Environmental and economic assessment of the potential of upstream activities in Portugal

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Thesis to obtain the Master of Science Degree in

Energy Engineering and Management

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June 2018

Acknowledgements

It is hard to thank everyone who helped me in this achievement, and who motivated me to push myself to the limits and to reach this result.

Firstly, I would like to thank my parents, who have always been an example to me in everyday life, and most importantly in my academic life. They have been my motivation to join the SELECT programme and follow my dreams. My Brother, who convinced me to go and study abroad, it was a wise advice, which resulted in most productive and most valuable time in my life.

I would like to express any gratitude to my supervisor, Patrícia de Carvalho Baptista, who guided me in this work through any hurdles and inconvenience, who committed a lot of time and always patiently gave me useful suggestions throughout many months of writing.

I would like to thank Innoenergy, for the wonderful organization of the last two years of my professional and academic career, and for all the given opportunities to grow both as a student and as a person. I find the whole experience extremely positive for my development and for the future opportunities of my career.

Huge thanks to the SELECT coordinator, Duarte de Mesquita e Sousa, who always helped us in times of need, and who not only coordinated us through the programme, but also though the customs of Portuguese tradition, culture and cuisine.

Special thanks go to my friends, the old and the new ones, who I got to know during the past years traveling around Europe: Joana, Antonio, Shereen, Omar, Tarsila, Fernando, Frederic, and many others, who made my stay abroad feel like home.

Last but not least, I would like to thank Galp Energia, for the extremely enriching experience I had in their company, having a chance to gain a better understanding of several topics, which I did not have an opportunity to explore during my studies.

Abstract

There is reportedly a large potential in exploration of off-shore oil resources, that would not only help Portuguese economy to grow, but could also lead to a global emissions drop. This work aims to analyze the environmental impact of scenarios, in which crude imports are replaced by domestic oil production. A life cycle impact assessment (LCIA) on the import activities related to a production of crude oil in Brazil has been performed, and compared to the scenarios of a successful introduction of a domestic fuel production in Portugal.

With well productivity at levels equal to 25kboe/d and sea freight transportation of resources, as assumed in the reference case study of oil imports from Brazil, the average environmental impact between all impact categories for Portugal is equal to 107,5%. In other analyzed cases, with larger input differences, the results scale down to 50,4% of the reference value for impacts related to ionizing radiation, and up to 847,8% for impacts on human toxicity. Those deviations are closely related to case study assumptions, such as well productivity, number of exploration wells needed to establish production or oil transportation method to the refinery in Sines, Portugal.

A relevant part of this work has been dedicated to the analysis of the economic benefits of potential upstream activities in Portugal. The analysis is investigating different state revenue streams, leading to a specific income estimation for the different scenarios varying between $20.6 billion, up to $94.2 billion assuming a fiscal regime transition.

Key words: LCIA, SimaPro, crude oil, environmental impact

Resumo

Este trabalho tem como objetivo analisar o impacto ambiental de cenários, em que as importações de petróleo bruto são substituídas pela produção nacional de petróleo. Uma avaliação de impacto do ciclo de vida (LCIA) sobre as atividades de importação relacionadas à produção de petróleo bruto no Brasil foi realizada e comparada com os cenários de uma introdução bem-sucedida de uma produção doméstica de combustível em Portugal.

Com produtividade do poço em níveis iguais a 25kboe/dia e transporte de carga marítima de recursos, como assumido no estudo de caso de referência das importações de petróleo do Brasil, o impacto ambiental médio entre todas as categorias de impacto para Portugal é igual a 107,5%. Em outros casos analisados, com maiores diferenças de insumo, os resultados diminuem para 50,4% do valor de referência para impactos relacionados à radiação ionizante, e até 847,8% para impactos na toxicidade humana. Estes desvios estão intimamente relacionados com os pressupostos do estudo de caso, como produtividade do poço, número de poços de exploração necessários para estabelecer a produção ou o método de transporte de óleo para a refinaria em Sines, Portugal.

Uma parte relevante deste trabalho foi dedicada à análise dos benefícios económicos de potenciais atividades de upstream em Portugal. A análise está investigando diferentes fluxos de receita do Estado, levando a uma estimativa de renda específica para os diferentes cenários, variando entre US$ 20,6 bilhões, até US$ 94,2 bilhões, assumindo uma transição de regime fiscal.

Palavras chave: LCIA, SimaPro, petróleo bruto, impacte ambiental

Contents

List of Figures

List of Tables

List of Graphs

Nomenclature

GHG – Green House Gasses
LCIA – Life Cycle Impact Assessment
kboe/d – thousand barrels of oil equivalent per day
CO_2 – Carbon Dioxide
toe -tonne oil equivalent
GDP – Gross Domestic Product
R/P – reserves-to-production
m - meter
kg – kilogram
FID – Final Investment Decision
ppmU – parts per million uranium
MTU – megaton uranium
TW – terawatt
TWh- terawatt hour
API – American Petroleum Institute
wt% - weight percentage
E&P – Exploration and Production
IEA – International Energy Agency
USD – United States Dollar
km – kilometer
2D – two-dimensional
3D – three-dimensional
FPSO - Floating Production, Storage and Offloading unit
ROV – remote operated vehicle
LCA – Life Cycle Assessment
ISO – International Organization for Standardization
LCI – Life Cycle Inventory
O_3 – Ozone
kg CFC-11 – kilogram of Trichlorofluoromethane
CTUh – Comparative Toxic Unit for humans
NOx -nitrogen oxides
SO_2 – Sulphur dioxide
kg PM2.5 eq – kilogram of particulate matter 2.5 equivalent
kg NMVOC eq – kilogram of Non-Methane Volatile Organic Compounds
mol H+ – Hydrogen equivalent
mol N eq – Nitrogen equivalent
kg P eq – kilogram of phosphorus equivalent
kg Neq – kilogram of nitrogen equivalent
CTUe – comparative toxic unit for ecosystems
kg C deficit – kilograms of carbon deficit
kg Sb eq – kilograms of Antimony
ANP - Agência Nacional do Petróleo
Mb – million barrels
nm – nautical miles
PSA – production sharing agreement
NOK – Norway Krone
DGEG – Direcao-General de Energia e Geologia
TPES – total primary energy supply
FPC -Portuguese Carbon Fund
EV – electric vehicle
EU ETS – European Emissions Trading System

1 Introduction

The global energy market is constantly evolving. To make proper policy changes in the present one has to look into the future to analyze different scenarios and their possible outcomes. World's energy production and consumption are increasing each year, and so are the related carbon dioxide (CO_2) emissions reaching a historic high of 32,5 gigatons of CO_2 emissions in 2017, what is a 1.4% rise from a previous year (IEA, 2018). Despite the fact that more countries are committed to their climate pledges and renewable technologies are advancing, oil is still the largest primary energy source constituting to 38,1% of total energy demand in 2017 (IEA, 2018).

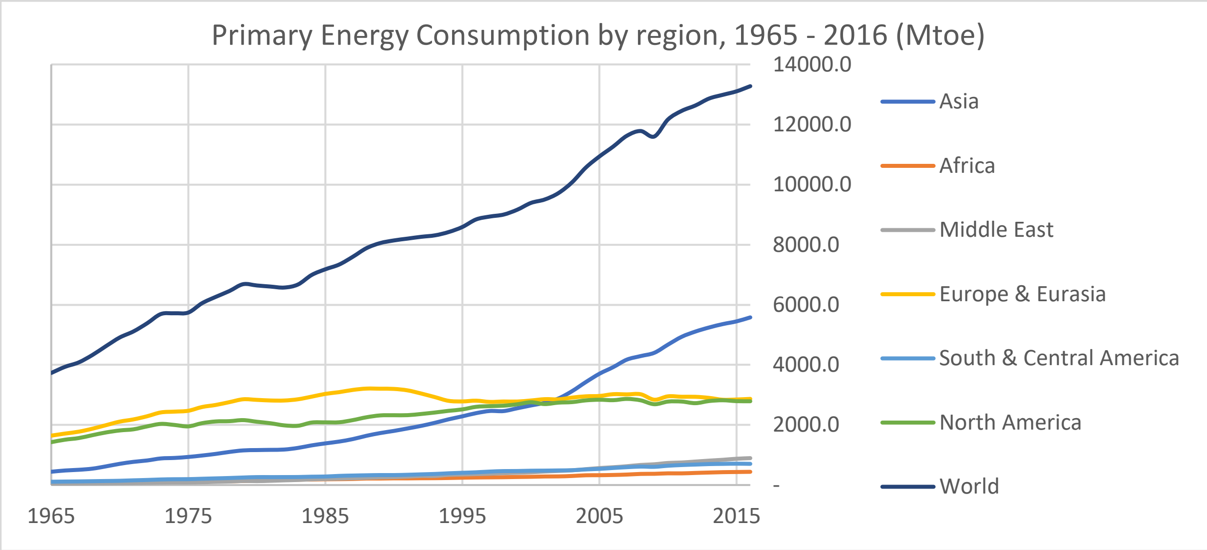
Portugal is one of the European countries in the process of rebuilding its economy since the great recession in recent years. Steady yearly growth can be seen both in the GDP and in the international trade with considerable yearly exports increase of 1% within last five years (mostly to the European Union stating 78,0% of total exports) (Simoes, 2011). However, with slowly decreasing, but still significant volume of imports, Portugal is recording a negative trade balance for many consecutive years. Taking into account that refined petroleum is the main exported commodity and the imports are led by crude oil, a looming discovery of domestic crude oil could be a pathway to strengthen Portuguese economy.

In this chapter a present world energy outlook has been provided with significant focus on oil, since it continues to be a dominant resource and a main subject of the undertaken analysis. Portugal will be taken up as a case study, while its economic situation and energy resources will be described. Furthermore, with the potential discovery of crude resources in Portugal, off-shore oil exploration will be taken under investigation.

1.1 Primary Energy Consumption Overview

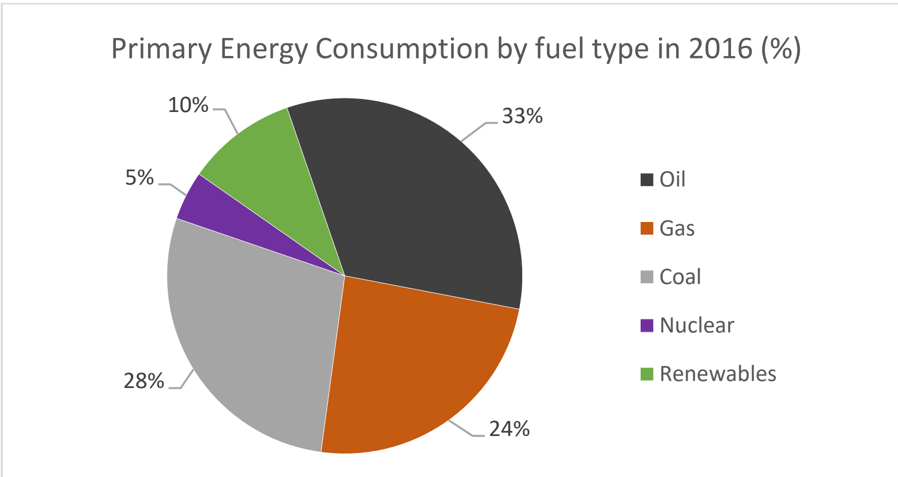
Throughout the history the civilization's achievements were closely related to harnessing of various forms of energy. World's development is based on increasingly efficient and continuous process of energy conversion and transformation. Energy can be found in nature in a form of primary energy, which is the energy contained in natural environment and raw materials (e.g. chemical energy contained in fossil fuels), and has not yet been subjected to processes of conversion. Secondary energy sources (or energy carriers), e.g. electricity or petrol, derive from transformation of primary energy sources to later provide final energy in a form of e.g. light or heat.

On Graph 1 the world's primary energy consumption by region between years 1965 and 2016 has been presented.



