, with a fishing area of 3068 km2 or 4.69% of the national fishing area. To the west, Oued Saf-Saf represents a large watershed of the Skikda coast (Cemali, 2019).

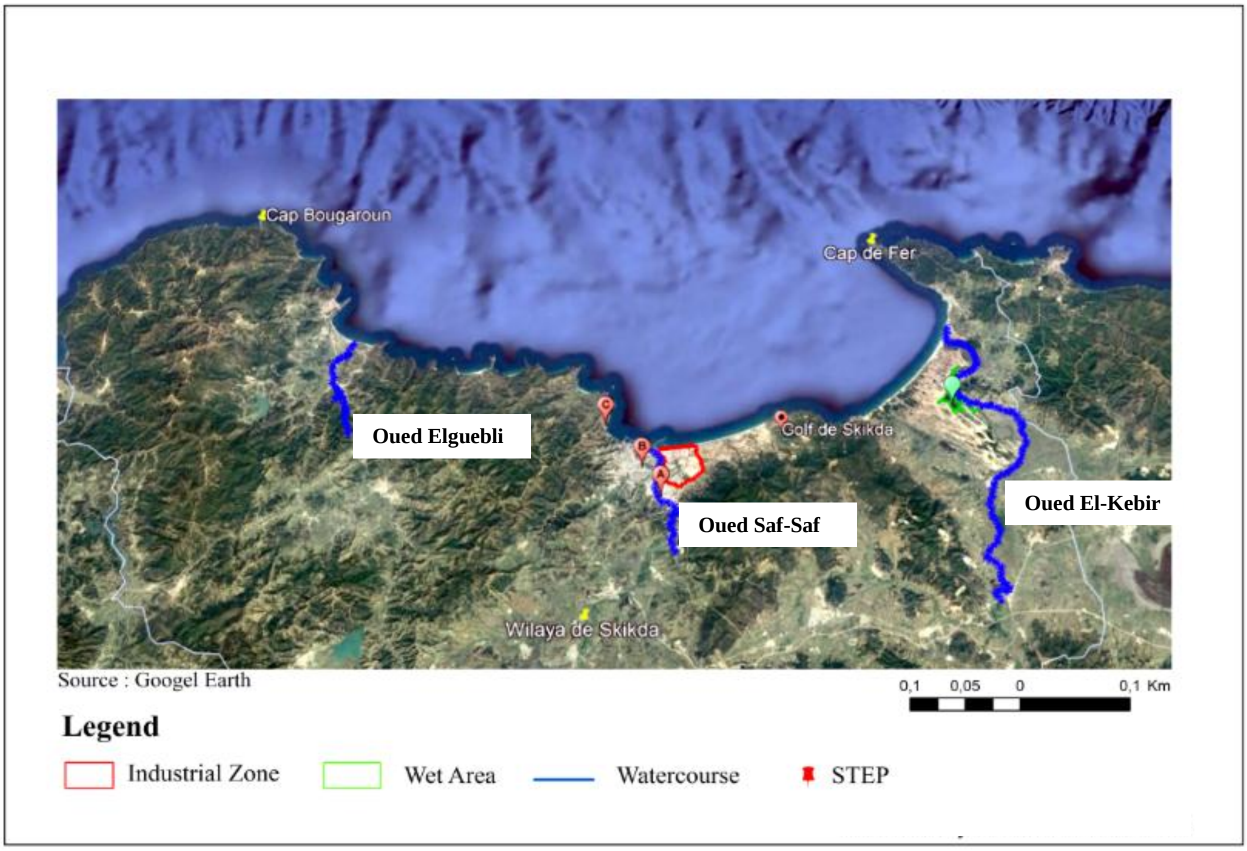


Figure 12: Skikda golf presentation (Map modified from Google Earth)

II.1.2.1 Climate and hydrography

The coast of Skikda is characterized by a humid climate from May to September with a wet and mild winter and a dry and hot summer. Precipitation is relatively abundant with an average of 713.93 mm and a percentage of 85% of the average annual precipitation, concentrated in the period from October to April. The average annual temperature is 18.55°C, with an average maximum of 28.2°C and an average minimum of 10.4°C.

The seasonal distribution of wind patterns in Skikda Bay shows that the prevailing wind blows from the west and northwest during the first, second and fourth quarter of the year, largely at speeds above 8 m/s. While in the third quarter, from July to September, the winds dominate from the East and North-East but most of them are at low speed (in LEM, 1996).

From the hydrological point of view, in the northeast part, the wilaya of Skikda includes an important hydrological network, consisting of several wadis with different watersheds such as the El Kébir wadi (1130.2 km²); Oued Saf-Saf (1050km2); Oued El Guebli (993 km2); in addition to others like Wadi Fendekh, Wadi Maboul, Wadi Magroune, Wadi Aneb, Wadi Dem El Bagraat, Wadi Bou Djenane and Wadi Ennkouche. (Boumezbeur, 2001).

II.1.2.2 Hydrodynamic context and batymetry

The coast of Skikda is subject to dominant swells coming from the Northwest sector of a frequency of 37.60%, also characterized by small amplitude of the tide between 25 cm and 30cm. The coast of Skikda is considered as one of the Algerian coasts where the swell plays a major role on the marphodynamic of the shore, it undergoes strong storms that manifest during the winter season from December to March, are also characterized by high winds that generate huge waves where the rise of the sea level can reach 7 to 11 m, which causes very important human and material damage, especially on the equipment the port infrastructures. (Cemali, 2019)

The Skikda region has a very diverse continental shelf. It is tormented and sometimes absent to the west towards the Ras Bougaroun area, but is increasingly spacious and extends eastward towards the marina area. Several studies have been carried out in the Skikda region, showing that the appearance and the steep and rugged nature of the seabed along the coastal line, covering more than 0.5 km from the edge line, with increasing depths of 10 to 12 m, Towards the North we find rather sandy muddy bottoms and the great depths of 100 to 200 m appear only towards the 4 to 7 nautical miles north of the coast (Mezedjri, 2008).

II.1.2.3 Marines fauna and flora

The coastline of Skikda presents the longest linear coastline of the coastal wilayas (130 km) with significant natural potential and high economic value (fishing, tourism and oil industry). However, the coastal ecosystems of this region are under urban pressure and biodiversity is affected (MEER 2018) .

a. Marine fauna

Skikda hides a great richness in the marine fauna that it is represented on the fifty species caught in the territorial waters of the wilaya, with a number of specific species not caught and therefore not recorded, according to the marine zonation (PAM, 2018).

For each floor there are:

- **Supra-littoral floor**: the biocenosis of the supra-coastal rock is represented by cyanophyte epithetic belts. This floor is mainly occupied by the black lichen Verrucaria symbalana, the gastropods melarhaphe Littorina neritoides , Littorina punctata , Patella rustica Patella lusitanica , Ligia italica and Pachygrapsus marmoratus.

- **Upper Sub-Floor**: In the 2 areas (centre and west) of the coast of the Skikda wilaya, belts of 2 species of cirripd Chthamalus stellatus and Chthamalus montagui cover the rock entirely. The characteristic algae are Rhodophyceae Porphyra leucosticta and Rissoella verruculosa and Nemalion helmintoides. Zoobenthos consists of Siphonaria pectinata and P. rustica and Trochidae Monodonta turbinata and Monodonta articulata. Also the species encountered in the supra-littoral are: L. neritoides, Ligia italica and Pachygrapsus marmoratus are observed at this stage.

- **Lower sub-floor**: The most identified characteristic species are P. caerulea, P. aspera, P. ferruginea and P. vulgata, Siphonaria pectinata, Emarginula sicula, Diodora graeca, Murex trunculus, Littorina punctata; Littorina neritoides; Ligia italica; Gibbula racketti and Gibbula pennanti. The zone is also due to the strong presence of Ulvophytes, the vertical distribution of the specimens of the algae recorded in the supra-littoral and mediolittoral zone of the Algerian coast, the Chlorophyceae are the most abundant macroalgae followed by Rhodophyceae. The dominant zoological group is that of the intertidal shellfish, Chthamalus stellatus and Chthamalus montagui. They were a majority and spread over the entire Skikda Bay. Only one specimen of pedunculate cirripd is found in this region, Mitella pollicipes , Pollicipes pollicipes.

Monitoring the population of the limpets by ecological descriptors has made it possible to report six species in the Skikda Gulf that they are: Patella caerulea, P. rustica, P.aspera, P. ferrugniea and P. saana. In addition, P. caerulea and P. rusca are the species that contributed the most (PAM, 2018).

b. Marine flora

In general, the flora of the Skikda region is very rich and includes several rare species of different forms: the plant species that colonize Skikda bay, which are marine species, and the terrain. The table in appendice 1 represents the dominant flora and fauna in the Skikda region (PAM, 2018).

II.1.2.4 Guerbes - Sanhaja - Skikda wetland ecosystems

Wetlands are areas where water is a major determinant of the environment and associated plant and animal life. They occur where the water table comes in or is close to the surface, or where the earth is covered with water. They represent the most productive environments in the world. The wetland complex of Guerbes Sanhadja (commune of Ben Azzouz wilaya of Skikda) is one of the main reservoirs of the biodiversity of the Mediterranean basin with an area of 42000 ha; plays an important role especially for irrigation and grazing (Fig 13). Is a large coastal plain bordered to the west by the coastal hills of Skikda and to the east by the coastal forest massif of Chetaïbi, was declared a RAMSAR area in 02/02/2001. (Abdi, 2014)

The altitudes of the zone are between 0 and 200 meters, 48.5% of the land has a slope less than or equal to 3% and the rest at 12.5%. The main lithological units are mainly wind and alluvial deposits (Boumezbeur, 2001).

Figure 13: Presentation of wetlands - Guerbes - Sanhaja complex (Boumezbeur 2001)

In these wetlands which covered an area of 194.36 hectares, the cork oak occupies an area of 82.24 hectares. The cork forest adjoins the marine pine forest, a third of which are natural residents who are located on an area equal to 32.62 hectares, with a small area of 5.65 hectares occupied by zenaie whish is the stand of a deciduous oak, the Zene grows from sea level to 1800m on cool, deep soils (C.F.S., 2006).

This complex represents sites of national and international importance, they provide a rare example of type of natural wetland for the Mediterranean region, even for the Maghreb, North Africa, sub-region North Africa - Central Africa.

Several criteria allow the Guerbes plain as a RAMSAR site (Boumezbeur 2001):

- It is a bioclimatic crossroads, due to the prevailing winter winds and promote some hot and humid cooling in summer.
- Characterized by the presence of certain species of particular characteristic, a nesting site of two very rare species, the Erismature à tête blanche (Oxyura leucocephala) which exceeds 1% of the world population, and even considered globally threatened, and its numbers are declining due to climate effects and human impacts on the habitats where the species is located. The Canvasback nyroca (Aythya nyroca), and the hen sultana and thus the presence of 23 rare floristic species..
- Maintains biological diversity on an area of more than 28,000 hectares, thanks to the richness and diversity of its fauna and flora, where there are about 234 plant species (out of 1800 in total for Northern Algeria) various biogeographical origins representing 145 taxa directly subservient to the aquatic environment, 50 bird species and 27 species of Odonates. Of the listed plant species, 19 are rare and 23 are extremely rare.
- Represents a favorable place for migration of eels and other marine species not yet determined such as mules, beards, because of food availability.
- Low-developed soils, a hydrological network consisting mainly of two large wadis: Oued El Kebir and Oued Magroune. The first is one of the most important in both length and volume, its width varies between 20 and 50 m. It leads to the beach of Marsa in the Mediterranean Sea. Eight other wadis of lesser importance complete the hydrological network of the plain.

II.1.2.5 Industrial and urban activities

The wilaya of Skikda is characterized by an important industrial, urban and harbour activity and especially intense in its capital (Fig. 14). 46.62% of enterprises in the Wilaya of Skikda range of metal and plastic packaging, hosiery and textiles, with a predominance of agri-food specializing in semolina production at the Coastal Mills, milk and its derivatives, as well as industrial tomatoes.

The Skikda industrial area is located in the coastal area less than 800 metres from the sea and is therefore considered an industrial project of national interest. The Skikda industrial zone is located to the east of the city and covers a total area of 1,200 hectares, with industrial units grouping together the hydrocarbon sector (transport, refining, energy and transformation).

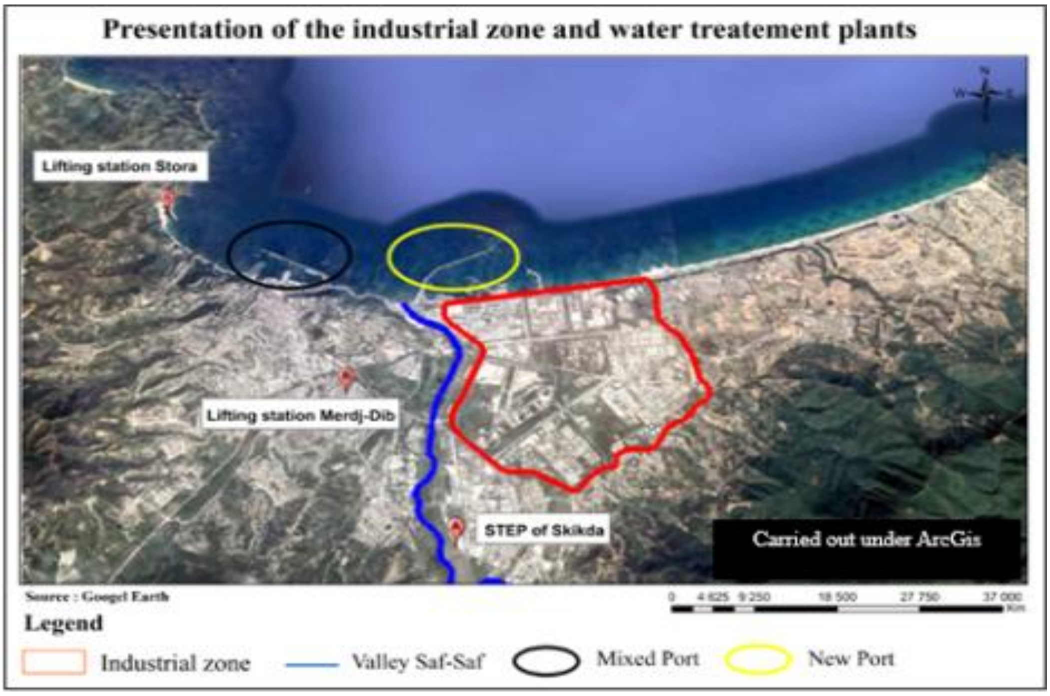


Figure 14: Industrial area of Skikda

There is a heavy industry which includes the most polluting activities such as hydrocarbons, mechanics, chemicals, metallurgy and iron and steel, and mining. The petrochemical complex of Eastern Algeria (1200 hectares) is considered the second industrial pole of the country after Arzew spread over.