Graph 1 Primary energy consumption by region, 1965-2016 (Mtoe) (BP, 2017)

The total consumption has been steadily growing in this period without major deviations. In 2009 a slight decrease of 1.1% has been recorded, following the 2008 global banking crisis. Significant global energy consumption growth has been recorded between 1990 and 2008, equal to 44.7%. The highest increase between these years has been recorded in the Middle East (152%) and China (138%). In 2016 those two regions still remain the fastest growing consumers of primary energy with growth of 2.34% and 2.42% respectively (BP, 2017). In Graph 2 presented below ,a breakdown of primary energy consumption by sector in 2016 has been visualized.



Graph 2 Primary energy consumption by fuel in 2016 (%) (BP, 2017)

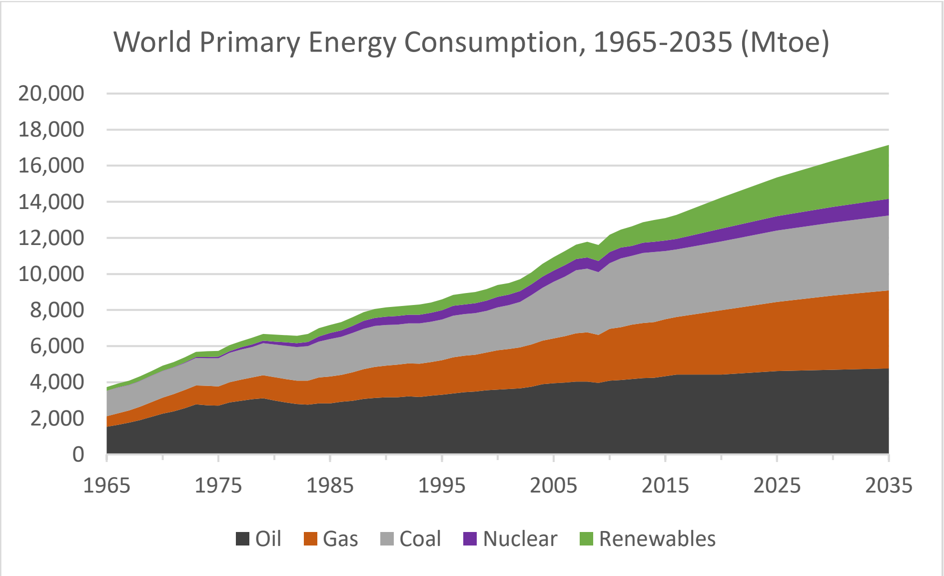
Fossil fuels are still a major part of global energy mix, where oil remains a main constituent with 33%. Coal and natural gas annual consumption are equal to 28% and 24% of total volume respectively. In 2016 a slight decrease in fossil fuels shares has been noted (0,49%), mostly caused by a significant consumption increase in renewables of 12.9% from numbers for year 2015. Renewables have increased their share in total primary energy consumption till 3.1%, while nuclear energy consumption has been stable between 2015 and 2016, amounting to 4.4% (BP, 2017).

1.2 Energy Demand Overview

Future energy demand is closely related to governmental policies, international climate policies, energy efficiency measures, and technological and social development. Taking into account estimations of International Energy Agency and BP annual statistical reports, a short energy demand forecast, and its main influential factors, can be described.

World's gross domestic product (GDP) is projected to almost double within the next 20 years (OECD, 2014), mostly driven by emerging economies. World's population growth, with estimated 8.8 billion people by 2035 (BP, Jan 2017), and increase in productivity, will be crucial in shaping of energy markets in the future. This rapid growth in economy and population is mostly propelled by countries like China or India. However, with energy efficiency increase, and therefore energy intensity decrease, the overall global energy demand in 2035 is projected to increase by 30.5% (BP, Jan 2017).

When comparing emerging economies, such as China or India, with well-developed European Union, a significant difference is visible in the forecasted demand changes. Between years 2015-2035, China and India are projected to grow their energy demand by 47% and 129%, while in the same period of time European Union is expected to decrease primary energy consumption by 8% (BP, Jan 2017). To understand world's primary energy consumption trends, a more detailed split by sector is shown in Graph 3.



Graph 3 Primary energy consumption by fuel, 1965-2035 (Mtoe) (BP, Jan 2017)

Renewables (including biofuels, wind power, solar electricity, hydroelectricity and geothermal energy) are prognosed to reach 17% of total consumption by 2035 with almost 3 billion toe. Consumption of renewables between 2015 and 2035 is estimated to be the fastest growing from all sources of energy, with 7.1% of annual growth, reaching globally over 291% in reference to 2015 (BP, Jan 2017).

Oil should still remain the most demanded commodity by 2035, with average annual growth of 0.7%. Total share of oil is prognosed to drop from 33% in 2016 to 29% in 2035, mostly because of advancement and decreasing costs in renewable technologies. However, combined share of all fossil fuels is estimated to be equal to 78%, in comparison to 85% in 2016. Out of these, natural gas will be increasing annually by 1.6% reaching up to 25% of total energy mix and overtaking coal (24%) for the second most consumed fuel in 2035.

The goal of this subchapter was to highlight the fact, that even though renewable energy technology is advancing and becoming more affordable, fossil fuels will still remain the main source of globally consumed energy, with oil as the most dominant commodity for the near to medium long term.

1.3 Available Resources

Fossil fuels were, are, and will be dominant source of primary energy in the near future, based on most of available forecasts. Therefore, it is crucial, knowing present consumption of fuels and the forecasted future demand, to have an understanding of current availability and proved reserves of those fuels. Fossil reserves can be defined in terms of proved and probable reserves. Proven reserves have been estimated with a higher degree of confidence than probable reserves.

1.3.1 Coal

In such case, the amount of e.g. coal, that is estimated to be present in the deposit of coalfield, is assessed. It has to be noted, that it takes into an account the economic feasibility of extraction of the resource, as not all fuels can be recovered with the use of current technology and without generating loses. Therefore, proved reserves will vary in time with direct relation to the price of fuel.

All the data presented below has been estimated based on geological and engineering information indicating possibility of recovery from existing or newly discovered reservoirs under current economic and technological conditions.

Table 1 presents the coal reserves by region. In case of coal, there are estimated over 1.1 trillion tones of proved coal reserves worldwide (BP, 2017). With current rates of production equal to 7.4 billion tonnes per year (BP, 2017), there is enough coal for almost 150 years of production, given by an R/P ratio (total reserves over annual production).

Table 1 Coal reserves by region, 2016 (BP, 2017)

Region	Coal reserves (million tonnes)	Share of total	R/P ratio
North America	259,375	22,8%	355.8
where US	*251,582*	*22.1%*	*380.8*
South and Central America	14,016	1.2%	137.9
Europe & Eurasia	322,124	28.3%	283.9
where Russia	*160,364*	14.1%	*41.2*
Middle East & Africa	14,420	1.3%	54.3
Asia	529,396	46.5%	101.8
where China	*244,010*	*21.4%*	*71.5*
World	1,139,331	100%	153.0

Most of the world's coal is deposited in Asia (46.5%), which is also the main producer of coal with total production in 2016 equal to 5,202.1 million tonnes of coal. The second largest producer in the same year was Europe and Eurasia recording 1,162 million tonnes, which was only 22.3% of Asia's output. Asia recorded also the reserves-to-production ratio (R/P) equal to 102. This ratio is a relation between the reserves remaining at the end of a year, divided by production in that year, giving the result in amount of years that those reserves would sustain on production rate from that year. For reference, North American region has 22.8% of total global proven reserves, but its R/P ratio is equal to almost 356 years.

The decrease in R/P ratios for coal in recent years has triggered discussion whether the "peak coal" level has been reached. Peak fuel level, as in case of petroleum based on M. King Hubbert's theory, is a point at which the maximum rate of extraction has been reached, and after which the production rate starts to irreversibly decline (Hirsch, 2005). The highest production levels for coal were recorded in 2013, when total world production reached 8,274.6 million tonnes in comparison with 7,460.4 million tonnes in 2016 (BP, 2017). This may be interpreted, as a positive signal for all the policymakers showing that the low-carbon energy transition is successfully progressing.

1.3.2 Natural Gas

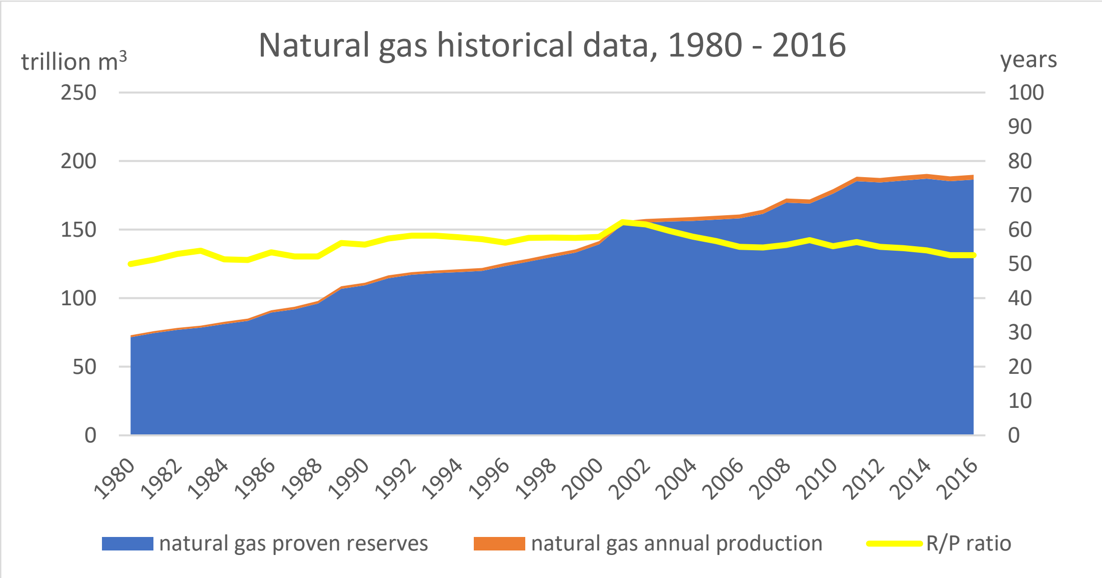
The world's natural gas proved reserves in 2016 were equal to 186.6 trillion m^3, as presented in Table 2, and they recorded a slight growth of 1.2 trillion m^3 from 2015 levels, due to increases in Myanamar (125%) and China (11.9%). Almost half of all global gas reserves belongs to three countries – Iran (18%), Russia (17.3%) and Quatar (13%). The total world R/P ratio is indicating that with production levels from 2016 there are estimated 52.5 years of natural gas extraction remaining. However, this general ratio is an average for all countries and should not be interpreted as a global gas production deadline.

Table 2 Natural gas reserves, 2016 (BP, 2017)

Region	Natural gas reserves (billion m^3)	Share of total	R/P ratio
North America	11,129.0	6.0%	11.7
South and Central America	7,589.4	4.1%	42.9
Europe & Eurasia	56,691.5	30.4%	56.7
^ where Russia	*32,271.0*	*17.3%*	*55.7*
Middle East	79,376.6	42.5%	124.5
^where Iran	*33,500.0*	*18.0%*	*165.4*
^ where Qatar	*24,299.1*	*13.0%*	*134.1*
Africa	14,251.5	7.6%	68.4
Asia	17,535.9	9.4%	30.2
World	186,573.9	100%	52.5

According to R/P ratios for the three main gas producers, at current production quantities Iran has estimated 165.5 years of production left and Qatar 134, while Russian Federation only 55.7 years. Russia is currently producing almost the same quantities of gas as whole Asia, amounting to 579 billion m^3. Nevertheless, the top producer of natural gas is United States, which with a lot smaller reserves of gas (4.7% share of total natural gas proven reserves for 2016), has produced almost 750 billion m^3 of gas in 2016, stating 22.1% of total world production.

Graph 4 shows, that even though the production of natural gas increased since 1980 by 148%, the proved reserves are also constantly growing (over 140% in comparison to 1980 levels), what can be identified as an indicator of stable gas supply with stable forecasted demand increase presented in previous section.