The industrial units of the petrochemical complex are listed in the table 3 below:

Etablissement	Designation	Activity
CP1K	Plastics complex	Production of 120,000 tonnes of ethylene.
CTE	Thermal power plant	A combined-cycle power plant has a capacity of 880 MW to generate more electricity from the country's large gas reserves
ENGI	National distribution and gas transport company	National electricity and gas company, specializing in the production and distribution and marketing of electricity and the purchase, transmission, distribution and marketing of natural gas.
HELISON	Helium and nitrogen production unit	A joint venture between LINDE and SONATRACH aims to build and put into production and operate a helium extraction and liquefaction plant..
RA1K	Refinery Complex	Based on atmospheric distillation, the platforming unit and the gas-plant unit are used to upgrade propane and butane. Produces butane with 110.000t/year, nafta (3.9 million t/year), jet fuel (565.000t/year), heavy gas oil (280.000t/year) and light gas oil (115.000 t/year).
RTE	Hydrocarbon Pipeline Transport unit	
SOMIK	Industrial Maintenance Company	A strong and professional specialized maintenance entity that supports the important needs of SKIKDA's hydrocarbons division in terms of industrial maintenance.
GL2K	Liquefaction Complex, new project	Designed to transform a very large amount of natural gas from gaseous to liquid.
STH Nouveau port	Hydrocarbon Transportation Company	A commercial port for petroleum materials, with a dock with a capacity of 23 million tons of oil.
TOPIC	Topping Condensats	An oil refinery with a processing capacity of approximately 5 million tones /year.

Table 3: Industrial activities of the petrochemical complex

In the petrochemical pole, the concentration of activities generates pollution of the water and the atmosphere. The discharges from these companies are discharged either directly into the sea or via Oued Saf-Saf which also ends in the sea.

The industrial zone has an indisputable national economic interest, but on the local aspect, it has a rather negative impact such as: Demographic explosion, Anarchisassions of the built space, etc. There are also various pipelines (gas, oil and multi-product) that cross the region. These pipes pose a risk of explosion and pollution of the area.

The following table 4 illustrates the type of waste and pollution generated by the industrial activity of the wilaya of Skikda.

Units	Types of waste	Quantities released	Use
CP1K : Plastics complex	- Mercury sludge -P.V.C - Residues of V.C.M - Sludge from the STEP of effluent	1000 tonnes / year 28800 tonnes / year 400 tonnes / year 40 tonnes / year	Stored in tanks
GL1K : Gas liquefaction complex	- Iron barrel - Wood, wood residues - Iron and plastic materials - Plastic barrels - Chlorine tank	10 tonnes / year 150 tonnes / year 1000 barils 15000 kg/ year	- Be sold to individuals Jetties - Either Sold to individuals Stored
RA1K : Oil Refining Complex	- Sand mud - Hydrocarbons and plastics	250 Kg à 500 Kg / year	Stored
UTE : Hydrocarbon Transport Unit	Empty barrels, scrap, paper	Variable	Recycled
CTE : central electricity	Scrap metal	60 Tonnes / year	-
ENGI : Industrial gas production company	Nothing	Nothing	-
Enamarbre : Production unit of the Marbles	Marble dust and mud	60120 Kg / year	A part jetty

Table 4: Types of waste and pollution generated by the industrial activities (Skikda Environment Department, 2008)

As for population growth on the Skikda coast, it has more than quadrupled since independence between 1960 and 2017 (from 233 to 1,344 hectares).The factors behind this growth are the migration flows, and the industrialization.

This population growth is associated with urban expansion to the detriment of rural and agricultural areas, and from a spatial point of view it has an impact on the development of consumption of natural resources and mainly increases tensions on agricultural land. Figure 15 shows the evolution of the urbanization perimeter of the city of Skikda between 1970 and 2017.

In 2017, the area of urban areas was close to that of agricultural areas, under the pressure of growing social demand, urban expansion took place at the expense of the best peri-urban agricultural land (Hadef, 2011).

Figure 15 shows the use of agricultural land through urbanization and industrialization in the Skikda area between 1960 and 2015 (Fig. 15).

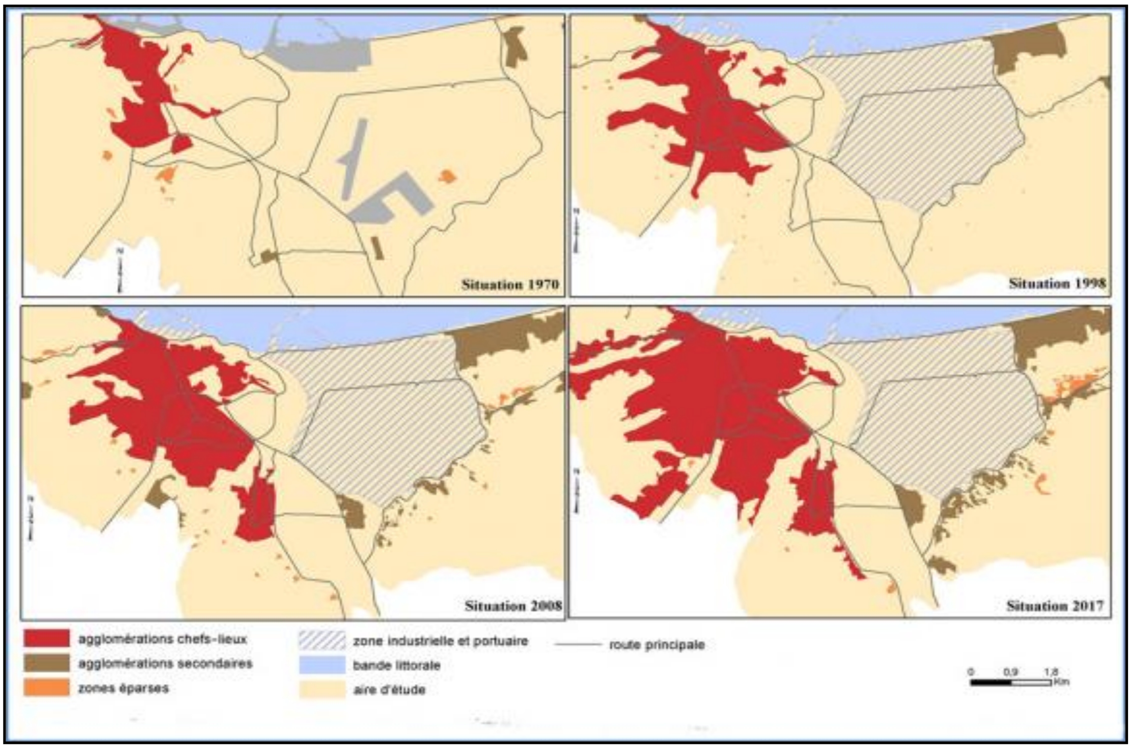


Figure 15: Agricultural land consumption by urbanization and industrialization in the Skikda wilaya (1960-2015)

*Treated by authors with from Google Earth 2015 and 1960 Skikda Topographic Map. PDAU intercommunal 2015

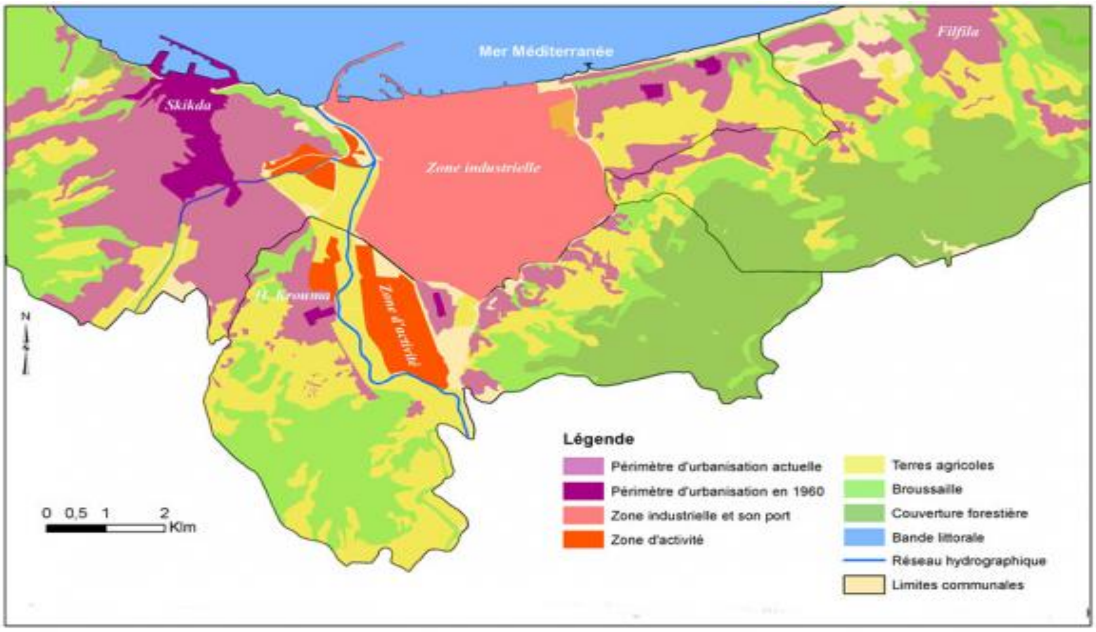


Figure 16: Evolution of the urban area of Skikda (1970- 2017)

*Treated by authors with ARGIS 10.0, from Google Earth and aerial photos 1972, district plans (ONS 1998, 2008)

II.2 Materials and Methods

II.2.1 Life Cycle Assessment (LCA) methodology

LCA is the most successful and recognized tool in the field of global and multi-criteria assessment of environmental impacts, thanks to its timeliness and its dissemination. This method is therefore widely applied in the context of environmental sustainability and the results of which can be used as a decision-making support for industrial or public policies. The LCA is a tool to quantify the impacts of a product or service, from the extraction of the raw materials that make it up to its end-of-life disposal, through the distribution and use sections. At each stage of the life cycle, the flows of energy and incoming and outgoing materials are inventoried. Then an assessment of the environmental impacts based on these data is carried out using pre-established coefficients to calculate the contribution of each stream to the various environmental impacts studied and the results are expressed as series of environmental scores. The use of LCA therefore makes it possible to identify the main sources of environmental impacts linked to the various alternatives considered by presenting an overall and detailed vision of the impacts generated by the products as well as their movements, according to various simulations.

According to the International Standards Organisation (ISO 14040-14044, 2006): “Life Cycle Assessment is a standard analytical tool which in its complete version, addresses the environmental aspects and potential environmental impacts (i.e. use of resources and environmental consequences of releases related to the functional unit of a product system) throughout a product’s life cycle from raw material acquisition through production, use, end-of life treatment, recycling and final disposal”. Thus, according to ISO the LCA is articulated in four standardized and interdependent steps (Fig. 17).

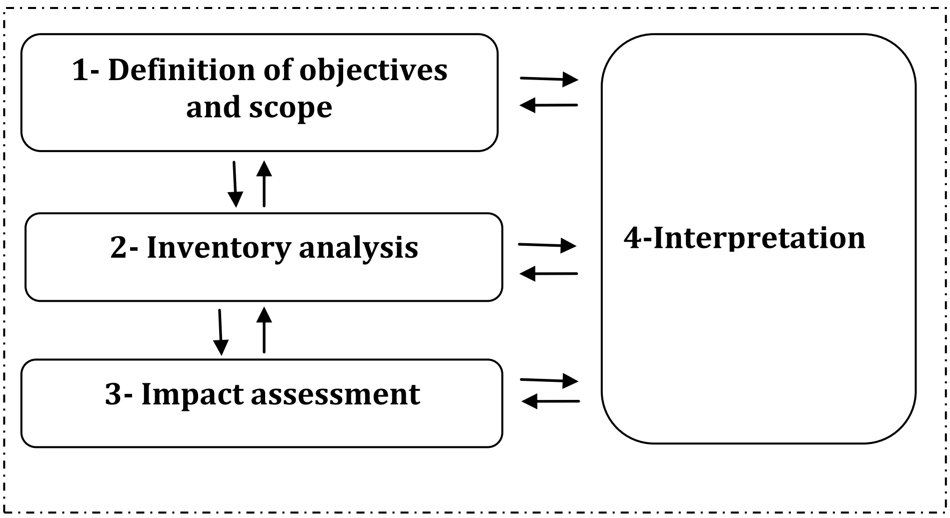


Figure 17: The four conceptual LCA steps (ISO 14040-14044, 2006)

1 - Definition of objectives and scope of study

It is a descriptive step, which mainly includes: (i) the definition of study objectives; (ii) the definition of the function of the system which informs about the nature of the system, as well as its role and functionality to which the material and energy flows relate; (iii) the choice of the functional unit which is a parameter to quantify the system function according to the objectives, by reporting the energy and material flows of all its processes; (iv) the definition of the limits of the system.

2- Inventory analysis

It is a set of data collection and calculation procedures, they allow to quantify the flows in and out of the system along the product life cycle. This analysis begins with a data collection preparation in which the system subdivides into sub-systems with a schematic diagram of elementary processes linked by flows. Subsequently, the data are collected from several sources such as: scientific databases, in situ measurements, bibliographic estimates, scientific journals, expert advice for each life cycle stage.

3- Impact assessment

Based on the material and energy flows identified, the results of the inventory analysis are translated into potential impacts, this step allows determining the importance and significance of the potential impacts of the system studied and it includes three mandatory elements:

1. Selection of impact categories with indicators and characterization models in a manner consistent with the study objectives.
2. Classification where the results of the inventory analysis are assigned to the corresponding impact categories.
3. Characterization which allows quantifying the contributions of the different emissions and extractions of the system’s life cycle to the corresponding impact categories.

4-Interpretation

This step is iterative with the previous three to always ensure that the results obtained are correct to achieve the objectives of the study. It is also here that an attempt will be made to assess the robustness of the results, to ensure that the associated uncertainties and variability are well below that of the differences observed between the environmental performances of the various systems studied.

II.2.2 Application of LCA to offshore exploration drilling

II.2.2.1 Definition of the scope and objectives of the study

This study focuses on the life cycle analysis of offshore oil exploration drilling in the coastal waters between Skikda and Annaba, within the perimeter bounded by national company Sonatrach in the figure 11. The primary objective of this analysis is to assess the potential environmental impacts associated with offshore exploration drilling in this area. It also involves comparing scenarios simulated to determine their environmental impact scores and thus to identify areas for improvement of the system and the choice of the best scenario.

The analysis focuses on a generic system that is an exploratory drilling well, with an average depth of approximately 3000m, including the water column according to the bathymetry of this area. The defined functional unit is therefore to drill a well at sea with an average depth of 3000 m with 500m3 of Water-Based sludge (WBM) and 2000m3 of Oil-Based sludge (OBM).

The system limits consist of successive sections of the 36", 26", 17 ½"; 12 $^{1/4}$" and 8 $^{1/2}$" well in addition to the treatment of liquid and solid discharges as drilling waste (fluids and cuttings). Three offshore well drilling scenarios have been defined based on the chemical composition of the drilling fluids and the options for managing the drilling waste. These options took into account the treatment processes available onshore: Centrifugation, Stabilization-Solidification and Thermal Desorption.

The figure 18 below shows the generic diagram of the modeled system limits and the drilling waste options (Fig.18).

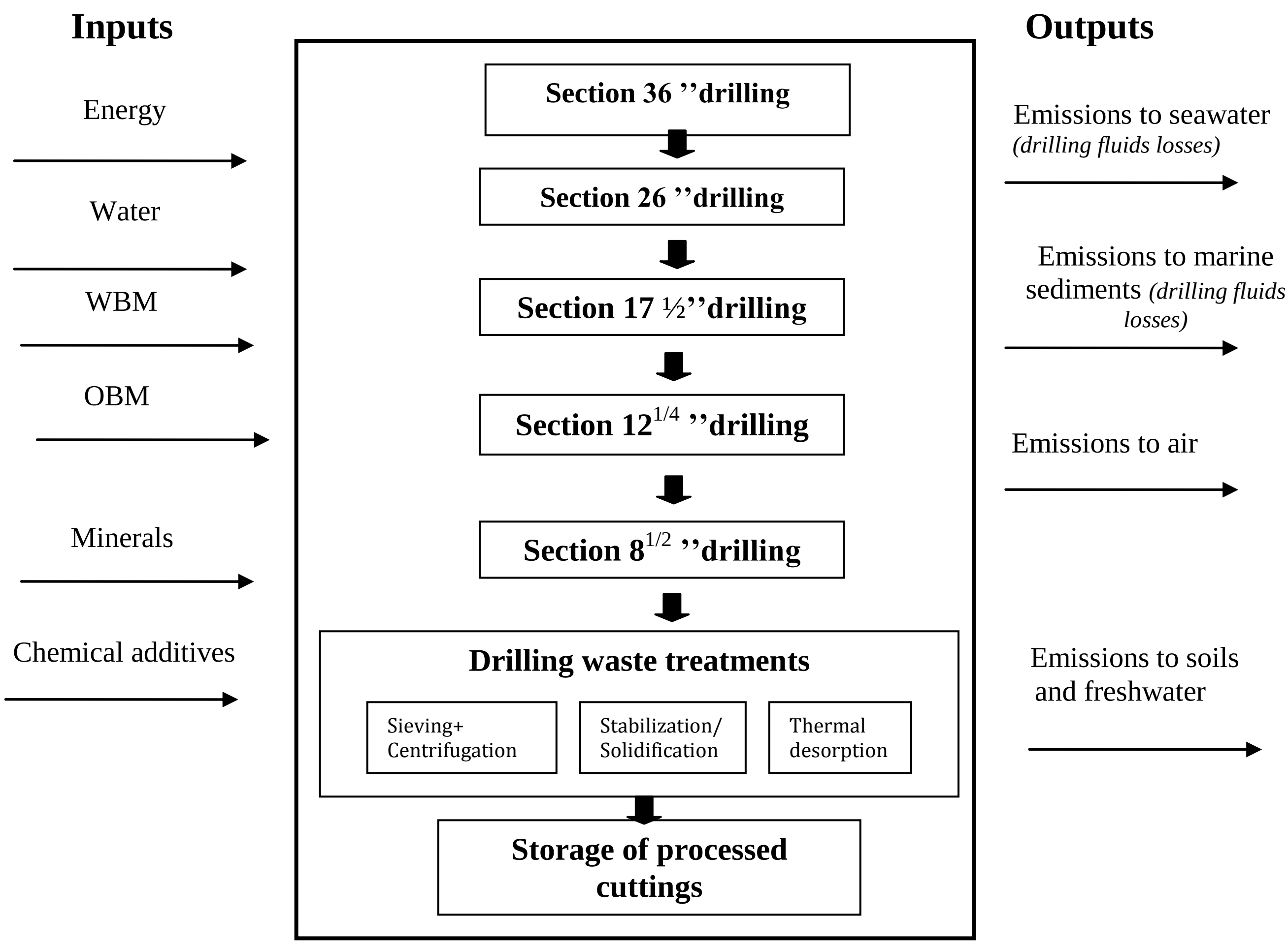


Figure 18: Limits of the analyzed system
(Well sections and drilling waste treatments)

II.2.2.2 Life Cycle Inventory Analysis

For inventory analysis and environmental impact analysis, Simapro software was used, where the data was collected from generic databases and the specialized bibliography from the work of several authors (Ghazi and al. 2011 ; Edwards and al. 2014, Abubaker and al. 2015).

The inventory of incoming and outgoing flows concerned the drilling stages of the well and those of the management of drilling waste as defined within the limits of the system. For incoming flows, the inventory data collected is:

- The volumes of fluids injected during the drilling of the successive sections (or sections) of the well down to the sea depth of 3000 m3 on average. These fluids have different chemical compositions depending on the sections of the well.

- The quantities of energy, water and minerals (e.g. bentonite) as well as the chemical additives used during drilling and the waste treatment processes.
- Emissions to seawater and marine sediments, estimated from the volumes of fluid circulation losses during the drilling of the well.
- Emissions to air linked to drilling operations on the platform, more particularly the physical separation of cuttings-fluids by the series of vibrating screens and the vertical centrifuge.
- Emissions to soils according to the three management scenarios for drilling waste including their transport offshore and onshore. The simulated cuttings treatment processes are solidification-stabilization, thermal desorption and centrifugation.

The life cycle inventory of simulated scenarios including the drilling well and the waste management was based on the reference flows incoming and outgoing which are represented in the appendix 2.

The life cycle inventory analysis of the offshore drilling system was carried out using the SIMAPRO7 which is an LCA software developed by PRé Consultant in the Netherlands. It contains several LCA methods and several databases each containing hundreds of life cycles of products, processes and other anthropogenic activities (Fig. 19). Thus, the inventory analysis of well sections and treatment scenarios results in matrices containing more than 300 emissions and extractions related to the functional unit. The table 5 is an extract from these matrices showing the incoming flows (water, energy, raw materials) during the drilling and waste treatment sections; as well as outflows from the system, in particular emissions to water, soil, sediment and air.

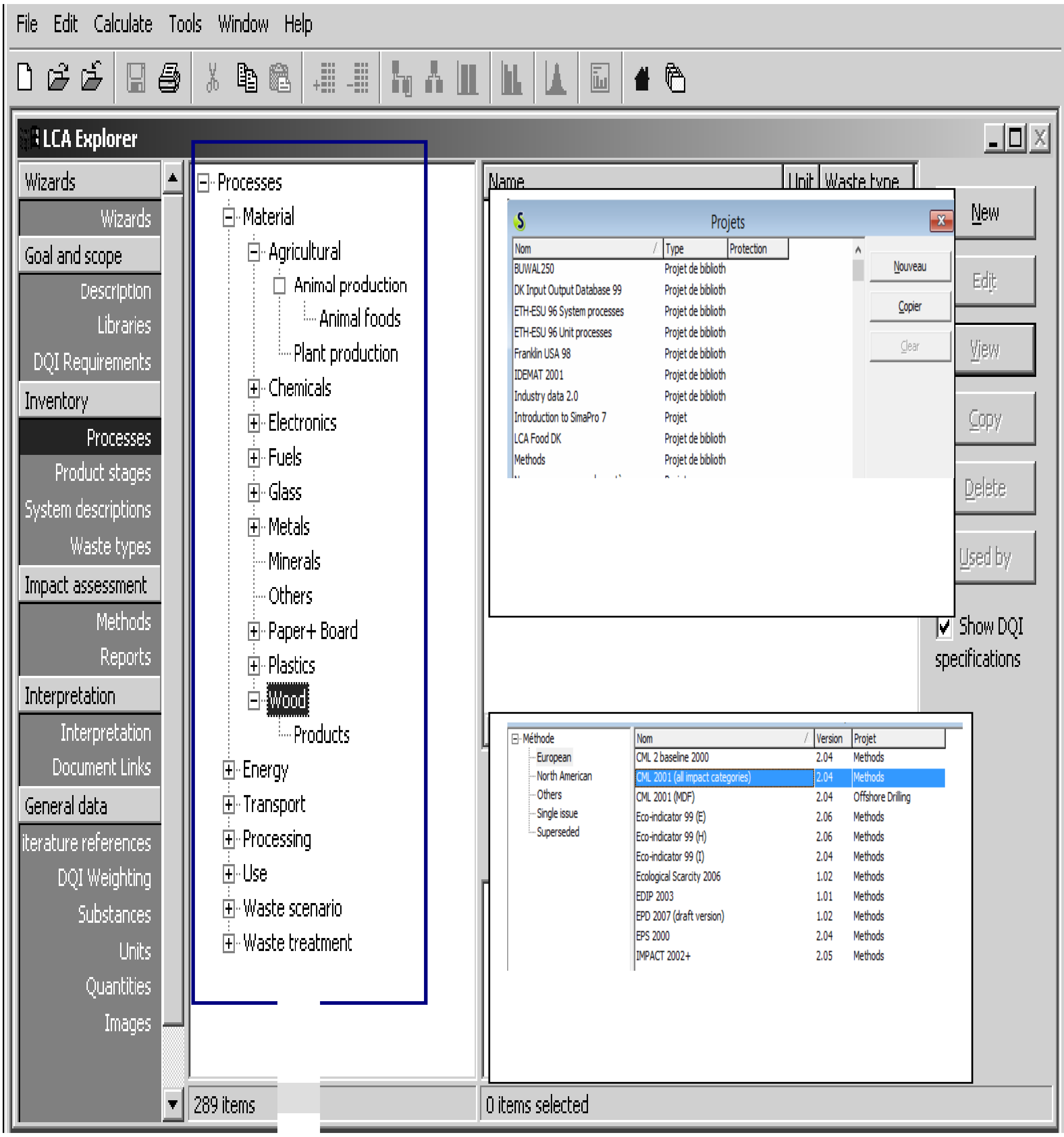


Figure 19: Overall structure of the SIMAPRO software interface

		Drilled sections of the well				
Ressources	Unit	**36"**	**26"**	**17 1/2"**	**12 1/4"**	**8 1/2"**
Oil	m^3	3,96E+01	6,47E+01	5,25E+02	1,82E+03	6,34E+04
Natural gas	m^3	1,37E+04	5,62E+04	3,21E+04	2,52E+04	1,02E+05
Water	m^3	2,01E+05	3,81E+04	8,70E+05	2,98E+05	3,24E+05
Barite	t	1,79E+02	1,78E+01	8,80E+02	3,00E+02	1,14E+00
Bentonite	kg	1,16E+05	4,10E+00	4,96E+00	2,86E+00	1,29E+01
Bauxite	g	4,12E+01	7,79E+00	1,78E+02	6,10E+01	6,65E+01
Zinc	mg	6,62E+01	3,98E+01	3,20E+02	1,07E+02	1,13E+02
Emissions to air						
SOx	kg	3,43E+02	1,54E+03	1,44E+03	7,98E+02	1,89E+03
NOx	kg	1,42E+02	1,54E+03	9,32E+02	6,50E+02	1,88E+03
PM	kg	1,34E+02	2,87E+02	9,45E+02	3,20E+02	9,25E+01
NMCOV	kg	3,57E+02	5,62E+03	2,89E+03	2,76E+03	5,06E+03
CH4	mg	1,86E+02	3,52E+01	8,07E+02	2,76E+02	3,00E+02
CO2	t	6,58E+01	2,88E+02	2,63E+02	1,50E+02	4,26E+02
CO	kg	2,81E+01	3,96E+02	2,11E+02	1,57E+02	4,73E+02
Emissions to waters						
Pb	g	2,67E+02	1,08E+02	3,39E+02	1,31E+02	1,88E+02
Cu	g	5,51E+01	1,17E+02	3,00E+02	1,20E+02	1,83E+02
Co	g	2,16E+01	1,11E+01	1,02E+02	3,43E+01	3,64E+01
Cr	g	1,14E+02	6,02E+01	5,21E+02	1,76E+02	1,99E+02
As	g	2,22E+01	8,22E+02	1,22E+02	4,89E+01	7,55E+01
Sb	mg	1,69E+02	7,14E+01	7,82E+02	2,64E+02	2,82E+02
Ba	kg	1,09E+01	1,26E+01	1,39E+01	8,38E+00	3,95E+01
Al	kg	4,01E+01	1,24E+02	5,62E+01	2,05E+01	2,66E+01
Aromatic Hydrocarbons	kg	1,65E+00	5,29E+04	1,17E+01	9,14E+00	2,52E+01

		Drill Waste Treatment Options		
Resources	**Unit**	**Sieving+ Centrifugation**	**Stabilization/Solidification**	**Thermal desorption**
Water	kg	5,11E+06	3,77E+05	2,33E+06
Energy	MJ	1,38E+05	1,13E+07	-1,32E+05
Barite	kg	6,13E+02	1,52E+02	4,35E+01
Bentonite	kg	4,18E+06	9,98E+00	3,78E+00
Carbon	kg	1,30E+04	8,20E+03	-3,14E+04
Natural gas	m^3	1,76E+03	1,41E+04	-6,80E+03
Iron	kg	7,86E+00	1,11E-02	9,61E+01
Emissions to air				
CO2	kg	4,75E+05	-4,82E+05	4,64E+05
CO	kg	1,85E+02	-9,23E+02	5,54E+02
CH4	kg	6,58E+02	-6,34E+03	6,20E+02
VOC	kg	2,03E+05	x	x
Emissions to soil				
Al	kg	7,60E+04	5,69E+04	7,71E+04
As	kg	2,90E+00	2,17E+00	4,71E-01
Ba	kg	2,29E+05	1,71E+05	1,17E+05
Pb	kg	1,06E+03	7,97E+02	2,06E+03
Ni	kg	4,84E+01	3,62E+01	3,26E+01
Zn	kg	7,26E+03	5,43E+03	2,09E+03
Aromatic Hydrocarbons	kg	3,87E+05	7,99E+04	3,62E+04

Table 5: Extract from the matrix of emissions and extractions of well sections and drilling waste treatments life cycle

II.2.2.3 Environmental impacts and risks assessment

The life cycle impact assessment was carried out using SIMAPRO7 which is an LCA software developed by PRé Consultant in the Netherlands. It makes it possible to evaluate the environmental impacts of a defined system with Life Cycle Impact Assessment models integrated to several LCA methods as Eco-Indicator99, EDIP, Impact 2002+, CML2001 and ReCiPe. The figure 20 shows the general structure of SIMAPRO7 software used in

For this study, the LCA method chosen was CML2001 to analyze the environmental impacts of the life cycle of the offshore drilling system. It is developed by the Institute of Environmental Sciences, Leiden University, Netherlands (Frischknecht et al. 2007; Crettaz et al., 2002) . The modeling of environmental impacts in this method is based on mathematical analysis models which are more suited to the characterization of toxic emissions from this system in different environmental compartments, in particular marine waters and sediments. The figure 19 below presents the conceptual framework of CML2001 method which was adopted and completed in this study.