Graph 4 Natural gas historical production, proven reserves and R/P ratios, 1980 – 2016 (BP, 2017)

1.3.3 Oil

Oil resources are those hydrocarbons, which both may or may not be explored in the near future. Those assumed resources have to go through the appraisal process by drilling delineation wells or acquiring seismic data to confirm the size of the field what will later lead to a project sanction. This moment in a project is often called Final Investment Decision (FID), which is a date when the operator on behalf of him and his partners authorize the project to proceed into the project execution phase. Depending on local legislation it is at this stage that a specific governmental body gives the oil company a production license, which enables the field to be developed for the agreed production period. FID is also the point at which oil reserves and gas reserves can be formally booked in company's financial statements.

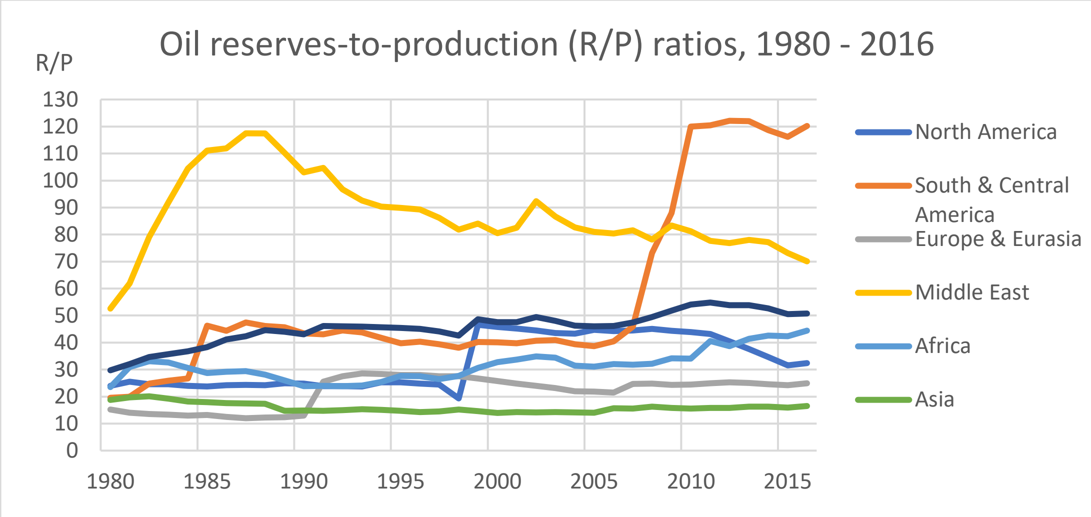
Oil reserves can be described as proved, probable or possible. Proved, same as in case of coal or gas, are the highest valued category with high certainty of being recoverable at present economic and technological conditions. Proved reserves are often denoted as 1P, or as P90 having 90 percent of being produced or more. Probable reserves are those less likely to be recovered than proved, but more certain to be recovered than possible reserves. Probable reserves can be found in the literature as P50, having 50% certainty of being produced. There the last category of reserves is called "possible", which resources are least likely to be recoverable, sometimes denoted as P10 with only 10% certainty of production. Proved and probable reserves are sometimes abbreviated in the literature as 2P, while proved, probable and possible together are constituting to a 3P term. In this paper only proved reserves have been investigated.

Table 3 Oil proved reserves by region, 2016 (BP, 2017)

Region	Oil proved reserves (Mtoe)	Share of total	R/P ratio
North America	34,527	14.3%	11.7
^where Canada	*27,630*	*11.5%*	*105.1*
South and Central America	50,846	21.1%	42,9
^where Venezuela	*46,971*	*19.5%*	*341.1*
Europe & Eurasia	21,839	9.1%	56,7
Middle East	110,099	45.7%	124,5
^where Saudi Arabia	*36,601*	*15.2%*	*59.0*
Africa	16,950	7.0%	68.4
Asia	6,449	2.7%	30.2
World	240,710	100.0%	52.5

As it was presented in previous subchapter, crude oil was the most widely consumed energy commodity in 2016, with 4,418.2 million tonnes of total world oil consumption. The estimated proven global reserves are reported to be equal to 240,709 million tonnes, what indicates a global R/P ratio of 50.6 years. Venezuela is the country with largest reported proven reserves, equal to 46,971 million tonnes and has a 19.5% share in global proven reserves. However, throughout the last decade Venezuela is recording production decline (-9.0% from 2015), and within last year has only produced 124.1 million tonnes of oil, what was below 3% of global production, and therefore its R/P ratio is largest from all oil producing countries and states that at current production rate

Venezuela could extract oil for 341.1 years. Other countries with significant share of total crude oil reserves are Saudi Arabia (15.6%), Canada (10%), Iraq (9.3%) and Iran (9%). The region of Middle East account for 47.7% of global oil reserves.

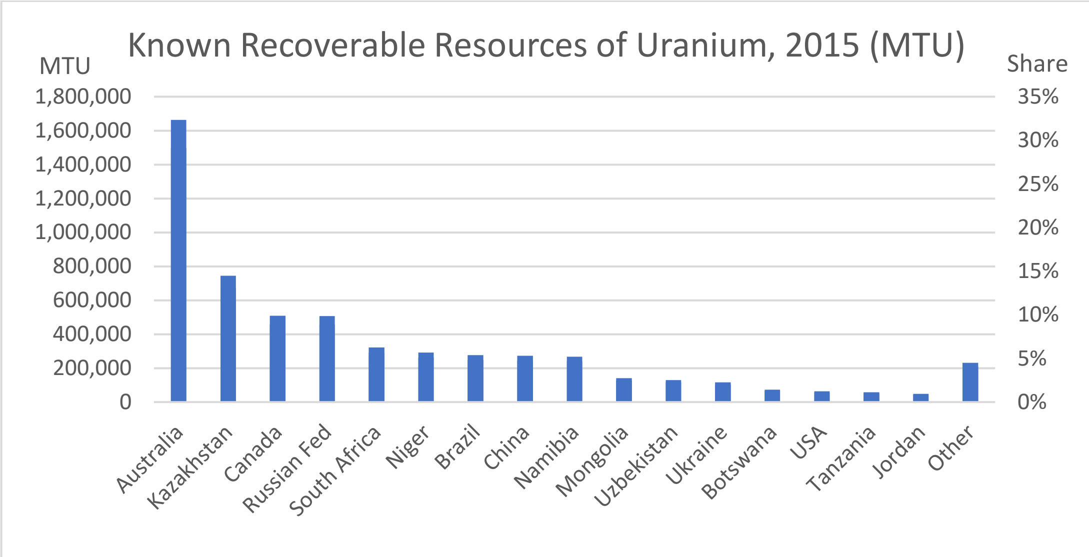


Graph 5 Oil reserves-to-production (R/P) ratios by region, 1980-2016 (BP, 2017)

The historical data on oil reserves shows substantial oil reserves growth. Throughout the last decade there has been a 23% increase in global proven crude oil reserves. The largest growth has been recorded in case of Venezuela, which increased its reserves from 87.3 million barrels in 2006 to 300.9 million barrels in 2016 (244.5% increase). Therefore, even with oil being currently the main primary energy source and its annually increasing demand (1.2% per year within 2005-2015), there is still maintained a balance with global proven reserves growth (2.1% per year within 2005-2015). Technological advancement is enabling producers to extract more crude oil from the reservoirs, but lowest prices per barrel since 2003 are hindering the possibility to use full potential of crude deposited underground.

1.3.4 Uranium

Enriched uranium is the most commonly used fuel in the conventional nuclear reactors. Therefore, global available uranium reserves will be shortly investigated, as the estimated potential of nuclear power as a primary energy resource. Uranium is a relatively common element. It is a metal found in almost all types of rocks, soil and even sea water. However, its concentration is the key to harnessing the contained within energy. In nature uranium can be found between 0,003 ppmU in sea water, up to 200 000 ppmU in high-grade ores excavated e.g. in Canada. Based on the data provided by the International Atomic Energy Agency, available resources per country can be presented as in Graph 6 below.



Graph 6 Known Recoverable Resources of Uranium, 2015 (NEA, 2016)

The graph above is presenting world total estimated recoverable reserves of uranium in 2015, which were equal to 5,7 million tonnes of U (NEA, 2016). With estimated global extraction in 2015 of around 63,000 tonnes of U per year (NEA, 2016), those reserves would last for over 90 years. However, as in case of fossil fuels, those numbers are valid only for current technological solutions for uranium utilization and excavation, and it's economic feasibility. From another perspective, uranium resources in nature are immense, and with time new methods of uranium harvesting will be developed, and so new reserves will be found. Therefore, nuclear energy supply can be assumed to be abundant.

1.3.5 Renewable Energy

When it comes to renewable energy sources, the key aspect is that they are in theory unlimited. However, based on natural phenomena and environmental constraints, rough estimation of renewables potential can be calculated. Solar Heating and Cooling Programme by the International Energy Agency, in their report from 2015 provided an estimation of the potential of all renewable resources available on the planet. Their findings have been presented in the Table 4 below:

Table 4 Yearly potential of renewables in 2015 (TW), (Perez, Apr 2009)

Source:	TW annually:
Solar	23,000
Wind	75 - 130
Hydro	3 - 4
Biomass	2 - 6
Geothermal	0,3 - 3
Waves	0,2 - 2
Tidal	0,3

In 2016 the global energy consumption was equal to 154 403 TWh (BP, 2017). In such case, only solar energy potential, if harvested with 10% efficiency, could cover the present world energy demand by factor of 130. However, real solar potential cannot be presented in such direct form, as it is not uniformly distributed around the planet and both natural and technological constraints are influencing the final output of a solar plant. Nonetheless, it gives a basic understanding of the extensive potential of renewable resources as a primary energy source.

1.4 Oil overview

Crude oil is a complex mixture of molecules consisting of organic compounds, mostly formed from hydrogen and carbon atoms (hydrocarbons). Depending on the mixture of hydrocarbons, crude oils can be divided into "light" and "heavy" crudes, what refers to the oil's relative density expressed in American Petroleum Institute (API) gravity. It is an inverse measure of oil's density relative to that of water. The higher the API gravity, the lighter the compound. Crudes with API gravity higher than 10, are lighter and will float on water, while oil with API gravity lower than 10, is relatively heavier and will sink. As an example, the API gravity of naphtha is around 50, while the API gravity of asphalt can be as low as 8 degrees in the API gravity scale (Michael, 1989).

Another important variable in determining the quality of crude is the sulfur content. The content of sulfur is usually measured in weight percentage, with 0.5 wt % as a reference value. Crude oil with less than 0.5 wt% is considered "sweet", as in such case it reportedly tastes sweet.

Such oil is easier to extract, transport and refine due to the damaging and corrosive nature of sulfur. Sour crudes, with sulfur content above 0.5 wt%, have to be cleared of the impurities before refining into, e.g. petrol, what increases the retail price of the final products. Sour crude oil also contains more carbon dioxide and small amounts of hydrogen sulfide, which is a toxic gas.

It has to be noted that the economic value of crude oil rises, as the API gravity increases and its sulfur content decreases. It is due to the fact that light crudes contain more valuable components, such as e.g. gasoline, than the heavy oils, and it is very costly to remove the high content of sulfur from the sour crude.

A typical composition of oil can be expressed as a following mixture of elements: carbon 82%, hydrogen 12%, nitrogen 4%, oxygen 1%, salts 0.5%, and 0.5% of metals, such as iron or copper, considered as waste (ANP, 2017).