In this LCA method, environmental impacts are analyzed up to the midpoint only, but in this study the analysis continued down to the damage level. The latter represent the risks on the final targets which are: human health, the quality of the ecosystem, climate change and the depletion of resources. The conversion of emissions and extractions from the system life cycle into potential impacts is carried out by characterization factors from mathematical models integrated into this method. The general formula for the impact score is expressed by the equation below where CI is the category indicator; M_x is the mass of substance x emitted or extracted as part of the inventory results (LCI); and $CF_{x,i}$ is the characterization factor of substance x contributing to impact category i.

$$CI = CF_{x,i} \times M_x$$

The category indicator allows the aggregation of inventory analysis results into common units within each impact category as an impact score.

For example, the general expression for multiple toxic substances emitted in multiple environmental compartments is (Huijbregts et al. 2001):

$$S_i = \sum_{e=1}^{e=m} \sum_{x=1}^{x=n} CF_{i,x,e} \times M_{x,e}$$

where Si is the impact score for category i (Human toxicity, Terrestrial ecotoxicity, marine ecotoxicity...), $M_{x,e}$ is the mass of substances emitted in compartment e, and $CF_{i,x,e}$ is the characterization of impact category *i* for substance *x* which is due to an emission in compartment *e; n* and *m* being the number of substances and compartments respectively.

The characterization factor takes into account the chemical fate of toxic substances in the various receiving environments and their effects on the exposed targets. The level of risk is determined by the exposure doses of species and humans in relation to tolerance thresholds specific to each toxic substance which are set by toxicologists and the World Health Organization (WHO). Thus, the severity of the damage to human health is expressed in DALYs (disability-adjusted life years) according to the WHO. It is a cost of illness scale that measures life expectancy in good health, by subtracting the number of years "lost" due to illness, disability or early death.

On the other hand, the damage on the quality of the ecosystem is expressed in pdf.m2.yr where the loss of biodiversity is considered as a potentially disappeared fraction of species in a certain area (m2) during a certain time (years).

The selected impact categories have been analyzed and aggregated into four categories of damage on final targets which are Human health, Ecosystem quality, Climate change and Resource depletion (Fig. 20). The impact categories and damage categories with their corresponding units are summarized in Table 7.

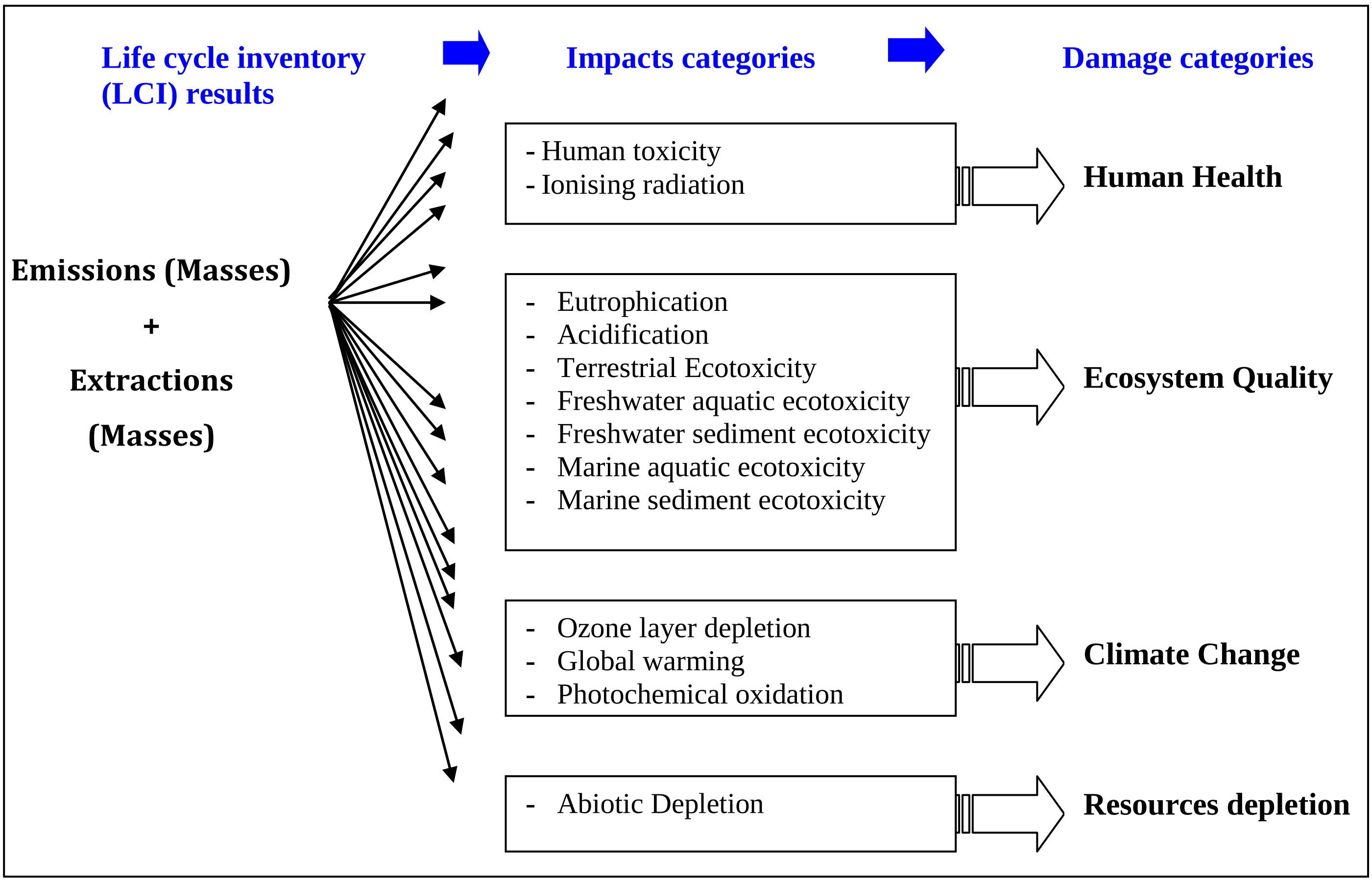


Figure 20: Selected impact and damage categories

Impact Categories			**Damage Categories**	
	Definitions	Units		Units
Human toxicity	The Human Toxicity Potential is a calculated index that reflects the potential harm of a unit of chemical released into the environment, and it is based on both the inherent toxicity of a compound and its potential dose.	kg 1,4-DB eq	[DALY/ kg 1,4-DB eq]	**Human Health** [DALY]
Ionising radiation	It is related to the damage to human health that is linked to the emissions of radionuclides throughout a product life cycle.	DALYs	[DALY/ DALYs]	
Acidification	Acidification potential is described as the ability of certain substances to build and release H+ions and is given in sulphur dioxide equivalents. The acidification of soils and waters occurs predominantly through the transformation of air pollutants into acids, which leads to a decrease in the pH-value of rainwater and fog from 5.6 and below.	kg SO2 eq	[PDF.m^2.yr / kg SO2 eq]	**Ecosystem Quality** [PDF.m^2.yr]
Eutrophication	Excess supply of nutrients (nitrates and phosphates) in an aquatic environment that can lead to the proliferation of aquatic plants.	kg PO_4^{3-} eq	[PDF.m^2.yr / kg PO_4^{3-} eq]	
Terrestrial Ecotoxicity	*It is about the toxic substances impact on the* terrestrial *ecosystem (organisms and terrestrial plants).*	kg 1,4-DB eq	[PDF.m^2.yr / kg 1,4-DB eq]	
Freshwater aquatic ecotoxicity	*It is about the toxic substances impact on the* freshwater aquatic *ecosystem. Sediment ecotoxicology focuses on the contaminants that adsorb to fine particles, and on the organisms that either live in the sediment or are impacted*	kg 1,4-DB eq	[PDF.m^2.yr / kg 1,4-DB eq]	
Freshwater sediment ecotoxicity		kg 1,4-DB eq	[PDF.m^2.yr / kg 1,4	
Marine aquatic ecotoxicity	*Marine ecotoxicity is about the toxic substances impact on the marine ecosystem. Sediment ecotoxicology focuses on the contaminants that adsorb to fine particles, and on the organisms that either live in the sediment or are impacted.*	kg 1,4-DB eq	[PDF.m^2.yr / kg 1,4	
Marine sediment ecotoxicity		kg 1,4-DB eq	[PDF.m^2.yr / kg 1,4	
Ozone layer depletion	*A thinning or even disappearance of this layer resulting from an imbalance between the production and destruction of ozone in the stratosphere*	kg CFC-11 eq	[Kg CO_2/ kg CFC-11 eq]	**Climate Change** [Kg eq CO2]
Global warming	*Gradual and long-term shifts in average world temperatures at sea level, primarily due to burning fossil fuels.*	Kg CO_2	[Kg CO_2/ Kg CO_2]	

Photochemical oxidation	*Secondary air pollution, formed in the troposphere caused mainly by the reaction of sunlight with emissions from fossil fuel combustion creating other chemicals (eg ozone).*	kg C2H4	Kg eq CO2/ kg C2H4	
Abiotic Depletion	*Reduction in availability of abiotic natural resources (minerals and fossils) for human use.*	kg Sb eq	MJ Primary/kg Sb eq	**Ressources** [MJ Primary]

Table 6: Definitions and corresponding units of selected impact and damage categories in CML method

III.3 ANALYSIS RESULTS AND DISCUSSIONS

II.3.1 Calculation of impact scores related to well sections

The overall analysis of the environmental impacts of the different sections of the well shows that the contribution score of the last section of well drilling (8" ½) is the most important in several impact categories. This is due to the fact that OBMs constitute the largest part of the drilling fluids for difficult technical reasons at this depth level of the well. However, it is section 26 which registers the greatest contribution in the total impact concerning acidification and eutrophication. As for marine aquatic ecotoxicity and that of marine sediments, the largest contribution comes from section 36" which, on the other hand, has the lowest scores in all the other impact categories.

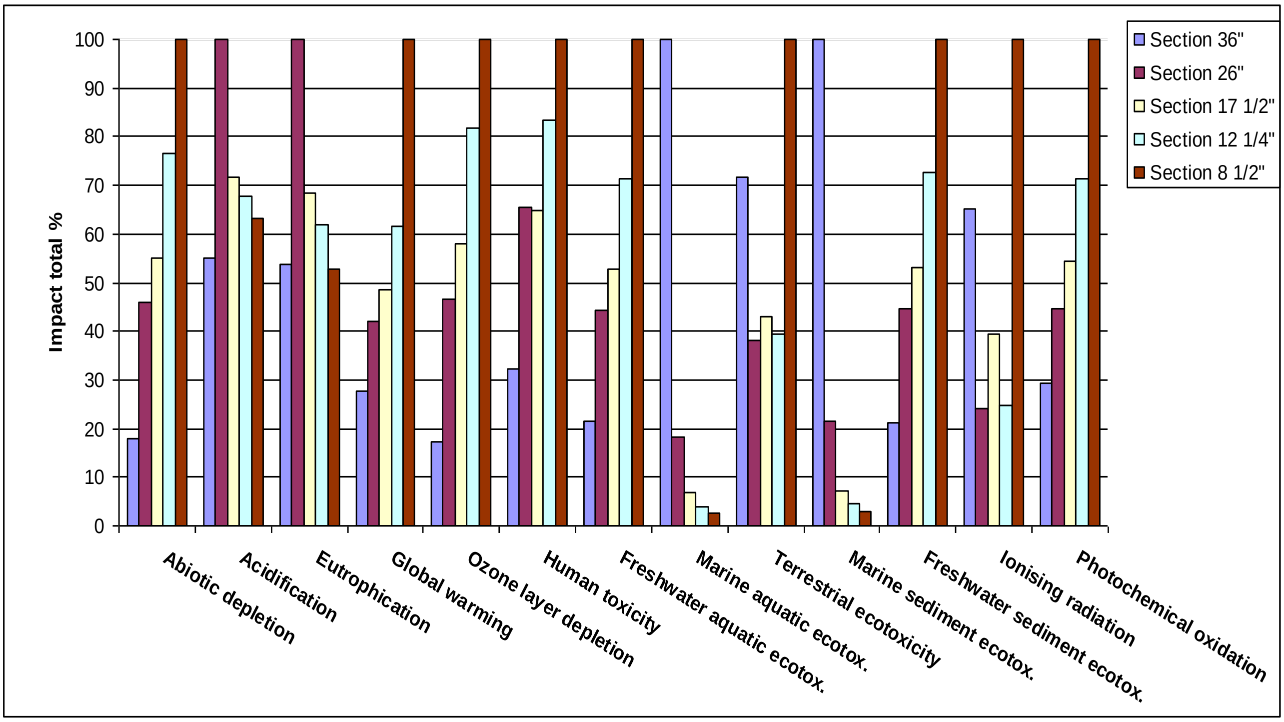


Figure 21: Percentage of impact scores related to well sections

II.3.2 Calculation of well section damage and risk scores

The graph in Figure 20 shows the total scores in the damage classes for the different sections of the well. Section 8'1/2 has the highest environmental burden on human health, climate change and resource depletion with respectively 2.23E+05 [DALY], 3.97E+03 [Kg CO2 eq.] and 1.64E+04 [MJ Primary]. For ecosystem quality, section 36" has the highest impact score with 4.98E+06 [PDF.m2.yr] followed by sections 26" with 1.09E+06 PDF.m2/yr and 17 ½" with 4.38E+05 PDF.m2/yr (Tabl.7).

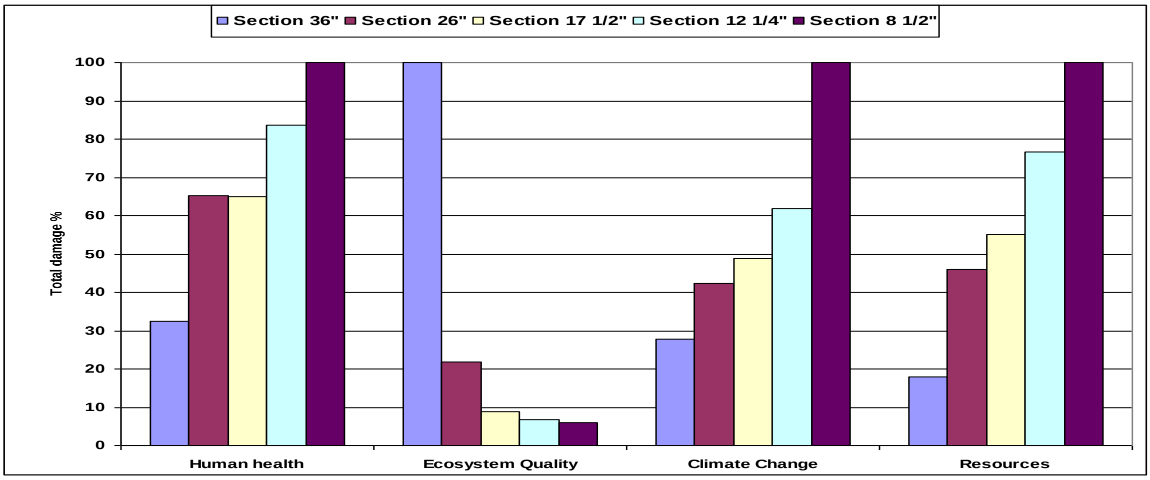


Figure 22: Damage and risks scores related to well sections

Catégorie de dommages	Unité	Section 36"	Section 26"	Section 17 1/2"	Section 12 1/4"	Section 8 1/2"
Human health	DALY	7.22E+04	1.46E+05	1.45E+05	1.86E+05	2.23E+05
Ecosystem Quality	PDF*m2*yr	4.98E+06	1.09E+06	4.38E+05	3.30E+05	3.01E+05
Climate Change	Kg CO2 eq	1.10E+03	1.67E+03	1.94E+03	2.46E+03	3.97E+03
Resources	MJ Primary	2.93E+03	7.52E+03	9.01E+03	1.26E+04	1.64E+04

Table 7: Well section damage and risk scores, expressed by corresponding units

II.3.3 Contribution scores of well sections on the risk to human health

The ionizing radiation and human toxicity are the two categories of impact that cause damage to human health, which are expressed in DALY. It can be observed that human toxicity has a higher potential than ionizing radiation for all the sections (Fig. 22). This shows the majority contribution of life cycle emissions from offshore drilling presenting a risk of human toxicity, such as metals and hydrocarbons, much greater than the contribution of ionizing radiation such as x-rays.

Compared to the other sections of the well, section 8 ½” has the highest score in human toxicity (Tab. 8) with 2.23E+05 [kg 1,4-DB eq] and also in ionizing radiation even with a small score of 2 mm section [1.55E-03 DALYs].

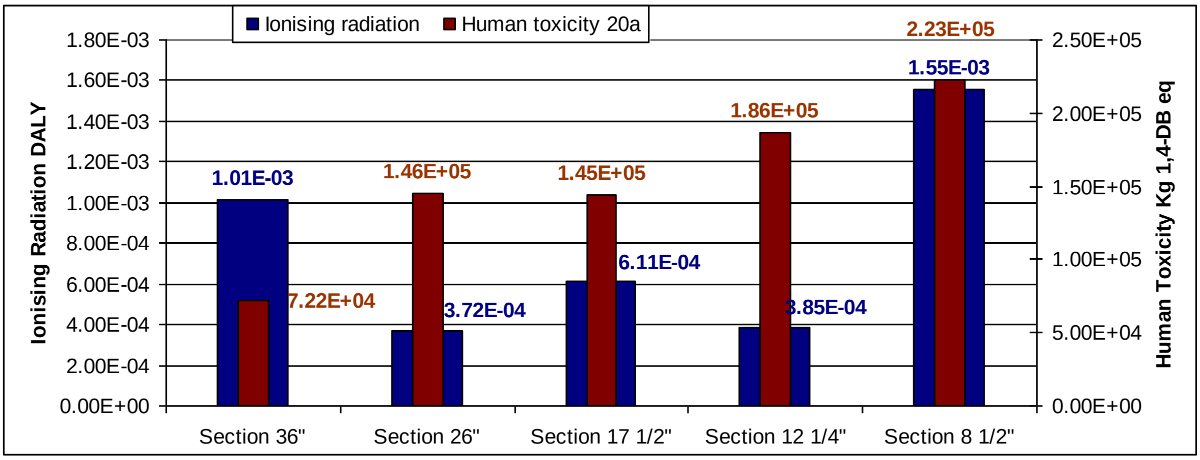


Figure 23: Contribution scores of well sections in Human health risk

Catégorie de dommages	Unité	Section 36"	Section 26"	Section 17 1/2"	Section 12 1/4"	Section 8 1/2"
Human health	DALY	7.22E+04	1.46E+05	1.45E+05	1.86E+05	2.23E+05
Human toxicity	kg 1,4-DB eq	7.22E+04	1.46E+05	1.45E+05	1.86E+05	2.23E+05
Ionising radiation	DALYs	1.01E-03	3.72E-04	6.11E-04	3.85E-04	1.55E-03

Table 8: Contribution scores of well sections in Human toxicity and Ionising radiation

II.3.4 Main contribution of life cycle processes on Human Health risk

The process tree of the system life cycle obtained by the SIMAPRO software made it possible to identify the processes that have the largest share of high scores (Fig. 23). Thus, for Human Health category, the majority impact for section 8 ½“, is mainly due to the large amount of diesel used for technical reasons, with a score of 1.91E5 DALY. For section 12 ¼“ and 17 ½”, there is also the role of diesel that contributes to the score increase, followed by organic chemicals and Barite. For the 26” section, both diesel and organic chemicals contribute to the total human health score. For the 26” section, both diesel and organic chemicals contribute to the total human health score. For Section 36″, the role of Barite is found with a score of 0.08255 Daly in addition to that of Soda with 0.13 Daly. These two chemical additives contribute most to the total score in the human health category, in particular human toxicity.

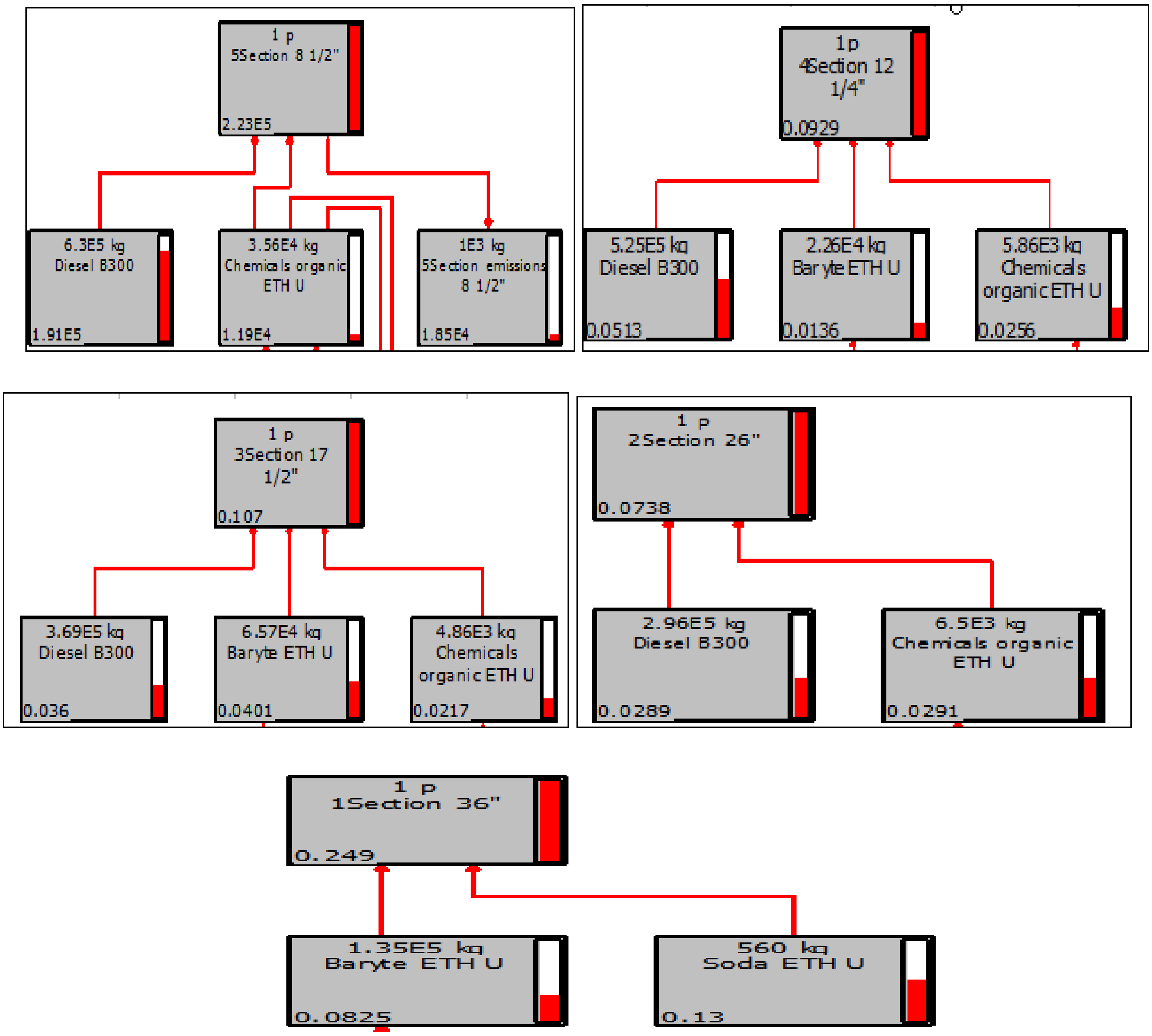


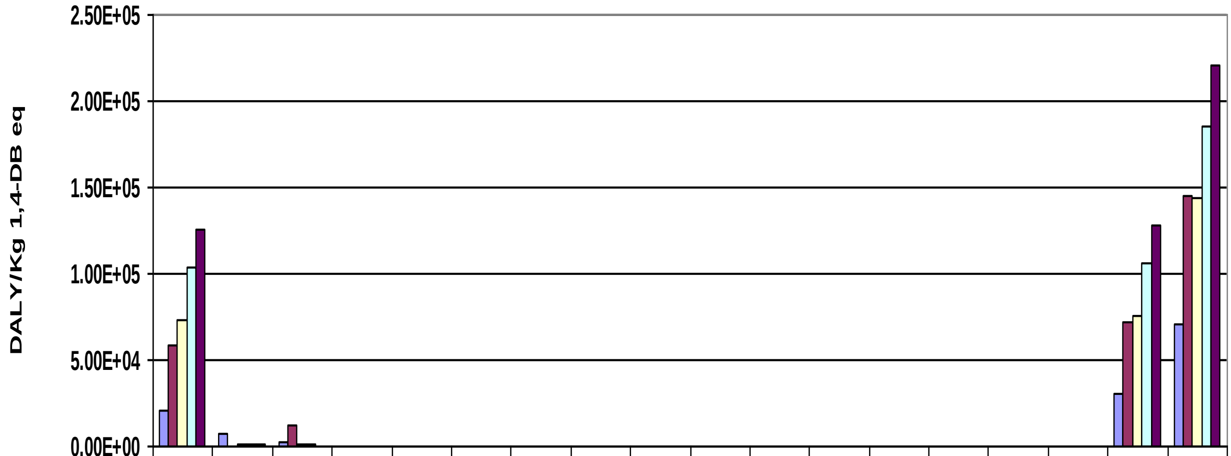
Figure 24: Main contribution of life cycle processes on Human Health risk

II.3.5 Human toxicity contribution scores of toxic substances emitted from drilling fluid losses

By refining the analysis, it is possible to identify the substances emitted locally from fluid losses during the drilling of the various sections of the well. It can be seen that polycyclic aromatic hydrocarbons PAH has the greatest contribution in human toxicity, followed by arsenic and barium and this, for all sections of the well. According to the life cycle impact analysis model integrated into LCA methods, human toxicity is assessed by taking into account the chemical fate of the substance emitted in the environmental compartment in question (here, it is the column d water and marine sediments) as well as its toxic effect.

Thus, the latter is assessed, in the case of human toxicity, by taking into account the fraction ingested by humans, via contaminated food (such as fish) or drinking water or even following inhalation of polluted air. The high scores of the substances identified therefore depend both on their concentrations (variable according to their mass in the fluids losses) but also on their toxicity thresholds.

The graph in figure 24 below shows also that total emissions to water (TEW) and total emissions to all environmental compartments (TEC) which are exposed during the life cycle of the system. It can indeed be seen that emissions due to drilling losses to water (marine waters and marine sediments) are greater than all emissions occurring during the other stages of the system's life cycle.