Oil industry is a complex sector incorporating various natural resources, different technologies and many actors from important politicians of major countries to simple automobile users. However, all activities related to its supply chain are usually grouped into three main categories:

- The **upstream** sector, also called the exploration and production (E&P) sector, consists of processes related to searching and extraction of oil, from first theoretical assumptions to the established plateau production. Exploration is a long and crucial part of the whole system, as it's creating fundaments for further supply chain steps. Areas with theoretical potential to contain hydrocarbons are subjected to geological and geophysical surveys, to detect relevant subsurface geological structures. Those with higher potential, often called leads, are investigated further to create the profile of the substructure, and if that later fits the criteria set by the oil company, the first exploration well is drilled to determine the presence of hydrocarbons at the prospect area. If the discovery has been confirmed the next step is the production, where the productivity of the well is slowly increasing up to a plateau level, which is its peak operating rate. Production can be limited by the market conditions or governmental regulation. Present market imbalance driven by the supply side of the industry and low oil prices can be an example of such situation, in which countries were forced to reduce the production in order to try to restore the global demand and supply balance. Therefore, upstream can be described as a well oriented sector investigating where to locate them, how deep and how far underground to dig them, and how to later construct and operate them, to ensure the highest return-on-investment (ROI) with the lightest, safest and smallest operational footprint. Oil exploration and production is a high-risk and expensive process which is usually undertaken only by large companies, consortiums and governments;

- **Midstream** is a part of the supply-chain providing the vital link between producing areas and industrial refining centers. Crucial element of midstream sector is the transportation, which includes assets such as marine vessels, pipelines, railroad machinery and road vehicle fleets. Throughout the transportation chain also storage units are used to temporarily store the unprocessed crude oil before it is ready to be moved to refineries or downstream distributors. Midstream operations often mix with some upstream or downstream elements, e.g. incorporating small purification plants to desulfurize the crude for transportation. Midstream, in contrast to upstream, is a low-risk part of the business. It is however very much dependent on the upstream part of the business, which is providing the commodity to be processed, transported or stored. It is also dependent on downstream, which is ensuring the demand for oil, and so it relates also to oil prices directly; and

- **Downstream** sector is focusing on crude oil processing, transporting and selling of the refined products to the final customers. Main downstream business activities are related to oil refining, product distribution and marketing, and retail sales. Refineries create variety of products by converting the crude oil using heat and pressure to separate the components obtaining e.g. gasoline, diesel oil, jet fuel, heating oil, asphalt, lubricants, and others. Some of the main consumers of downstream products are petrochemical industry, utilities, airlines or independent distributors. Downstream is related to both crude prices and retail products market prices. It is therefore a margin-oriented business, defined by the difference of latter. Therefore, current low prices of oil, that are negatively influencing the upstream part of the oil industry, are on the other hand beneficial for the downstream activities.

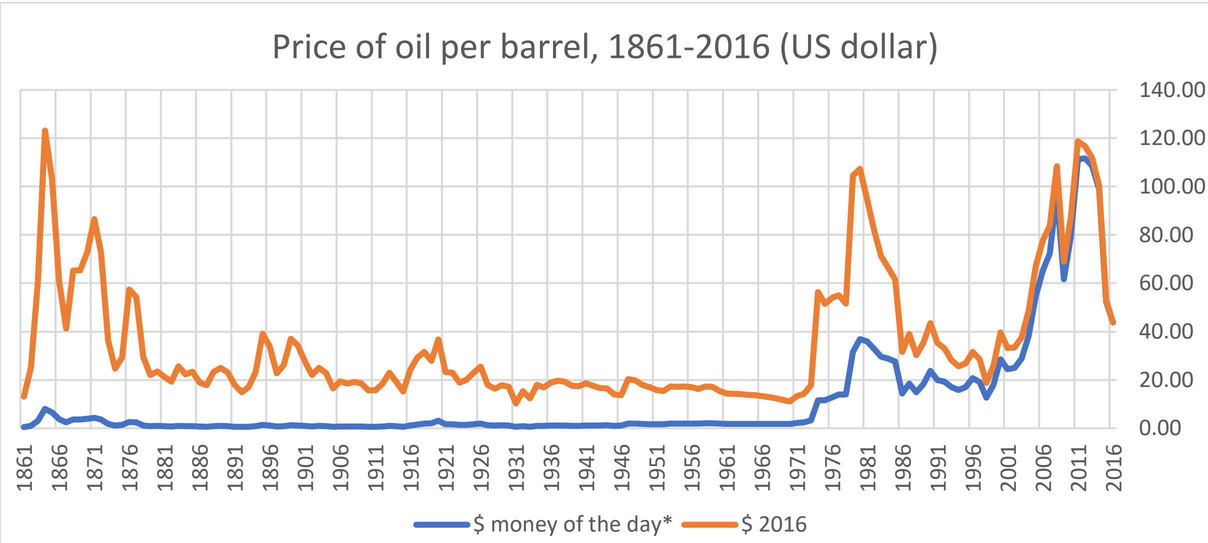
Not only the supply chain is divided, but also the petroleum production itself is also often split into three main methods of oil recovery based on the reservoir exhaustion – primary, secondary and tertiary.

Primary recovery methods are related to the use of the natural pressure of the oil reservoir. It may be amplified by a pump or a gas lift to increase the oil recovery. A gas or water injection is common to maintain the pressure of the reservoir. It is a typical practice to use the same as the one produced alongside crude oil.

Secondary recovery methods are focusing on gathering of the trapped hydrocarbons around the collector wells by pumping significant amounts of water into the reservoir. It is usually a follow-up stage after the production from primary methods starts to decline. However, nowadays those methods are often commercially used as a first production approach allowing easier reservoir management and higher well productivity.

Tertiary recovery is connected to CO_2 or steam utilization for oil viscosity reduction to achieve higher oil outputs. It is a most expensive method of oil production, therefore it is only practiced when other methods are not feasible anymore. It is however a typical method for ultra-heavy crudes extraction, when steam injection is used from the beginning of the project production phase.

The selection of one of the above methods is connected to various factors, such as reservoir geological, environmental and financial feasibility studies. For companies, the most important factor is the economic viability of the project, therefore the oil price is crucial and often decisive factor.



Graph 7 Price of oil per barrel, 1861-2016 (US dollar)

As previously mentioned the crude oil price is directly affecting both upstream and downstream part of the industry. Investment decisions are made based on estimated price margin per barrel of oil. Because of high investments stable oil prices are most desirable by the companies, however as presented in Graph 7 the price volatility is quite high throughout the years. Primarily oil prices have not very stable, but at that time the market was not yet well established and with each discovery or increase in one country's exports the price was dynamically changing. More recent deviations are rather related to significant historical events, first of which is the Yom Kippur War in year 1973, which resulted with proclamation of oil embargo by countries of the Middle East on nations such as United States, Canada, United Kingdom, Netherlands, South Africa and Portugal.

At that moment in history Middle East was producing over 36% of total world oil production (BP, 2017). Those events are commonly called as the “first oil shock”. Shortly after that the “second oil shock” followed, as in year 1979 in the wake of Iranian Revolution the world oil output decreased by around 4% (BP, 2017). After the first oil crisis only few years before, the widespread panic resulted in increase of prices even higher than during the first crisis. In the money of that day, within only 12 months the price doubled, and was at that point ten times higher in comparison to levels from before the first oil crisis. From that point, the history noted a 20 year long price decline except of short increase caused by the First Gulf War in the beginning of 1990’s. In most recent history the Second Gulf War, known as Iraq War (2003-2011), resulted with one of the highest oil prices in history reaching over $111 for barrel of crude oil, what was a 445% increase in comparison to levels from before the war.

In last years the oil price was significantly dropping to levels as low as $43 in 2016. This short analysis intended to show how crude oil price is dependent on geopolitical situation within the borders of major oil producing countries and how fragile the oil price is. Taking into account the fact that some investments are made in billions of dollars and that the exploration and production phase lasts for decades, extreme oil price changes are directly affecting the whole oil industry.

From technological perspective, oil can be produced on-shore and off-shore. Those two types of drilling have certain advantages over the other, but both are actively used by companies around the globe to satisfy the growing energy needs of the world. The most significant differences are related to location, costs, profits, drilling timelines and related technological solutions.

On-shore drilling is a more mature and therefore well-developed process from the technological standpoint. The rig is built on a stable ground at the prospect site, taking into account the topography of the area and all the geological information gathered earlier through various surveys. Usually, it is located vertically above the point of maximum thickness of the geological layer where hydrocarbons are expected to be trapped. The drilling rig is a structure containing all necessary equipment to introduce the drill strings under the ground, which are transmitting the torque into the drill bit and pumping down the drilling fluid to cool down the drill bit, consolidate the sides of the borehole and to remove the rock cuttings to the surface. After few hundred meters the measurements are taken to measure the parameters of the rock being drilled, what allows the on-site personnel to validate the hypotheses about the geological formations and fluids that they contain. The well walls are reinforced during the drilling process by special casings cemented to the outer soil. When hydrocarbons are successfully found and their pressure is sufficient to reach the surface, the probable productivity of the field is measured. If the results are promising, several other wells are drilled in the area to refine the knowledge about the reservoir. At this point the operator has to make a decision to proceed to the production stage, or to give up exploration in that area. Drilling rig is not only responsible for well drilling, but it is also providing auxiliary services to the drilling processes and generating on-site power for all rig’s operations. On-shore drilling offers a variety of options for storage and transportation of oil after its extraction from the well.

Based on the information of IEA the off-shore production was equal to nearly 30% of global crude oil output in 2015 (Manning, 2016). Most of the off-shore production is located on shallow waters, which are cheaper and less technically demanding, but more recently there has been a movement towards the deep-water projects. In general case of off-shore the basic equipment is similar to the on-shore drilling, however the environment is a lot more challenging than for the land-based installations.

Most of the development in recent years around the oil drilling is related to overcoming these challenges, where platform stability and deep-water drilling seem to be the key to the new large quantities of available oil resources. One of the differences from on-land production, is that the crew members have to live on the platform for a certain period of time. A platform has to provide all necessary services to the personnel such as sleeping quarters or cafeteria. However, recently with technological advancement more functions are being automated or supervised from the shore through the advanced control systems. Another major difference is the time needed for well completion. For off-shore wells it usually takes up to few months to drill down to the reservoir depending on the water and ground depth, and on geological characteristics, while for on-shore a well can be complete within days. In case of installations operating close to the shore the oil transportation can be conducted by set of pipelines, but for deep-water production special equipment for oil exploration, processing, storage and transportation is needed. Sample of available technologies for off-shore exploration have been presented in the Figure 1 and described below.

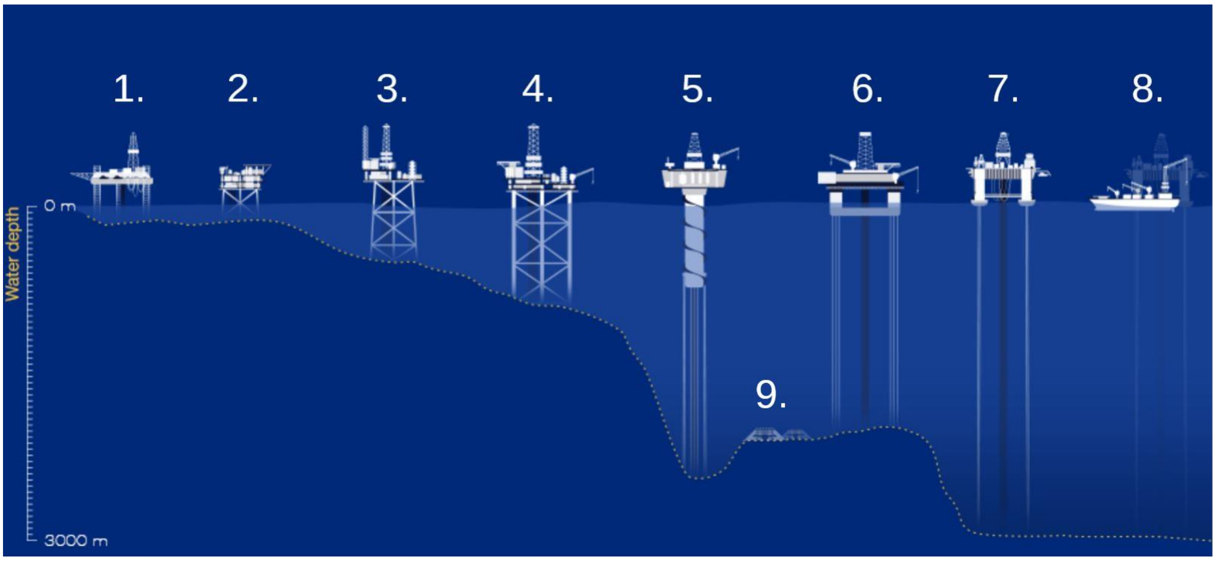


Figure 1 Off-shore production technologies (wintershall, 2018)

1. Jackup rig –bottom founded mobile platform with movable legs, which can be lowered and raised depending on the water depth, mainly used for short-term exploratory and drilling operations. Water depth: 100-170m.
2. Satellite platform – small and usually unmanned auxiliary production platform, which can be remotely controlled and is always connected to a nearby central processing unit by oil and gas flowlines. Water depth: 100-3000m.

3. Fixed platform – long-term immovable oil and gas production platform with legs anchored directly onto the seabed supporting the deck with drilling equipment, production facilities, and sleeping quarters for the crew. Water depth: 100-520m.
4. Compliant tower rig – fixed rig structure, with narrow compliant tower and pilled foundation, built to withstand lateral deflections and forces such as strong currents. Water depth: 400-900m.
5. SPAR platform – floating oil platform chained to the seabed and consisting of large diameter vertical cylinder, which is constructed to lower the center of gravity of the platform and therefore provide more stability. The cylinder is also shaped in a helical way to mitigate vortex-induced motion. Water depth: 1800-2500m.
6. Tension leg platform (TLP) – buoyant floating platform vertically anchored to seabed by groups of chains on each corner with high tension to block any vertical movement. Water depth: 300-2000m.
7. Semi-submersible rig – deep-water mobile off-shore drilling and producing unit supported by pontoon-type columns, which can be classified as a marine vessel with very good stability and multi-function character. Water depth: 100-3000m.
8. Floating Production, Storage and Offloading (FPSO) unit – floating marine vessel designed to receive oil produced by itself or from nearby platforms, processes it and stores until it's offloaded onto a tanker or through a pipeline. Water depth: 100-3000m.
9. Subsea completion – under-water system consisting of production wellheads located on the ocean floor, connected to the platform or a vessel by flowlines. Water depth: 100-2000m.

For off-shore, due to unfavorable environmental conditions, the costs of upstream and midstream activities are much higher than for on-shore production. The costs of an on-shore well can range from 4.9 to 8.3 million dollars, with additional 1.0 to 3.5 million dollars in lease and operating expenses over the 20-year well life cycle (U.S. Energy Information Administration, 2016). In case of off-shore wells the costs can be estimated between 60 and 240 million dollars, for wells drilled at water depths ranging from 2,000m to 4,000m (U.S. Energy Information Administration, 2016). Regarding costs per barrel, it is highly dependent on well productivity and the size of discovered reservoir. Therefore, because of its technological complexity, high risk and associated high costs, off-shore drilling projects are usually undertaken by a group of partners rather than a single company. This spreads risks and allows to find financing for much more costly exploration than the one on-shore.

1.5 Portugal Overview

In a perspective of imminent discovery of hydrocarbons in the Portuguese off-shore basins, Portugal has been selected as a case study for this work. To understand the potential behind possible domestic crude oil production a short revision of Portuguese natural resources, trade balances and the present off-shore exploration status, has been presented in this chapter.

Portugal's main natural resources include fish, forests, iron ore, copper, zinc, tin, tungsten, silver, gold, uranium, marble, clay, gypsum and salt (Martins, 2012). Forests are a significant resource of Portugal covering about 34%

of the country, with cork as the most characteristic product, of which Portugal is a leading producer with over half of world's annual cork production (MENESES, 2015). Although the country is rich in metallic and nonmetallic resources, Portugal is completely dependent on imported energy resources.

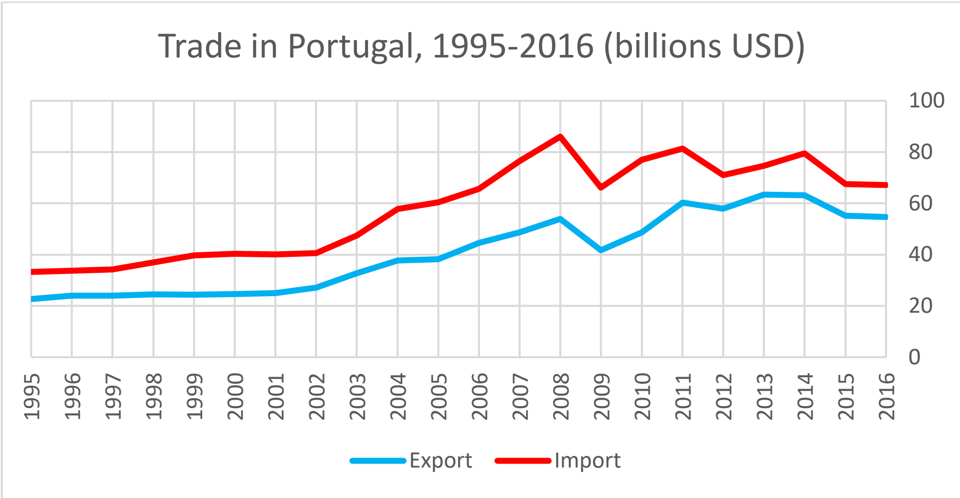
Portugal relies on imported crude oil as it has no local production of oil established yet. It imported 10.5 million tonnes (Mt) of crude oil in 2014, sourced from Angola (27.6%), Saudi Arabia (12.5%), Algeria (10.5%), Kazakhstan (9.8%), Nigeria (9.6%) and others (IEA, 2016).

In Portuguese energy balance for 2014, transport consumed almost 60% of oil share. Industry accounted for 19%, while nearly 7% was used by energy sector, leaving the reminder for services and residential sector (Pacheco, 2017).

Approximately 36% of domestically produced oil products were exported in 2014 (4.6 Mt). Exports have surged over the past decade, increasing by 131% from 2004 to 2014 (IEA, 2016). They are mainly destined for Spain (21.4%), the United States (13.8%), France (9.4%), the Netherlands (8.1%) and all across Europe and North Africa (IEA, 2016).

In 2016, imports of all mineral products amounted to 6.74 billion dollars, where 64%, 13% and 4.5% were constituted by crude oil, natural gas and coal respectively (Simoes, 2011). Total imports to Portugal in 2016 were equal to 67.1 billion dollars, where cars (6.69%) and crude petroleum (6.39%) had the highest share of total (Simoes, 2011). Those two categories have been also leading the imports through the whole last decade. This shows that the demand for both vehicles and fuels is stable within close markets, and that the dependency on imports in transportation sector is huge.

On the other hand, in 2016 exports in Portugal totaled to 54.7 billion dollars, with 4.1% share of refined petroleum (2.24 billion dollars) (Simoes, 2011). The main importers of Portuguese petroleum were United States (26%), Spain (22%) and Morocco (14%) (Simoes, 2011). Taking into account the well-developed refining industry in Portugal with total capacity of refineries equal to 53,000 m^3/d (Galp Energia, 2018), in case of successful discovery of hydrocarbons Portugal could in time increase the exports of its already most outflowing commodity, what could lead to decrease in its negative trade balance. The import and export data for years 1995-2016 has been presented in Graph 8.



Graph 8 Trade in Portugal, 1995-2016 (billions USD) (Simoes, 2011)

The negative trade balance occurs when country's imports exceed exports, and it generally represents an outflow of domestic currency to foreign markets. As presented on the graph above, Portugal has been noting a negative trade balance for a sustained period of time. That is usually a result of political or economic instability and may lead country into debt. Although that statement is true, in modern economy when domestic companies manufacture their goods in foreign countries the raw materials sent abroad count as exports, while the finished products count as imports. Therefore, a trade balance cannot be itself a decisive factor for investors, but in most cases a thorough analysis of the domestic market has to be done. In fact, to some extent trade deficit can be profitable for a country, as it means that country is importing more goods from abroad in competitive prices improving the standard of living of its citizens who can afford more products. It can also be a mean to reduce inflation, while creating lower prices. Although, in long term with more products being imported the local production decreases and so the home country creates fewer jobs in the industry increasing unemployment rates or leading to workforce emigration. However, with domestic crude oil production Portugal could not only improve the trade balance but also create a whole new industry with new employment possibilities.

The oil exploration in Portugal is not a new notion and it goes back to 1938, when the first exploration and production concessions have been granted. Since then there have been total of 72,600 km^2 two-dimensional (2D) seismic surveys performed across the country.

Regarding the new three-dimensional (3D) method, since 2010 exact of 10,372 km^2 were acquired. Throughout almost a century there were total of 175 wells drilled, where 117 had hydrocarbons shows and 27 established production tests. Due to technological constraints only 81 wells were deeper than 500m. Other exploration efforts on the Portutuese basins include aeromagnetics (26,086 km^2) and piston core surveying (57 samples).

Most of the physical exploration activities were on-shore, with only 27 wells drilled off-shore and 4 out of that in the deep waters. However, regarding the 2D and 3D surveys most of them were acquired offshore amounting to 67,009 km^2 and 9,752 km^2 respectively. All exploration activities have been presented on the map in Appendix 1.

There are currently 5 active concessions for oil exploration in Portugal. The location of the contracted areas has been presented in the Figure 2 below. Based on the Portuguese legislation the duration of such concession is divided into two stages. The initial (exploration) period of the concession is 8 years, and can be extended up to 10 years (ENMC, 2017). If the concession holder declares a commercial discovery during the initial period, the area of oil field enters the production period, which has duration of 25 years, and can be extended up to 40 years, if justified (ENMC, 2017). All current contracts are at the exploration period and first perforations are planned in the near future, as most of the off-shore contracts already reached extension period.

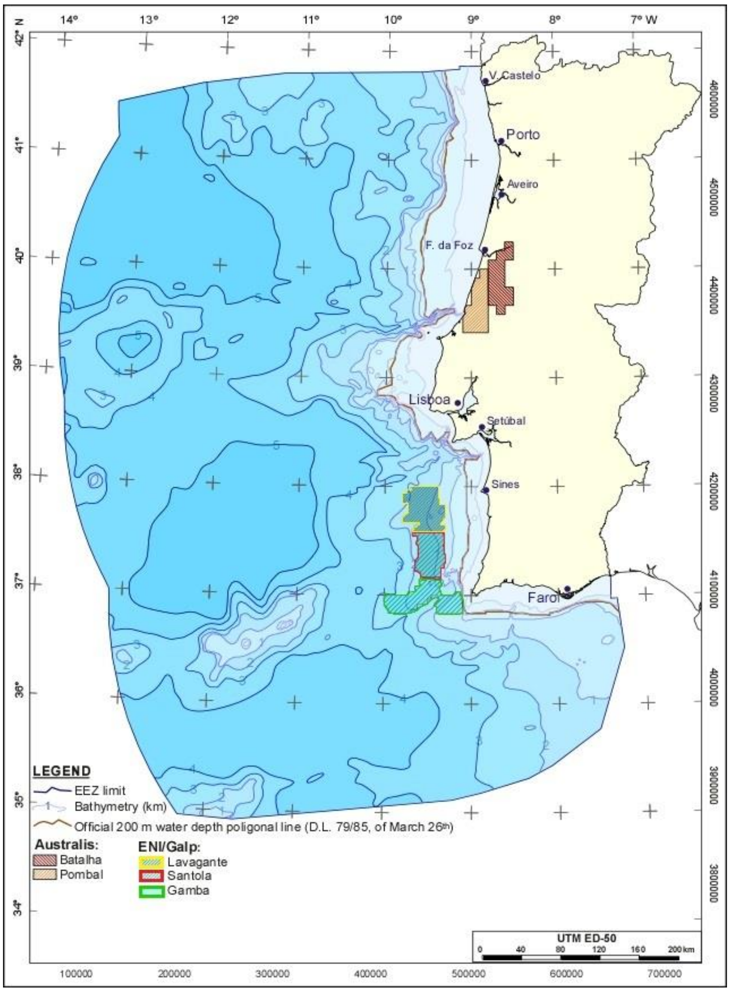


Figure 2 Active oil exploration concessions in Portugal (ENMC, 2017)

The first exploration well is planned to be drilled in Santola block (Santola-1), by the ENI and Galp consortium. It will be located 46,5km away from the coast line and 88km away from the Sines refinery. The drilling will take place at a water depth of 1,070m, therefore an Ultra-Deep Water Dynamic Positioning Drilling Ship Saipem 1200 (Vunda Simao, 2016) has been selected by the operator. This ship can operate as an FPSO, with a remote operated vehicle (ROV) installed permanently with the platform. The technical specifications of the ship have been attached in Appendix 2.