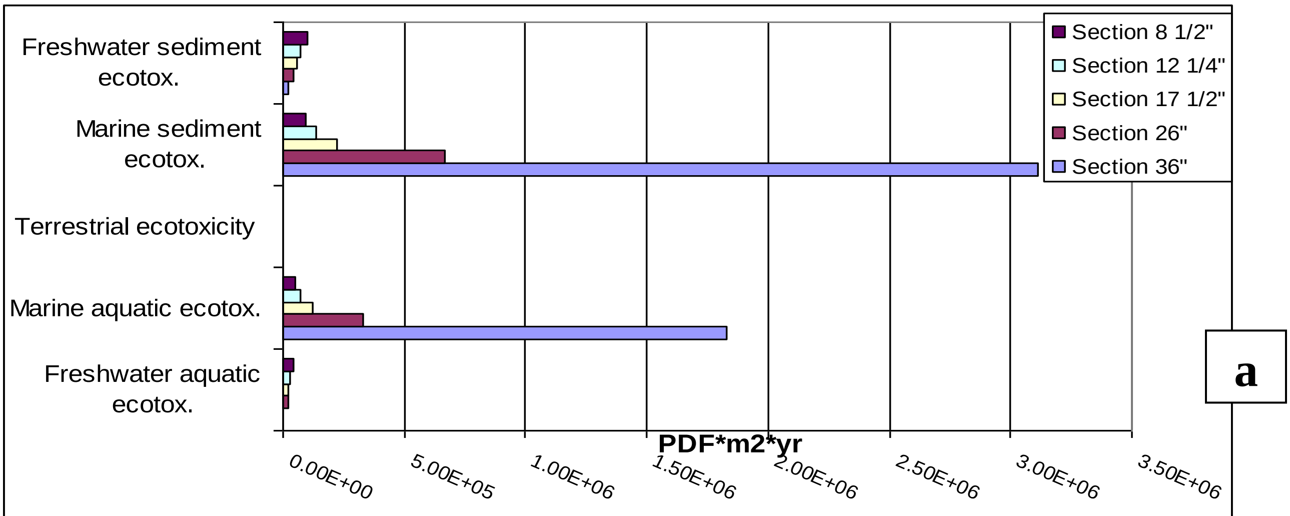


	PAH	Ba	As	Barite	Benzene	Se	V	Mo	Ni	Co	Pb	To	Cr	Zn	Cd	Sb	TEC	TEW
Section 36"	2.09E+04	7.04E+03	2.21E+03	1.03E+02	9.17E+01	3.21E+01	1.63E+01	4.76E+00	3.37E+00	1.52E+00	3.61E-01	2.09E-01	1.14E-01	1.09E-01	6.71E-02	6.30E-02	3.04E+04	7.09E+04
Section 26"	5.86E+04	5.89E+02	1.26E+04	1.20E+02	4.66E+01	1.13E+01	5.74E+00	1.69E+00	3.46E+00	5.33E-01	2.88E-01	5.88E-01	4.31E-02	3.64E-03	1.72E-01	2.29E-02	7.21E+04	1.45E+05
Section 17 1/2"	7.30E+04	9.83E+02	1.74E+03	7.21E+01	4.15E+01	1.85E+01	9.44E+00	2.77E+00	4.63E+00	8.79E-01	3.99E-01	7.32E-01	6.63E-02	2.26E-02	2.15E-01	3.77E-02	7.59E+04	1.44E+05
Section 12 1/4"	1.03E+05	1.09E+03	1.58E+03	6.46E+01	2.98E+01	1.17E+01	5.94E+00	1.75E+00	5.44E+00	5.53E-01	4.26E-01	1.04E+00	4.24E-02	2.33E-02	3.01E-01	2.38E-02	1.06E+05	1.86E+05
Section 8 1/2"	1.25E+05	1.32E+03	3.16E+02	3.18E+02	1.44E+02	4.70E+01	2.40E+01	7.05E+00	9.10E+00	2.23E+00	8.27E-01	1.26E+00	1.73E-01	4.37E-02	3.72E-01	9.58E-02	1.28E+05	2.21E+05

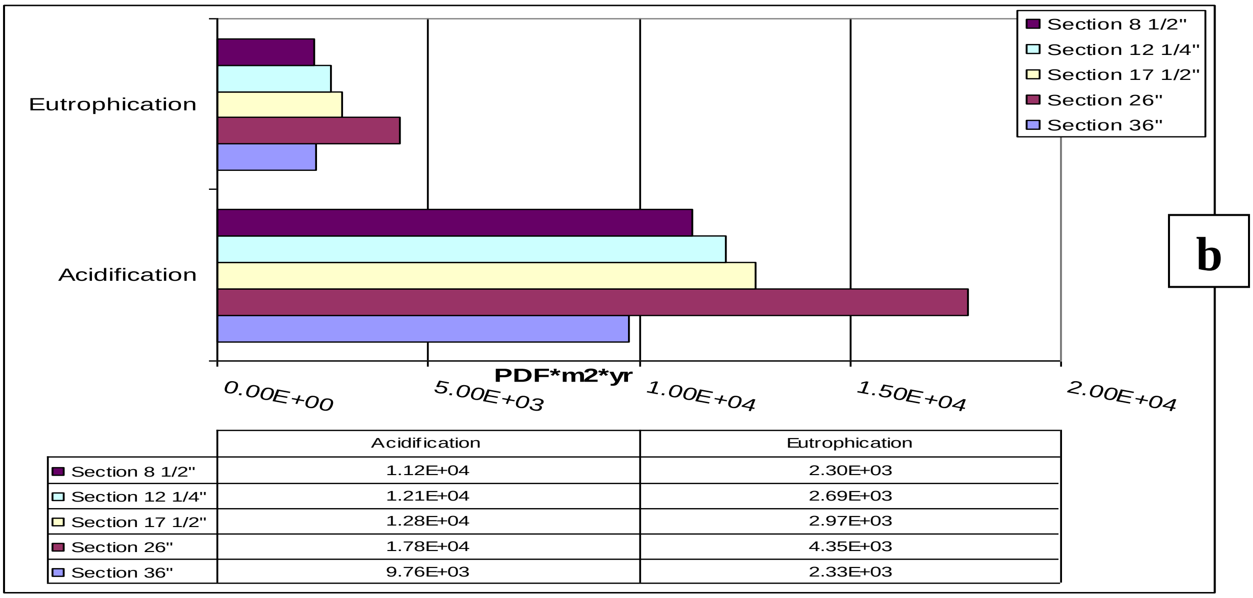
Figure 25: Human toxicity scores of toxic substances emitted from drilling fluid losses

II.3.6 Contribution scores of well sections on the risk to ecosystem quality

The graph in Figure 25 (a, b) shows the impact of toxic substances on marine species that are emitted during drilling fluid losses. It can be seen that section 36 has the highest load contributing to marine sediment ecotoxicity and marine aquatic ecotoxicity with respectively 3.11E+06 and 1.83E+06 [pdf.m2.yr]. This is due to the use of barite for technical reasons at this depth level. The 26" section has the second highest score in the same impact categories with 1 and 2 respectively. This is due to the contribution of diesel and chemical additives composing the fluids at this level of the well. On the other hand, for acidification and eutrophication, it is the 26" section which contributes the most; even if the scores in these impact categories remain much lower than those of the marine ecotoxicity of the 36" phase (water column and sediment). It should be noted that the contributions in these two categories of acidification and eutrophication impact are essentially linked to other stages of the life cycle of the systems such as the manufacture of the chemical additives used in the fluids and consequently, the environmental targets of eutrophicating and acidifying emissions are other aquatic environments from other regions where these industries exist.



	Freshw ater aquatic ecotox.	Marine aquatic ecotox.	Terrestrial ecotoxicity	Marine sediment ecotox.	Freshw ater sediment ecotox.
Section 8 1/2"	4.04E+04	5.04E+04	1.22E+01	9.21E+04	1.03E+05
Section 12 1/4"	2.89E+04	7.23E+04	4.84E+00	1.39E+05	7.49E+04
Section 17 1/2"	2.13E+04	1.22E+05	5.27E+00	2.24E+05	5.48E+04
Section 26"	1.80E+04	3.32E+05	4.65E+00	6.68E+05	4.60E+04
Section 36"	8.63E+03	1.83E+06	8.79E+00	3.11E+06	2.13E+04

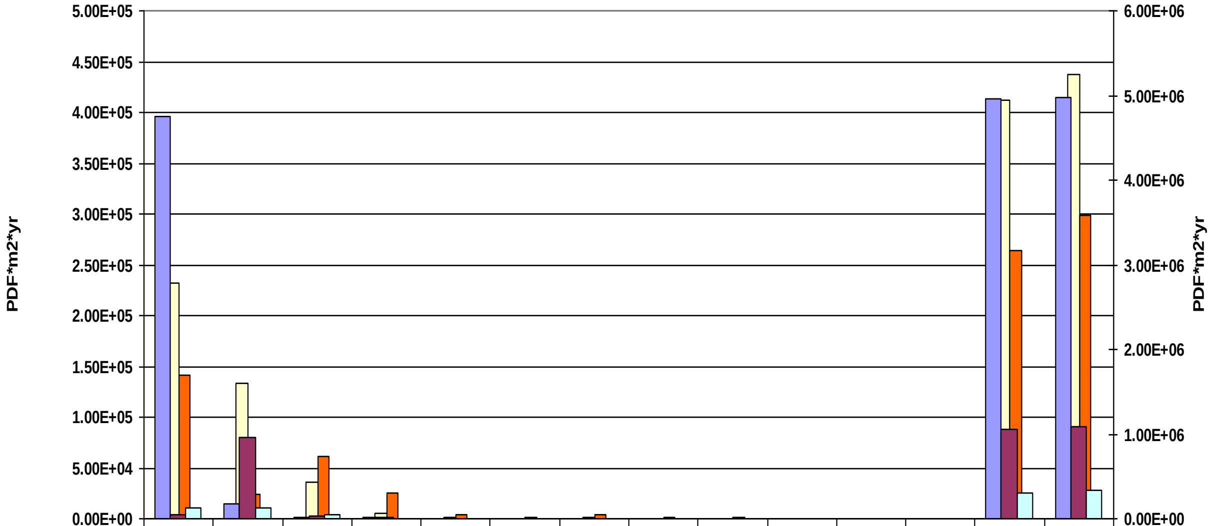


	Acidification	Eutrophication
Section 8 1/2"	1.12E+04	2.30E+03
Section 12 1/4"	1.21E+04	2.69E+03
Section 17 1/2"	1.28E+04	2.97E+03
Section 26"	1.78E+04	4.35E+03
Section 36"	9.76E+03	2.33E+03

Figure 26 (a, b): Contribution scores of well sections on the risk to Ecosystem quality

II.3.7 Marine ecotoxicity scores of toxic substances emitted from drilling fluid losses

For marine ecotoxicity (marines water column and sediments), the graph presented in figure 26 allows the identification of the major contribution of the substances emitted locally from fluid losses during the drilling of the various sections of the well. It can be seen that barium, arsenic, PAH and barite have the greatest contribution for all sections of the well. Indeed, barium has the highest marine ecotoxicity contribution score in section 36 followed by section 17 ½” with respectively 4.76E+10 and 2.32E+05 [PDF.m2.yr]. The second toxic substance presenting a risk of ecotoxicity for the marine environment is the PAH, especially during the drilling of section 8 ½” due to the large quantity of diesel used in the fluids (OBM); followed by section 36" because of the quantities of barite composing the water-based Mud (WBM).



	Ba	As	PAH	Barite	V	Zn	Ni	Se	Cu	Co	Mo	Cd	TEW	TEC
Section 17 1/2"	2.32E+05	1.33E+05	3.59E+04	5.78E+03	1.61E+03	4.92E+02	1.84E+03	3.64E+02	4.73E+02	1.83E+02	6.24E+01	1.41E+02	4.12E+05	4.38E+05
Section 8 1/2"	1.42E+05	2.41E+04	6.16E+04	2.55E+04	4.09E+03	9.56E+02	3.62E+03	9.25E+02	9.52E+02	4.64E+02	1.58E+02	2.44E+02	2.65E+05	2.99E+05
Section 36"	4.76E+06	1.69E+05	1.03E+04	8.28E+03	2.79E+03	1.89E+03	1.34E+03	6.32E+02	3.89E+02	3.17E+02	1.07E+02	4.40E+01	4.95E+06	4.98E+06
Section 26"	4.81E+04	9.66E+05	2.88E+04	9.63E+03	9.80E+02	1.52E+02	1.38E+03	2.21E+02	3.48E+02	1.11E+02	3.79E+01	1.13E+02	1.06E+06	1.09E+06
Section 12 1/4"	1.23E+05	1.21E+05	5.08E+04	5.17E+03	1.02E+03	5.30E+02	2.16E+03	2.29E+02	5.31E+02	1.15E+02	3.93E+01	1.98E+02	3.05E+05	3.30E+05

Figure 27: Marine ecotoxicity scores of toxic emissions from well sections

II.3.8 Calculation of impact and damage scores related to offshore drilling waste treatments

Drilling waste is largely composed of cuttings resulting from rocks broken by the mechanical tool which crosses the geological formations all along the sections of the well until the hydrocarbons arrive at the reservoir. There is also in this waste, the residual fluids coming from the sections of the well especially those drilled with oil-based muds (OBM). Three discharge management methods were simulated, including transport from the offshore platform and three treatment processes for these discharges heavily polluted by hydrocarbons and chemical additives. These treatment processes are: (i) physical separation of fluids and oils by a series of sieving and centrifugation (ii) stabilization-solidification which consists of stabilization or inerting of pollutants and their solidification in a cemented solid matrix (iii) thermal desorption where the cuttings soaked in fluids are subjected to an indirect high temperature (~1000°C) making it possible to recover the oil for recycling. These three treatment processes are already applied to drilling waste onshore at Hassi Messaoud.

The comparison of these three scenarios shows an environmental benefit of thermal desorption due to the reduction of hydrocarbon content in cuttings up to less than 1% and the recovery of oil for reuse or recycling (Fig. 27). This process therefore appears to be the least harmful given its lower scores in the categories of damage to human health, climate change and resource depletion. The recovered part of the hydrocarbons which is recycled thus makes it possible to avoid the same environmental impacts which would be due to the use of the same volume of hydrocarbons. The avoided impacts of this process are negative on the graph. The avoided impacts of this process are negative on the graph. This advantage is also observed on damage, especially the avoidance of resource depletion and climate change (Fig. 28). On the other hand, treatment by solidification-stabilization seems the least advantageous given its high scores in several impact categories (abiotoc depletion, acidification, eutrophication, global warming, terrestrial ecotoxicity, ionizing radiation and photochemical oxidation) followed by physical separation where the contribution is higher in the marine and terrestrial ecotoxicity categories as well as human toxicity. The disadvantage of these two processes is reflected in the damage to human health, ecosystem quality, and climate change and resource depletion (Tab. 9).

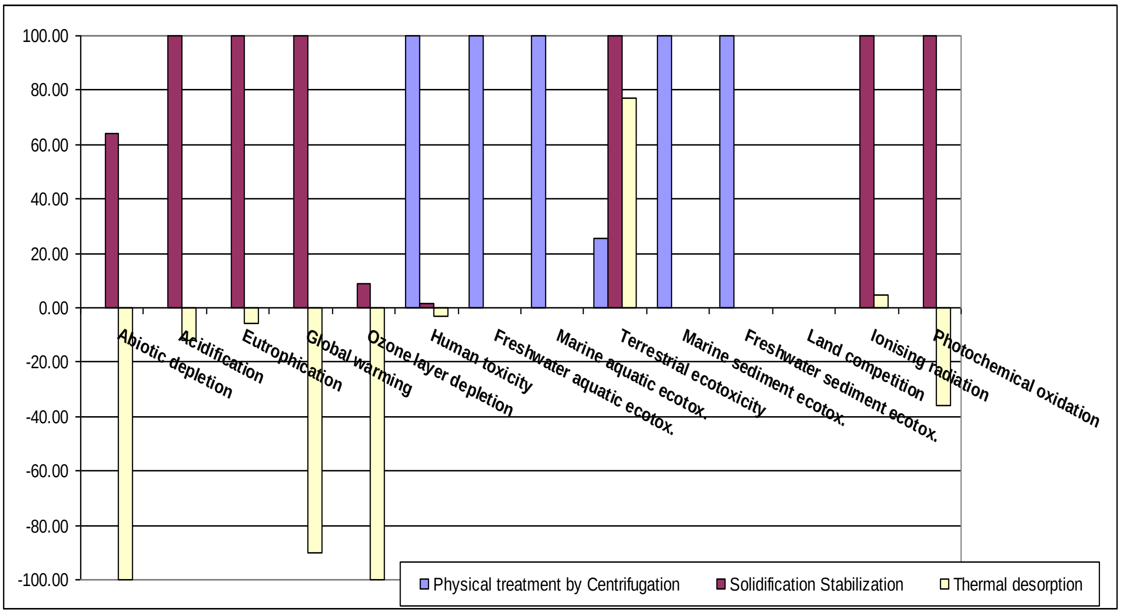


Figure 28: Impact scores related to the treatments of offshore drilling waste

Figure 29: Damage scores related to the treatments of offshore drilling waste

	Units	Sieving+ Centrifugation	Solidification Stabilization	Thermal desorption
Human health	DALY	1.00E+02	1.77E+00	-3.17E+00
Ecosystem Quality	PDF*m2*yr	1.00E+02	1.14E-01	-1.27E-01
Climate Change	Kg CO2 eq	9.35E-03	1.00E+02	-8.52E+01
Resources	MJ Primary	0.00E+00	6.43E+01	-1.00E+02

Table 9: Damage scores of the drilling waste treatments expressed in specific units

II.3.9 Terrestrial ecotoxicity scores of toxic substances emitted from drilling waste treatment

The graph in the figure shows the dominant substances that have a potential terrestrial ecotoxicity impact to which the microbial biodiversity of the soils of the region may be exposed. These soils are the receiving environments for the pollutants that can be emitted during the treatment processes as well as from the surface deposition of the treated cuttings. These majority substances are, in ascending order, cobalt, arsenic and chromium, especially through physical treatment where the cuttings would still contain quantities of hydrocarbons and chemical additives after treatment.

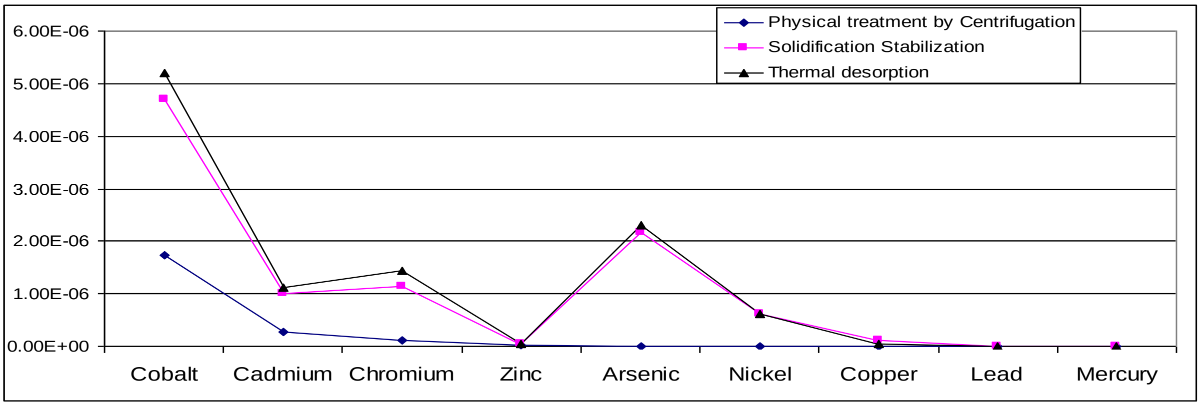


Figure 30: Terrestrial ecotoxicity scores of toxic emissions emitted to soils from drilling waste treatments

II.3.10 Environmental performance comparison of offshore drilling scenarios

In order to compare the environmental impacts and risks associated with offshore hydrocarbon drilling, three scenarios were simulated in the study area where an exploration perimeter is planned in the study area. These scenarios were defined based on the chemical composition of the drilling fluids as well as the methods of managing the drilling wastes, including the transport distance of the wastes for treatment onshore: (i) Well 1 where the rejects are treated by the centrifuge after passing through the vibrating screens; (ii) well 2 where the rejects are treated by stabilization-solidification on land; (iii) well 3 where the rejects are treated by thermal desorption. The graph in figure 30 shows the environmental performance of the well 3 thanks to the oil recovery by the thermal desorption treatment. On the other hand, the well 2 seems the most disadvantageous scenario for all the impact categories followed more closely by the well 1 except in the Terrestrial Ecotoxicity category due to the drilling waste management on the platform without transport to the continent. This also explains the high scores of this last scenario in marine ecotoxicity (water column and marine sediments) due to the discharge of drilling waste directly into the sea.

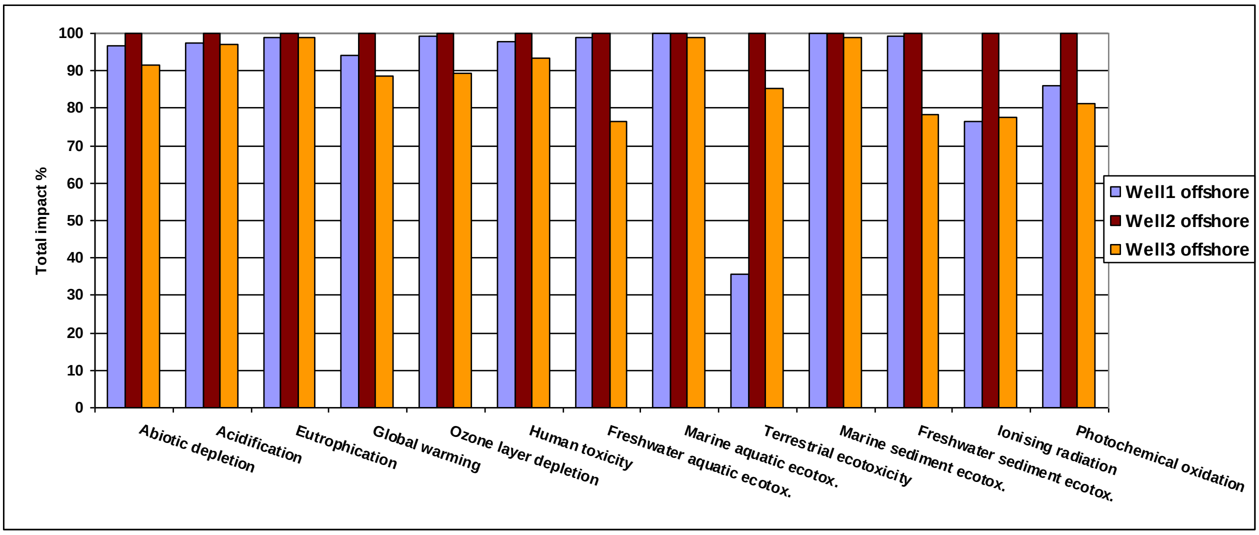


Figure 31: Comparison of three offshore exploration drilling scenarios (3 Wells)

Conclusion

This study focused on the analysis of the environmental impacts and potential risks related to the drilling of hydrocarbons for exploration at the level of a drilling perimeter in the coastal waters of Skikda. It was a question of a drilling simulation of a well according to three scenarios differentiated by the mode of management of the drilling rejects. The analysis of the offshore drilling stages as well as the comparison of the environmental performance of the three scenarios was carried out using the life cycle analysis (LCA) methodology. It turned out that this tool is relevant for quantifying and comparing the environmental impacts on the marine and terrestrial ecosystem as well as on humans.

The results showed the major role of drilling fluid losses in the impacts and damage to marine ecosystems, in particular the toxic risk due to diesel, barite and chemical additives. The contribution of the latter to marine toxicity (water column and marine sediments) was significant even in phase 36, where the drilling fluids used are made up of more than 90% water (Water-Based Mud). With regard to the management methods for drilling rejects, stabilization-solidification treatment had the most significant contribution to terrestrial ecotoxicity because of emissions to the ground of hydrocarbons and certain metals.

Thus, the results of the LCA can be used to identify areas for improvement and provide some recommendations:

- Control of formation losses to avoid or at least reduce the toxic risks to which marine species may be exposed.
- Minimization of the volumes of drilling rejects by separating those generated in the 36" section (water-based muds) from the oil-based muds generated by the other sections of the well.
- Tracing of chemical additives and replacement with other alternative products to neutralize or reduce the toxicity of certain metals such as arsenic and barium.

However, the analysis must be further refined by completing the missing data and improving the quality of the inventory data, especially those of the chemical composition of the fluids, the field data on the marine hydrodynamics which influences the behavior and the transfer of pollutants. There is also a need for better knowledge of the biology and population dynamics in the marine waters and the coastline concerned by the offshore drilling perimeter.

Finally, life cycle analysis can offer a decision-making tool to better ensure and anticipate the environmental sustainability of this type of drilling by preserving the marine environment and its resources, especially if its future development is required in Algeria, given the increasingly variable and uncertain global context.

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APPENDICES

Appendix 1: Dominant flora and fauna in the Skikda costline

Species	Depth	Characteristics
Ulva lactuca **(ulvales)**  (seaweedsolutions.com) ▪ Plantae (Reign) ▪ Viridiplantae (Under - Reign) ▪ Chlorophyta (Branch) ▪ Chlorophytina (Under - Branch) ▪ Ulvophyceae (Class) ▪ Ulvales **(**Order**)** ▪ Ulvaceae (Family) ▪ Ulva (Type) ▪ *Ulva lactuca* (Specie)	Shallow waters up to 10m from the mediolittoral stag	-A thin, flattened thallus, lobed. -Two layers of cells each with a single chloroplast. -A soft blade. -The seaweed adheres to the substrate thanks to a small fixation disc, surmounted by a very short stem.

Enteromorpha Linza **(ulvales)**  ***(www.shutterstock.com)*** ▪ Plantae (Reign) ▪ Viridiplantae (Under-reign) ▪ Chlorophyta (Branch) ▪ Chlorophytina (Under-branch) ▪ Ulvophyceae (Class) ▪ Ulvales (Order) ▪ Ulvaceae (Family) ▪ Ulva (Type) ▪ *Ulva lactuca* (Specie)	They are in the upper part of the foreshore	-Have flattened branched or unbranched tubes. - The length of the thallus varies from 1.9 to 36 cm with an average length of 18.6 cm. -*Ulva linza* is distinguished by its smooth thallus. - Most with a ruffled margin. -*Ulva linza* can tolerate a wide range of salinities and water qualities
Cladophora rupestris **(Cladophorales)**  (seaweed.ie/descriptions/Cladophora) ▪ Plantae (Reign) ▪ Viridiplantae (Under-reign) ▪ Chlorophyta (Branch) ▪ Chlorophytina (Under-branch) ▪ Ulvophyceae (Class)	They are found in the lower part of the foreshore in the basins or in the area of Fucus and Ascophyllum	- These are always branched filamentous algae. - The filaments that grow through multiplications. - Each filament consists of a single file of large cylindrical cells. -Numerous reticulated chloroplast and nuclei. -These chloroplasts often contain lenticular pyrenoids framed on each side by a concave starch grain.

▪ Cladophorales (Order) ▪ Cladophoraceae (Family) ▪ Cladophora (Type) ▪ *Cladophora rupestris* (Specie)		
***Patella vulgata* (Patellidae)**  **(https://www.researchgate.net)** ▪ Biota (World) ▪ Animalia (Reign) ▪ Mollusca (Branch) ▪ Gastropoda (Class) ▪ Patellogastropoda (Under-class) ▪ Patelloidea (Super-family) ▪ Patellidae (Family) ▪ Patella (Type) ▪ *Patella vulgata* (Specie)	Average level of foreshore.	- The body of the patella consists of a head, a pall cavity, a foot and a visceral mass. - The head is equipped with two large tentacles with tactile function and which may also be the seat of the chemical sense. - The shell is conical in shape not perfect, its base is not exactly circular and its top, quite clearly off-centered.

***Patella caerulea* (Patellidae)**  **(https://ar.wikipedia.org/)** ▪ Biota (world) ▪ Animalia (Reign) ▪ Mollusca (Branch) ▪ Gastropoda (Class) ▪ Patellogastropoda (Under-class) ▪ Patelloidea (Super-family) ▪ Patellidae (Family) ▪ Rotule (Type) ▪ P. caerulea (Specie)	Main genus representing in the Mediterranean	-The blue patelle is the most common in the Mediterranean. - Its shell, cone-shaped, is flat, fine, sculpted from strong radial ribs, and with slightly marked intermediate ribs. -This cone is often asymmetrical, with an offset apex on the anterior side. - It is dirty grey-brown and measures 2 to 4 cm in diameter.
Euraphia depressa (Chthamalidae)  **(https://doris.ffessm.fr/Especes/Euraphia-depressa)** Biota (Monde) Animalia (Règne) Mollusca (Embranchement) Hexanauplia (Classe) Thecostraca (Sous-classe) Chthamaloidea (Super-famille) Chthamalidae (Famille) Euraphia (Genre) Euraphia depressa (Espèce)	Shelf supra -littoral Lowest on the foreshore	- Appearance of a small flattened volcano up to 12 mm in diameter. - Six limestone plates forming the shell. - Oval-shaped lid, consisting of 4 plates. - Structure of the operculum forming a right angle, located at the posterior third.