However, the exploration well that was planned for the offshore Alentejo Basin in the summer of 2016 has been postponed to 2018, as the contractor did not comply with documentation requested by the government. As a result, the meteorological window for exploration in the Alentejo basin was lost in 2017, and may only be attempted – if conditions are met – in 2018.

If the discovery of crude oil will be successfully confirmed, there is an undoubtful economical potential in domestic oil production in Portugal, however there is also a significant social movement against such actions based on the environmental risks associated with production activities. In the next chapter a detailed analysis of the environmental impact of potential domestic crude oil exploration and production activities will be performed. Due to a lack of significant developments in the Portuguese off-shore basins, the information regarding the Santola-1 well, will be used as a source for reference values in the further analysis.

1.6 Objective

The goal of this work is to perform an environmental impact analysis and create a comparison of impacts related to the import of crude oil from Brazil to Portugal, with the potential domestic off-shore oil exploration and production in Portugal. Few case studies are to be investigated, with different input data based on different assumptions related to factors, such as e.g. oil production efficiency, number of wells to be drilled, number of platforms or oil transportation method. The analysis is focusing on the emissions rated to different impact categories influencing the environment, and therefore the nature, resources and human health. The main constituents for most relevant categories have been identified. All domestic production scenarios' impacts have been normalized and compared to the reference study of imports from Brazil.

Although it'd be of high importance to investigate the social aspects of offshore activities in Portugal, those are not a part of this analysis. It is due to a fact, that crucial sources for such analysis are in Portuguese, and the objectivity of this work might be at stake, as it is a very delicate topic.

With established case studies for environmental impact analysis, the aim of the research focuses on evaluation of current fiscal regime regarding crude oil exploration and production and comparison with more developed systems in well-established producing countries, such as e.g. Norway. A rough estimation of revenues is to be presented, taking into account current and potential future oil taxation scheme. Knowing that, some recommendations of possible ways of investment are to be given.

1.7 Document Outline

1.7.1 Structure

This work has been divided into 4 main chapters. The first chapter provides an introduction into current trends on the energy markets, with focus on crude oil sector. It also explains the details of different segments of the crude oil exploration industry. Few different technologies are presented for the target category, which is off-shore exploration. The current Portuguese off-shore development is described to draft a picture of actual and potential domestic exploration and production activities.

The second chapter is presenting an environmental impact analysis methodology, with focus on undertaken elements of life cycle assessment (LCA) tools. It also shows the selected data and assumptions in case studies of Brazil and Portugal, for which the further impact evaluation has been performed, using an LCA software chosen for this work – SimaPro. The main impact categories have been described, and a method of calculating input variables is explained. It also explains the method of calculation of revenues, given examples of different fiscal regime elements.

Third chapter focuses on presentation of the results of simulations, with more detailed information on relevant impact categories, and most contributing processes. And provides rough estimation of state revenues for domestic exploration and production of crude oil in Portugal. A discussion on possible ways to utilize those funds is indicated

Chapter four concludes the findings from previous chapters, and summarizes the most valuable information. It also discusses the points for future work to be performed on the topic and discusses the issues identified during the course of preparation of this report.

1.7.2 Stakeholders

This project has been organized with a help of Prof. Tiago Morais Delgado Domingos, who through The Business Council for Sustainable Development Portugal (BCSD PT) and MEET2030 initiative, established a link with a Portuguese oil company Galp Energia, and managed to employ them as a stakeholder of this project. The department of Oil Exploration and Production (E&P) of Galp, was responsible to provide data and guidance throughout the duration of the project. Galp was also verifying the assumptions to ensure that they align with reality and the scope of the project.

2 Data and Methods

2.1 LCA Methodology

To properly estimate the environmental impacts of any industrial activities a life cycle assessment (LCA) has to be performed. The LCA is by definition a "compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its lifetime" (ISO, 2006). It allows to establish an environmental profile of a given system defined as a product or a process used to create that product. The process based LCA comprises of many standards described by the International Organization for Standards (ISO), which are necessary to govern the requirements and to later certify the LCA. According to the ISO standards, an LCA should be structured as presented in Figure 3 below.

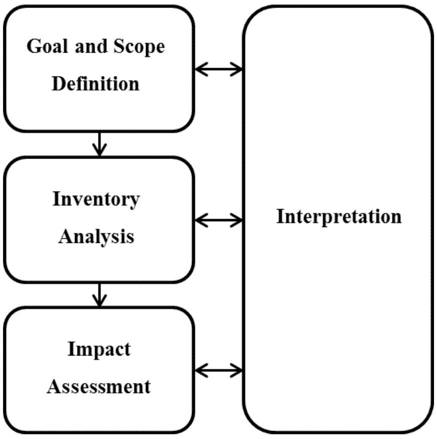


Figure 3 LCA stages according to ISO 14040, 2006a

The goal and scope stage of the LCA is of high importance to the study, as at this point the boundaries of the selected system are defined. Functional unit is also selected to provide a clear reference to which the inputs and outputs can be related. At this stage it is also important to define the time horizon of the study and possible implications related to spatial importance to the location of the study. Depending on the intended application of the work, a clear goal has to be defined to select the parameters accordingly. All assumptions and limitations have to be listed at this stage to ensure that the data quality requirements are met.

The inventory analysis stage is dealing with data gathering and interpretation of all processes or resources included within the previously defined system boundaries. It involves an identification of all material and energy inputs/outputs, and waste outputs. The inputs and outputs can be divided in two groups based on origin and characteristics, as presented in Figure 4 below.

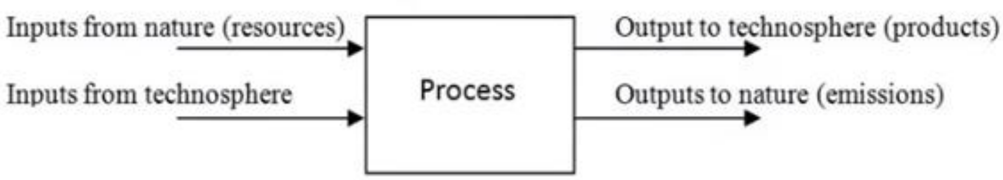


Figure 4 Process flows structure

The inputs from nature, are those which origin is natural, pre-processed, related to raw materials and natural resources (e.g. water, natural gas, ore). The inputs from technosphere are any processed materials or processes related to human activity (e.g. diesel, brick, heat). Those inputs are usually composed of processes with different inputs/outputs and have to be thoroughly investigated during case preparation stage. The "process" bracket in-between inputs and outputs depicts the activity which is analyzed within the LCA.

Third phase of the LCA is the impact assessment, which aims to evaluate the significance of potential environmental impacts. Selection of impact categories, proper indicators and characterization models is important. All inventory parameters have to be assigned to specific impact categories. Characterization is the last compulsory stage based on ISO requirements. However, a typical practice for impact evaluation is normalization, when all impact categories from different datasets are compared to a single common scale for simpler impact comparison.

During all stages of LCA the constant interpretation of gathered information is essential for evaluation of raw inputs or obtained results. If interpretation is implemented from the early stages of work, consistency of the work is ensured and higher level of confidence in final results can be achieved. It helps in reaching of pre-defined goals, and allows to revise the goals based on the specific stages of the analysis. With thorough interpretation of results, clear conclusions and recommendations can be developed.

The goal of this environmental impact analysis is to perform a comparison of impacts related to the import of crude oil from Brazil to Portugal, with values based on production data for year 2016, and the potential established domestic off-shore oil exploration and production in Portugal in ear 2030. The system boundaries in both cases have been selected from the early stages of well drilling, to the final crude arrival in the refinery in Sines, Portugal. The functional unit selected for this LCA is 1kg of crude oil produced offshore, and transported to the entrance of Sines refinery. Therefore, with little information on oil quality, impacts related to oil composition or quality are excluded from the scope of this work. The gas produced during the extraction process has been assumed to be negligible for simplification reasons, as it is mostly flared or injected back to the reservoir.

Also, topics such as oil spills, impact on biodiversity and marine environment are not a part of this study, as such analysis has already been performed by the stakeholder, and further investigation would be too much of an overlap. Also most of the data in literature related to such information is in Portuguese. With such complexity, this would be a good idea to investigate such impacts on a local scale as a future work.

The dataset for Brazil has been based on the average numbers publicly available in the literature, or in some cases on the assumptions discussed with the project stakeholder – Galp Energia. In case of dataset for Portuguese study, few scenarios related to annual oil production have been created based on the estimated time between reservoir discovery to first production, average well completion time and average well productivity. The functional unit selected for this analysis is one kilogram of crude oil at the entrance of Sines rafinery, what will ensure easy and accurate results comparison, as it is the common output from both process trees. The impact categories will be revised in detail in the following sections based on their normalized magnitude of impact on the environment, and based on specific processes contribution.

The software selected for the analysis is SimaPro 8.0, which is one of the most widely used LCA programs by the industry and academics. It is a professional tool that enables the thorough environmental analysis of products or services. It comes with a variety of inventory libraries and impact assessment methods. The inventory database chosen in this work is Ecoinvent version 3.3 from 2016, which incorporates a variety of LCI data from industries such as energy production, transport, production of chemicals, metal production and agriculture. It has a well-established process data related to oil production. The impact calculation method selected within the software is ILCD 2011 Midpoint+ version 1.09 from 2016, which was released by the European Commission Joint Research Center (EC-JRC) in 2012. It supports the correct use of characterization factors for impact assessment according to the guidance document "Recommendations for Life Cycle Impact Assessment in the European context" by the EC-JRC.

There are 15 impact categories for which the environmental impact has been estimated. To fully understand the results of the environmental analysis in this work all 15 categories are briefly described below:

1. Climate change – Takes into account all inputs or outputs that result in greenhouse gas emissions. The greatest contributor is usually the combustion of fossil fuels. It is an impact affecting the environment on a global scale. During the calculations, the global working potential of all greenhouse gas emissions are compared to the amount of the global warming potential of 1 kilogram of CO_2.
2. Ozone Depletion – The depletion of stratospheric Ozone (O3) layer, which protects the planet from hazardous ultraviolet radiation (U-VB), can have dangerous consequences in form of increased skin cancer cases in humans and damage to plants. During the calculations, the potential impacts of all relevant substances for ozone depletion are converted to their equivalent of kilogram of Trichlorofluoromethane (kg CFC-11 eq).
3. Human toxicity (non-cancer effects) – Potential impacts on human health caused by absorbing substances from the air, water and soil. Human toxicity is an impact which predominantly affects people at local and regional scale. It's measured in Comparative Toxic Unit for humans (CTUh).
4. Human toxicity (cancer effects) – Potential cancer related impacts on human health caused by absorbing substances from the air, water and soil. It's measured in Comparative Toxic Unit for humans (CTUh).
5. Particulate matter – The adverse impacts on human health caused by emissions of Particulate Matter (PM), and its precursors (e.g. NOx, SO2). It's measured in kilogram of particulate matter 2.5 equivalent (kg PM 2.5 eq).
6. Ionizing radiation – The environmental footprint of the impacts of radioactivity on human health, considering only emissions under normal operating conditions. Potential impact of different ionizing radiations is converted to the equivalent of kilobequerels of Uranium 235 (kg U235 eq).
7. Photochemical ozone formation – While stratospheric ozone is responsible for protection from ultraviolet radiation, the in the troposphere is harmful. It attacks organic compounds in animals and plants, and increases the frequency of respiratory problems through the photochemical smog in the

cities. This is an impact with effects on a local scale. All substances contributing to photochemical ozone formation are converted to the equivalent of a kilogram of Non-Methane Volatile Organic Compounds (kg NMVOC eq).

8. Acidification – It contributes to a decline of forests and increase in fish mortality. It can be caused by emissions into air, water and soil. The most common contributors are combustion processes in electricity, heating, production and transport. Highest contribution occurs, when the substance has a high level of Sulphur. It is a regional impact category. It's measured in moles of Hydron equivalent (mol H+ eq).
9. Terrestrial eutrophication – It impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). These nutrients cause a growth of algae or specific plants and limit growth in the original ecosystem. It is a regional impact category. The impact of substances contribution to terrestrial eutrophication is presented in moles of Nitrogen equivalent (mol N eq).
10. Freshwater eutrophication – Nitrogen emissions into the aquatic environment are caused largely by fertilizers used in agriculture, but also by combustion processes. The most significant sources of phosphorus emissions are sewage treatment plants and leaching from agricultural land. It is a regional impact category. It is expressed per in kilograms of phosphorus equivalent (kg P eq).
11. Marine eutrophication – Same as in other eutrophication categories its related to nitrogen and phosphorus emissions. For the marine environment it's mostly dangerous due to an increase in nitrogen. It is a regional scale impact category. It's measured in kilogram of Nitrogen equivalent (kg N eq).
12. Freshwater eco-toxicity – Calculated for potential toxic impacts on ecosystem, which may damage individual species as well as the functioning of the whole ecosystem. Measured in Comparative Toxic Unit for ecosystems (CTUe).
13. Land use – This category analyses use and transformation of land for agriculture, roads, housing, mining or other purposes. The impacts may very and include loss of species, of the organic matter content of soil, or lead to erosion. It's an indicator of loss of soil organic matter content expressed in kilograms of carbon deficit (kg C deficit).
14. Water resource depletion – Depletion of water is related to withdrawal of water from lakes, rivers or groundwater. It considers the availability or scarcity of water in the regions, where the activity takes place. It's measured in cubic meters (m^3) of water use related to the local scarcity of water.
15. Mineral, fossil and renewable resource depletion – There is a finite amount of non-renewable resources on earth, such as metals, minerals and fossil fuels (coal, oil, gas). This impact category investigates the inevitable situation, in which high volume extraction of resources today will force future generations to lower volume extraction or moving to lower value resources. It's measured in kilograms of Antimony (kg Sb eq).

2.1.1 Process description

To prepare a customized process tree for the study cases, a reference process from the database had to be selected. The process related to the off-shore production oil and gas in Norway has been chosen based on the similarity of described related upstream activities. This process has been later modified according to the acquired data on oil production in Brazil for the import case, and based on the assumptions in scenarios prepared for Portuguese production case. Therefore, based on one reference process selected from the Ecoinvent database, four new processes have been created for later analysis.

Firstly the origin of the values assigned in SimaPro to the Norwegian process has been investigated. This process evaluates the emissions and discharges from 178 production wells located on the Norwegian Continental Shelf (NCS). All the data in this process has been introduced in year 2000, therefore the crucial values such as e.g. total annual production of oil corresponds to the values from that year. After a revision of values with the IEA and BP databases, the data has been verified.

The reference annual outputs pre-set in the program are equal to 159,6 billion kilograms of oil and 49,6 billion cubic meters of natural gas. According to SimaPro process description assumption that 100% of oil was produced off-shore has been made. To understand the importance of total production values in the impact analysis, a sample formula for SimaPro input value calculation has been presented below.

Given in the process description the data for emissions to air of non-methane volatile organic compounds (NMVOC) has been sourced from the environmental report for the Norwegian offshore production in year 2000, and was equal to 209060000kg of NMVOCs. The SimaPro input value is being calculated in the following method:

$$SP_{NMVOC} = \frac{M_{NMVOC} * (0{,}9617 * M_{o_{ref}} + 0{,}0383 * M_{g_{ref}} * \rho_g)}{0{,}9617 * M_{o_{total}} + 0{,}0383 * M_{g_{total}} * \rho_g}$$

where:

M_{NMVOC} – total annual NMVOCs emissions to air = 209060*10^3 kg

$M_{o_{ref}}$ – reference value of produced oil = 1 kg

$M_{g_{ref}}$ – reference value of produced gas = 0 kg

$M_{o_{total}}$ – total annual oil production = 159,6*10^9 kg

$M_{g_{total}}$ – total annual gas production = 49,6*10^9 m^3

ρ_g – natural gas density = 0,84 kg/m^3

As previously mentioned the total annual NMVOCs emissions to air in 2000 were equal to 209060000kg. The reference values of oil and gas are defined by the user, depending on the analyzed case. Within this work only crude oil production is investigated, while the natural gas production is assumed to be negligible. Therefore, the reference value of produced oil is set to 1kg, while the reference value of produced gas is set to 0kg. The total annual production of oil and gas has been also previously mentioned and are equal to $159,6*10^9$ kg and $49,6*10^9$ m^3 respectively. The natural gas density is pre-defined in the software and is equal to 0,84 kg/m^3. As the NMVOC's emissions to air are mostly related to oil production a specific multiplier is pre-defined in the formula assigning 96.17% of those emissions to oil production and only 3,83% to gas production. Therefore, after data substitution the SimaPro input value for the NMVOCs is equal to 0,001296kg. Similar calculation is performed for all other inputs and outputs, however the assigned shares of oil and gas production influence are changing.

In the calculations of SimaPro input values for the case of imported crude from Brazil to Portugal some data was acquired from the literature or from project stakeholders (Galp Energia), but in other cases assumptions and simplifications had to be made. In some cases, where no data could be found in literature, the input values have been calculated by multiplying the initial data from the Norwegian process by a scaling factor, being a total number of production wells in a case study over the number of wells on which the Norway's process was established.

2.1.1.1 Brazil

The first case study is based on the 2016 data of Brazil's crude oil production from the information given by Agência Nacional do Petróleo (ANP), which shows that Brazil produced 2.5 million barrels of oil per day (mbpd), 94.9% of which came from offshore deep-water sites (ANP, 2017). Therefore, in this work a simplification will be introduced in which case 100% of oil produced in Brazil will be assumed to be of offshore origin. The development of deep-water and especially "pre-salt" resources have driven huge increases in Brazil's production in recent years, with pre-salt production making up to 40.7% of overall production in 2016, what is a n increase of 45% in one year. Brazil's oil production is estimated to reach up to 4,4 Mb/d by 2035 (BP, Jan 2017). In this work it has been assumed that the production of crude oil and natural gas for 2016 are 136.7 million tonnes and 23.5 billion m^3.

As the study is related to crude oil production, in calculations of impacts related to a production of 1kg of oil, the production of natural gas is set to be 0 m^3. However, a total annual production of natural gas has to be included in the formula, as the indicators are calculated based on a case study of Norwegian offshore farms, which included both oil and gas.

The following data, presented in Table 5, has been assumed and consulted with a representative of Galp Energia Exploration and Production (E&P) department. All consequent calculations are based on these information, therefore the final results are directly connected to the assumptions.

Table 5 Assumptions for Brazil case study

Parameter	Value	Unit
crude oil reference value	1	kg
natural gas reference value	0	m3
total oil production per year	1,36655E+11	kg
total gas production per year	2347932089	m3
average well productivity	25	kboe/d
number of wells per platform	20	-
number of production wells per platform	10	-
number of injection wells per platform	10	-
average well vertical depth	5500	m
average distance of imports	5500	nm

The inputs from nature for the case study CS1, which relates to the exploration and production of oil in Brazil, include water (sole and ocean), natural gas and crude oil. Those inputs and corresponding processes in SimaPro are same for all case studies investigated in this work, however they vary in the amount corresponding to the functional unit of 1kg of crude oil.

Other known and defined inputs to this analysis are the materials, fuels and other processes from technosphere. In case of CS1 the following processes can be defined: offshore well, offshore platform, sea freight, diesel and chemicals (organic and inorganic). The SimaPro values for those processes have been recalculated similarly to the NMVOCs example in a subchapter above, and are directly based on the predefined process of crude oil production in Norway found in Ecoinvent 3 database.

In 2016 Galp's imports of crude oil from Brazil amounted to 2,953,580 tonnes, and this value has been used to calculate the environmental impact of sea freight related to the imports. A process corresponding to a transoceanic tanker transportation has been selected from Ecoinvent 3 database.

Final inputs from technosphere are related to on-site electricity and heat production. Following up with the Norwegian model, the processes taken into consideration are: sweet gas burned in gas turbine, and diesel-electric generating set production 10MW. Both have been investigated for global geographical data and considering an average over all gas turbines, motors, boilers and electric generating sets used on the Norwegian offshore oil fields. All inputs and corresponding values have been listed in Appendix 3.

Taking into account the large amount of outputs in form of emissions to air and water, and outputs from technosphere, all imacts for the main scenarios have been listed with corresponding SimaPro values in the Appendix 4.

2.1.1.2 Portugal

To prepare an environmental impact analysis for Portugal firstly some assumptions had to be made. However, as the situation within the oil sector is still at its early stages of pre-discovery exploration, a few scenarios had to be designed for a better understanding of importance of several factors, such as well productivity or drilling efficiency. The general data assumptions for all scenarios has been presented in Table 6.

Table 6 Assumptions for main Portuguese case studies

Parameter	Value	Unit
crude oil reference value	1	kg
natural gas reference value	0	m3
number of wells per platform	20	-
number of production wells per platform	10	-
number of injection wells per platform	10	-
average well vertical depth	3 500	m
average length of one pipeline per platform	100	km

The technology selected for the exploration and production phase of the case study is, as previously described in Chapter 1.5, an FPSO vessel. It has similar capacity when it comes to number of possible well connections (up to 10 production and 10 injection wells). The average well vertical depth is set to 3,500m, as the first drilling activities in the Alentejo Basin will be undertaken at the water depth of 1070m (Economia, 2007), and the best shows of oil in this area presented in literature were in Upper Jurasic deposits (ENMC, 2017). The method of transportation of oil from the FPSO vessel to the port of Sines has been chosen to be a pipeline as the distance from the Santola area to the Sines refinery is equal to only 88km. The length of one pipeline per FPSO is set to 100km, taking into account changes in the underwater terrain.

To calculate the total oil production per scenario the first thing to be assumed has to be the well productivity. There have been three main domestic production scenarios prepared in this work, corresponding to three study cases – PT1, PT2 and PT3. The production assumptions for all these scenarios have been presented in Table 7 below.

Table 7 Production assumptions for the different case studies

	PT1		PT2		PT2	
year	no. of production wells (-)	production (kboe/d)	no. of production wells (-)	production (kboe/d)	no. of production wells (-)	production (kboe/d)
2018	0	0	0	0	0	0
2019	0	0	0	0	0	0
2020	0	0	0	0	0	0
2021	0	0	0	0	0	0
2022	1	25	1	15	1	35
2023	5	125	4	60	6	210
2024	9	225	7	105	11	385
2025	13	325	10	150	16	560
2026	17	425	13	195	21	735
2027	21	525	16	240	26	910
2028	25	625	19	285	31	1085
2029	29	725	22	330	36	1260
2030	33	825	25	375	41	1435

In all cases, the first established production well is assumed to commence in year 2022, so 4 years after the drilling of first exploration well. This assumption has been made based on the available information on different international projects and relates to the fastest field development times for different technologies (Barton, 2017). The number of production wells in case of scenario PT1 has been estimated based on data from the project stakeholder's (Galp Energia) annual report for 2016, where it is stated that in 2016 the company achieved a significant reduction of well drilling and completion time reaching 85 days per well, what gives around 4 wells per year.

Scenario PT1 is based on the most balanced data with similarity to the study of Brazil, and therefore with the same well productivity of 25 kboe/d. In two other case studies PT2 and PT3, the average well productivity has been decreased and increased by 10 kboe/d respectively. Therefore, with well productivity of 15 kboe/d scenario PT2 is a more pessimistic than the reference case PT1, so consecutively the well completion time has been lowered from 4 to 3 wells per year. While, in PT3 both well productivity and well completion time have been increased to 35 kboe/d and 5 wells per year, respectively.

An additional case study PT0 has been simulated, but is not described in much detail, as it has same input data as case PT1, with only difference in transportation method of the extracted crude oil. After establishing all scenarios, an environmental analysis using SimaPro software has been performed, and the results have been described more in detail in Chapter 3.