Appendix 2: Some reference flows from well drilling and waste management

		Well drilling						Drilling waste managment		
	Unit	**Section 36"**	**Section 26"**	**Section 17 1/2"**	**Section 12 1/4"**	**Section 8 1/2"**	**Well**	Primary and secondary oil removal (Vibrating sieves and centrifuges)	Stabilization/Solidification	Thermal Desorption
Depth	m	52	365	505	992	1052.00	2966			
Inputs										
Electricité	KWh	132000	264000	132000	132000	660000	1320000	238700	7200	9620
Eau	tonne	873	161.92	59.07	32.4	22.8	1149.19	125	600	738
Diesel	tonne	100	295.84	369.09	524.97	630.1	1920	48	16	51
Steel	tonne						232			
Cement	tonne						322		600	
Ilmenite	tonne						1028			
Barofibre	tonne					1.69	1.69			
Barite	tonne	135	12	657.69	225.92	0.72	1031.33			
Bentonite	tonne	91	1.25	0.1	0.05	0.06	92.5			
Caustic Soda	tonne	1.05					1.05			
Soda Ash	tonne	0.56					0.56			
Activated carbon										6.8
Lime	tonne		15.6	19.1	6.34	4.54	45.58		30	
NaCl	tonne		10.87	9.25	3.07	0.29	23.48			
Grease	tonne						0.41			
washing chemicals	tonne						5.45			
Additifs organiques	tonne	2.56	6.5	4.86	1.83	35.58	51.33			
Citric acid	tonne	0.2					0.2			
Polyalkylene glycol	tonne	1.8					1.8			
Potassium chloride	tonne	6.8					6.8			
Polyanionic cellulose polymer	tonne	0.5					0.5			
Sodium carbonate	tonne	0.04					0.04			
Sodium hydrogen carbonate	tonne	0.1					0.1			
Transport chip	tkm						25000			
Transport Truck 28	tkm						12500		2000	16000
OUTPUTS										

Recycled fluids				569.64	213.84	250.8	1034.28		55.8		225
Ilmenite							244.6				
Bentonite							90.9				
Carboxymethyl cellulose							11.2				
Soda ash							1.7				
Emissions to air											
CO2	Kg	795	1468	980	856	2080	6179			0.077	0.24
NOx	Kg	17.42	32.25	21.5	18.82	45.7	135.69			0.002	0.003
nmVOCs (Non-methane volatile organic compounds)	Kg	1.25	2.3	1.6	1.34	3.26	9.6				
THC (Total hydrocarbons)										0.00012	0.00025
SO2										0.00011	0.00021
CO										0.00047	0.000817
TSP (Total suspended particles)										0.00011	0.000229
VOCs (Volatil Organic Compounds)										0.002	0.003
Emissions to sea	Kg										
Hydrocarbons (Gazole)		1.8075	54	7182	7308.36	145.8	1900.8				
Baryte BaSO4		8194	2	266	270.68	5.4	70.4				
Ca(OH)2		0	2.4	319.2	324.816	6.48	84.48				
NaOH		65.07	0	0	0	0	0				
NaCL		0	2	266	270.68	5.4	70.4				
COT		9.64	0.6	79.8	81.204	1.62	21.12				
Al		7.23	0.12	15.96	16.2408	0.324	4.224				
As		0.14	0.0008	0.1064	0.108272	0.00216	0.02816				
Pb		0.05061	0.00084	0.11172	0.1136856	0.002268	0.2				
Cr		0.0723	0.0012	0.1596	0.162408	0.00324	0.04224				
Fe		216.9	0.36	47.88	48.7224	0.972	12.672				
K		96.4	1.8	239.4	243.612	4.86	63.36				
Zn		1.446	0.0024	0.3192	0.324816	0.00648	1.5				
V							0.886712				
Co							3.36				
Sr							4.441				
Sb							111				

Ni							0.01				
Cd							0.075				
Ba							47.252				
Cu							0.2				
Emissions to soils	Kg										
Zn										576	339
Pb										570	193
Cu										22	10
Cr										37	30
Ni										9	10
Cd										0.077	0.045
Ba										32192	43580
Sr										2879	2038
Sb										21.8	39.5
Co										3.4	2.1
Emissions to surface waters	mg										
Zn									1552		
Pb									220		
Cu									201		
Cr									36		
Ni									10		
Cd									0.075		
Ba									47252		
Sr									4441		
Sb									111		
Co									3.36		
Aromatic hydrocarbons									1.0013		

Appendix 3: Extract of the emissions linked to the life cycle of the offshore drilling well according to the three scenarios.

Emissions to soil				
	Unité	**Well1**	**Well 2**	**Well 3**
Aluminum	kg	5.20164584	6.88427942	-1.33119956
Arsenic	kg	0.00208696	1.63336171	1.73007152
Cadmium	kg	0.00028504	0.97703591	1.07689532
Calcium	kg	20.8065052	23.6171027	-9.28481319
Carbon	kg	15.7533305	17.9257244	-7.58897197
Chromium	kg	0.02608706	0.8185214	0.97739401
Cobalt	kg	0.00038645	0.9520494	1.05185477
Copper	kg	0.00017417	1.76024727	0.75927312
Heat, waste	MJ	7109.15032	9124.4897	7190.46758
Iron	kg	10.4032794	12.7405465	-4.54921141
Lead	kg	0.00079399	0.88412719	0.87968731
Manganese	kg	0.20806568	0.86717103	0.53815187
Mercury	kg	4.8248E-06	6.9089E-06	-1.9829E-05
Nickel	kg	0.00026143	0.96437115	0.96290894
Nitrogen	kg	0.00141142	0.00201545	-0.00551325
Oils, biogenic	kg	0.00318174	0.0129068	0.25121529
Oils, unspecified	kg	1.09728943	64.887517	59.0996257
Phosphorus	kg	0.26188841	0.29784562	-0.12236591
Phosphorus, total	kg	0.00020304	0.00020304	0.00020304
Sulfur	kg	3.12184904	3.54381312	-1.39634697
Zinc	kg	0.08000318	0.87703785	0.74390983
Emissions to water (marines water and sediments)				
Aluminum	kg	0.00798	0.00798	0.00798
Arsenic, ion	kg	1170	1170	1170
Barium	kg	8632	8632	8632

Chromium	kg	1.81007	1.81007	1.81007
Hydrocarbons, aromatic	kg	272970	272970	272970
Iron	kg	218.23	218.23	218.23
Lead	kg	0.60005	0.60005	0.60005
Mercury	kg	5.74E-06	5.74E-06	5.74E-06
Metallic ions, unspecified	kg	0.00443	0.00443	0.00443
Nickel, ion	kg	1.089E-05	1.089E-05	1.089E-05
Solved substances, inorganic	kg	73.33	73.33	73.33
TOC, Total Organic Carbon	kg	27100	27100	27100
Zinc, ion	kg	2.78	2.78	2.78
Emissions to air				
Nickel	kg	3.77345333	3.91486595	3.6700921
Hydrogen fluoride	kg	4.37688909	5.24043848	4.42311413
Sulfur dioxide	kg	5.06022591	5.06022591	5.06022591
Propane	kg	5.47674589	6.52295465	-4.33102042
Silicon	kg	6.72944068	8.89138172	6.89663153
Nitrogen	kg	12.7856545	13.7277147	12.9834709
Ethane	kg	16.4344822	17.3067878	14.2033011
Metals, unspecified	kg	21.7251596	21.7270194	21.7270194
Benzene	kg	23.0826137	23.2034852	22.0841701
Dinitrogen monoxide	kg	23.5764404	25.6229176	22.810447
Hydrogen chloride	kg	36.6153598	46.4927236	37.4719709
Hydrocarbons, aromatic	kg	41.2385373	41.2479764	41.2347789
Particulates, < 10 um (stationary)	kg	58.8574882	70.2668589	39.3458883
Particulates, > um (process)	kg	265.693978	642.849194	326.12379
Particulates10	kg	540.2009	540.228192	540.228192
Carbon monoxide	kg	1532.52403	2224.91024	1592.34096
Sulfur oxides	kg	6658.58016	7504.6025	6503.74768
Methane	kg	8538.45058	9244.55612	8133.88856
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	26091.2214	26213.1793	25111.3738
Nitrogen oxides	kg	111188.473	112436.678	111171.465
Carbon dioxide	kg	1286026.58	1862563.17	1300039.83

Abstract

The objective of this work is to assess the environmental impact of the drilling sludge system in Algeria in the sea between Skikda and Annaba. Water-based sludge (WBM) and oil-based sludge (OBM) are used when drilling wells in the projected sea between Skikda and Annaba and have significant pollution potential. A Life Cycle Assessment (LCA) approach is used to assess the effects of many drilling sludge systems at all stages of their life cycle, such as their use, treatment and disposal. The environmental impacts are compared to two treatment scenarios corresponding to the management of drilling waste already applied to Hassi Messaoud: stabilization/ solidification and absorption. Impact analysis using the CML method and LCIA model is performed in SIMAPRO7. This assessment identifies human and marine toxicity as the primary impact category in this specific marine context and identifies contributions to emissions. The impact on the local marine environment is the largest drilling mud life cycle is mainly related to emissions from stocks, treated cuttings and stage 16 drilling for aquifers. The main contributing substances are aromatic hydrocarbons and minerals, particularly barium, zinc, antimony, arsenic and aluminium. For comparison of treatment scenarios, stabilization/solidification seems to be the best solution, as it has the lowest effect in the two dominant categories due to waste reduction: avoided sludge storage in the reserve pit. The second best case scenario is thermal adsorption, which has the lowest carcinogenic effect due to reduced hydrocarbons (<1%) and avoided effects of recovered oil. Modelling of the fate of toxic substances will be improved taking into account their specific impact on the site.

Keywords: offshore exploration drilling, mud, hydrocarbons, treatments scenarios, life cycle impact assessment.

Résumé

L'objectif de ce mémoire est d'évaluer l'impact environnemental du système de boues de forage en Algérie dans la mer entre Skikda et Annaba. Les boues aqueuses (WBM) et les boues à base de pétrole (OBM) sont utilisées lors du forage de puits dans la mer projetée entre Skikda et Annaba et présentent un potentiel de pollution important. Une approche d'évaluation du cycle de vie (ACV) est utilisée pour évaluer les effets de nombreux systèmes de boues de forage à toutes les étapes de leur cycle de vie, comme leur utilisation, leur traitement et leur élimination. Les impacts environnementaux sont comparés à deux scénarios de traitement correspondant à la gestion des déchets de forage déjà appliqués à Hassi Messaoud : stabilisation / solidification et absorption. L'analyse d'impact à l'aide de la méthode CML et du modèle LCIA est effectuée dans SIMAPRO7. Cette évaluation identifie la toxicité humaine et marine comme la principale catégorie d'impact dans ce contexte marin particulier et identifie les contributions aux émissions.

L'impact sur l'environnement marin local est le plus important cycle de vie des boues de forage est principalement lié aux émissions provenant des stocks, des déblais traités et du forage de phase 16 pour les aquifères. Les hydrocarbures aromatiques et les minéraux, en particulier le baryum, le zinc, l'antimoine, l'arsenic et l'aluminium, en sont les principales substances. Pour la comparaison des scénarios de traitement, la stabilisation/solidification semble être la meilleure solution, car elle a l'effet le plus faible dans les deux catégories dominantes en raison de la réduction des déchets : stockage des boues évité dans la fosse de réserve. Le deuxième meilleur scénario est l'adsorption thermique, qui a l'effet cancérogène le plus faible en raison de la réduction des hydrocarbures moins de 1 % et des effets évités du pétrole récupéré. La modélisation du devenir des substances toxiques sera améliorée en tenant compte de leur impact spécifique sur le site.

Les mots clés : analyse d'impact, forage d'exploration offshore, boues, hydrocarbures, scénarios de traitement, cycle de vie.

ملخص

الغرض من هذا العمل هو تقييم الأثر البيئي لنظام الحفر البحري الجزائري بين سكيكدة وعنابة. تستخدم الحمايات المائية المعتمدة على النفط عند حفر الآبار في البحر بين سكيكدة وعنابة ولديها إمكانات تلوث عالية. يتم تطبيق طريقة تقييم دورة الحياة لتقييم ثوران العديد من أنظمة الحفر الطينية طوال دورة حياتها. على سبيل المثال، الاستخدام والمعالجة والتخلص. تقارن الآثار البيئية بسيناريوهات المعالجة المقابلة لإدارة نفايات الحفر المطبقة بالفعل على مستشعر تثبيت/تصلب والامتصاص الحراري. ويجري تحليل الأثر باستخدام هذا التقييم للسمية البشرية والسمية البحرية بوصفهما فئة التأثير الرئيسية في ويحدد المساهمات في الانبعاثات. ويعد التأثير على البيئة البحرية المحلية أهم دورة حياة لحمأة الحفر ويرتبط أساسا هذا السياق البحري في نموذج بالانبعاثات من المخزونات، وتخفيضات المعالجة والحفر في 16 مرحلة تحت الأرض. المساهمون الرئيسيون هم الهيدروكربونات والمعادن العطرية، وخاصة الباريوم والزنك والألينتيمون والزرنيخ والألومنيوم. لمقارنة سيناريوهات المعالجة، يبدو أن التركيب/التصلب هو الحل الأفضل، حيث أن له أدنى تأثير في الفئتين المهيمنتين بسبب تقليل النفايات: تجنب تخزين الطين في الفتحة الاحتياطية. ثاني أفضل سيناريو هو الامتزاز الحراري، الذي ينتج أقل تأثير ويتجنب آثار الزيت المسترد. سيتم تحسين نمذجة مصير المواد السامة مع مراعاة تأثيرها المحدد أقل 1% مسرطن بسبب انخفاض الهيدروكربونات)

الكلمات الرئيسية: تحليل الأثر، والحفر البحري، والحمأة، والاحتمال، والقشور