2.1.2 Scenario definition

To investigate the differences between current situation of oil imports from Brazil and potential oil exploration and production activities in Portugal, the case study of Brazil has been treated as a reference situation, while the scenarios for Portugal are assessed by comparison. The data describing each of the scenarios has been presented in Table 8 below.

Table 8 Summary of variable data for all scenarios

Input	Unit	Brazil	PT0	PT1	PT2	PT3
Investigated year	-	2016	2030	2030	2030	2030
Average well productivity	kboe/d	25	25	25	15	35
Total annual oil production	kg	1,37E+11	4,22E+10	4,22E+10	1,92E+10	7,33E+10
Total annual gas production	m3	2,35E+09	5,02E+07	5,02E+07	2,28E+07	8,73E+07
Number of production wells	-	107	33	33	25	51
Wells completed per year	-	-	4	4	3	5
Total number of wells (exploration+production+injection)	-	241	75	75	57	93
Average well vertical depth	km	5500	3500	3500	3500	3500
Total lenght of wells	km	1323,76	259,87	259,87	196,87	322,87
Number of wells per platform	-	20	20	20	20	20
Total number of platofrms	-	13	4	4	3	5
Transportation Method	-	Tanker	Tanker	Pipeline	Pipeline	Pipeline
Distance for transportation	km	20372	88	88	88	88

As introduced before, there is a reference case study of Brazil with data for year 2016. The other cases have been prepared based on data from literature, project's stakeholders inputs, assumptions or calculations, and correspond to a potential scenario of established domestic crude oil production in Portugal in year 2030. The results on environmental analysis for those cases have been presented in Chapter 3, followed by an estimation of state revenues in the three main cases varying more significantly in inputs (PT1,PT2 and PT3).

2.1.3 Results Normalization Methodology

Another way of presenting the results in by a normalization. Normalization is a notion of interpreting the results in a away, so that the characterization scores are divided by a reference situation's scores. Normalization converts complicated units into fractions of reference scores per impact category. This method has been used to calculate the environmental footprint of previously described scenarios.

In this analysis the reference situation's system is a global system for emissions and resource extraction in 2010, based on EF 2017 method (Sala, 2017). The reference values for normalization have been presented in Table 9.

Table 9 Global Normalization Factors for emissions and resource extraction 2010 (Sala, 2017)

Impact Category	Unit	Value
Climate change	kg CO_2 eq	5,79E+13
Ozone depletion	kg CFC-11 eq	161000000
Human toxicity, non-cancer effects	CTUh	266000
Human toxicity, cancer effects	CTUh	3270000
Particulate matter	kg PM2.5 eq	2,41E+09
Ionizing radiation HH	kBq U235 eq	2,91E+13
Ionizing radiation E (interim)	CTUe	0,00E+00
Photochemical ozone formation	kg NMVOC eq	2,8E+11
Acidification	molc H+ eq	3,83E+11
Terrestrial eutrophication	molc N eq	1,22E+12
Freshwater eutrophication	kg P eq	5060000000
Marine eutrophication	kg N eq	1,95E+11
Freshwater ecotoxicity	CTUe	8,15E+13
Land use	kg C deficit	3,15E+14
Water resource depletion	m3 water eq	7,91E+13
Mineral, fossil & ren resource depletion	kg Sb eq	5,03E+07

To calculate the global factors, the world population has been set to 6,895,889,018 people (UNDESA, 2011). Knowing the global factors for normalization, and total annual crude oil production in each scenario, the calculations have been performed according to a formula:

$$Normalization\ Result = \left(\frac{Ch_{result}}{NF_{global} * P_{global}}\right) * Oil_{annual} * 100\%$$

where:

Ch_{result} – result of characterization per impact category

NF_{global} – global normalization factor

P_{global} – world population

Oil_{annual} – annual production of oil per scenario

2.2 Revenue Methodology

Oil extraction plays a dominant role in many economies as a source of export earnings, but the most important benefit for a country from development of the oil and gas sector is likely to be its fiscal role in generating tax and other revenue for the government. To ensure that the state as resource-owner receives an appropriate share of the profits generated from extraction of oil and gas, the fiscal strategy must be properly designed.

The government, as resource owner, has a valuable asset in the ground. This asset can only be exploited once. In order to convert this asset into profit, the government has to attract capital on terms that ensure it gets the greatest possible value for its resources. There is always a high uncertainty about what the value of the resources will turn out to be. Therefore, there is always a conflict between oil companies and the governments over the division of risk and reward from a petroleum projects. Both want to maximize their profits and shift as much risk as possible to the other party. However, the right choice of fiscal strategy can provide a properly balanced trade-off between each party's interests. Those agreements and the associated fiscal rules establish the price of the resource in terms of the licenses, royalties, taxes or other payments the investor will have make to the government over the whole life of the project. Designing fiscal strategy that encourages a stable fiscal environment and efficient resource development maximizes the revenues to be divided between the investor and the government.

The government can collect revenue from the oil and gas sector by a variety of tax and nontax mechanisms. This sub-chapter contains a brief description of those mechanisms and a summary of the present fiscal strategy implemented within the Portuguese oil exploration and production sector.

Royalties:

Royalties to the government are payments in return for the permission to engage in certain activities on government lands. Oil exploration and production projects are common activities given as an example of royalties payments. When a company starts such a project on government lands or waters, it must lease the area and then pay a royalty fee on the value produced on government's property, since it is still technically owned by the government.

Royalties are attractive to the government, as the revenue is received as soon as production begins and they are easier to manage than many other fiscal instruments, at least for simple royalty regimes. Furthermore, they ensure that companies make a minimum payment for the minerals they extract. Royalties are typically either specific levies based on the volume of oil and gas extracted or levies based on the value of oil and gas extracted. Therefore, royalties are production-based instruments, which can ensure that the government receives at least a minimum payment for its mineral resources (Vann, 2012).

Income Tax:

While taxes are also based on rates, they do not depend on particular land leases or activities. Taxes are payments that must be made on revenue that is generated from normal business activities. Anytime revenue is produced, including through typical income or through investment, taxes must be taken out. However, while there are few exceptions for royalties, tax regulations provide many deductions, reductions and refunds to help taxpayers.

Many countries provide an incentive for exploration and project development by allowing exploration costs to be recovered immediately and allowing accelerated recovery of development costs. Accelerated cost recovery brings forward payback for the investor and a possibility of retirement of debt. It can therefore reduce both investor risk and tax-deductible interest costs. It also facilitates project financing. Some countries offer special incentives to encourage exploration in particular regions.

The income tax should be levied on oil and gas companies, as on all other companies. It is not unusual for the profit tax rate for oil companies to be higher than the general rate for other companies. This is one way to capture a share of the resource rents from the project. The taxes are usually divided into levels based on production volume or value (Vann, 2012).

Concessions and Licenses:

Petroleum exploration and production licenses are the legal agreements of performing E&P activities at specific geographical areas at land or sea, and they are granted to a company or a joint venture allowing them to search for commercially feasible deposits for the extraction of petroleum, and to establish a consequent production throughout the time limits of the license. Under a concession, an oil and gas company is granted exclusive rights to exploration and production of the concession area and owns all oil and gas production. Under concession an oil and gas company typically pays royalties and an income tax. Other payments to the government may be applicable as well and may vary depending on local legislation (Vann, 2012).

Production sharing:

Under a Production Sharing Arrangement (PSA), a national oil company or a host government enters into a contract directly with an oil and gas company. A company finances and carries out all E&P operations and receives a certain amount of oil or gas for the recovery of its costs along with a share of the profits. In such case the ownership of the resource remains with the state and the oil and gas company is contracted to extract and develop the resource in return for a share of the production. The government keeps the right to petroleum reserves in the ground but appoints the investor as a contractor to handle the development of the resource for the government. Instead of paying the contractor a fee for this service, while the government is exposed to the risk, cost and expense, the parties agree that the contractor will meet the exploration and development costs in return for a share of any production that may result. In such case the contractor has no right to be paid in the event that discovery and development does not occur. Typically, the PSA specifies a portion of total production, which can be retained by the contractor to recover costs (cost oil). Any oil over the amount needed for cost recovery is called a profit oil, and is divided between the government and the contractor according to some formula agreed upon in the PSA. Royalties can also be introduced into the production sharing regime. An alternative to a royalty is to have a limit on cost oil, which ensures that there is always a certain share of profit oil, as soon as production begins (Vann, 2012).

In most countries the government share of economic rent is collected primarily through production-based or profit-based instruments. To create a mutual interest between the government and the oil companies many fiscal instruments may be needed and designed with significant care. Profit-based instruments allow the government to relatively high gains in case of highly profitable projects, but they also increase the government's share in the project's risk, as the government may receive no revenue if the project turns out to be unprofitable. In addition to product-based and profit-based instruments, there are bonuses and rental payments of various types that can be applied while designing a fiscal regime. Bonuses can ensure some up-front revenue for the government and may encourage companies to explore and develop contract areas more rapidly. Annual rental payments typically are not a significant source of revenue but can be designed to encourage companies to explore and develop contract areas more quickly or to case their efforts and waive their rights to operate.

While searching for a good example of a well-designed and highly profitable fiscal regime, an example of Norway is highlighted in many sources of literature (e.g. "Petroleum taxation: Experience and issues" by Kjell Løvås and Petter Osmundsen). The revenue streams from the oil exploration and production are mostly profit-based with an addition of concessions for exploration and production. A company involved in the off-shore upstream activities is subject to a marginal tax rate of 78%, where 27% corresponds to an ordinary corporate income tax and 51% resource rent tax) (Ministry of Petroleum and Energy , 2013).

Transportation and activities related to extraction but performed outside of Norwegian territorial borders may be subject to Norwegian tax, if the Norwegian authorities have the right to impose on these activities under international law or bilateral agreements. Also, support activities performed onshore by oil companies are subject to the 78% tax rate as well. To calculate the taxable income properly a "norm price" is established by the governmental body. If the sales price is higher than the norm price, then the additional amount is tax-free. However, if the price achieved is lower than the norm price, then the seller is still taxed at norm price. The norm price is published quarterly, and is based on actual prices obtained by the contractors.

Upstream companies are subject to a CO_2 tax, which is levied on gas consumed for exploration and production activities or flared on the platforms offshore. The CO_2 tax is NOK1 ($0,12) per standard cubic meter (Sm^3), introduced in in January 2015. When it comes to NOx emissions, a fee of NOK19,19 ($2,37) per kilogram is levied based on legislation imposed in 2015 (Ministry of Finance, 2013).

All production licenses are subject to an area fee that is paid after the initial exploration period has expired. The exploration period is normally four to six years, after which the annual area fee increases from NOK34,000 ($4,200) to NOK137,000 ($16,900) per square kilometer. In the exploration period a specific work commitment shall be completed in the form of e.g. seismic data acquisition and surveys, or exploration drilling. If the work commitment is completed during the exploration period, the company can extend its license up to 30 years for production purposes.

There are a lot of incentives for producers operating on Norwegian territory, such as losses transferring, tax refunds, capital allowances, group reliefs, etc.. However, as those are very much dependent on the company's structure and business model, they are not further covered in this work.

2.2.1 Assumptions for Portugal

Oil exploration in Portugal is not a new concept, however oil production has not yet been established at commercial level. Therefore, the laws related to oil exploration are not yet well tailored to the considerable potential of local crude oil production. The government is open for new investment in oil exploration but does not consider the sector as a major priority for public policy and spending.

The authorities are in general passively responding to the initiative of interested companies, rather than promoting their resource extraction. Taking that into account, with a perception of high exploration risk, there has not been much of a breakthrough in E&P activities in Portugal. However, there has been a significant social movement against oil exploration. Press and other media are frequently highlighting the fact, that such activities may have large short-term social and economic impact endangering the tourism in the areas located close to the granted concessions.

Nevertheless, due to technological advances in deep off-shore exploration and production and with development of geological knowledge, and a flexible and favorable tax regime, in case of a first successful discovery of crude oil on Portuguese off-shore territory, the region may become very attractive for large oil companies considering its petroleum potential.

The fiscal regime as it is right now is based on few instruments. There is a royalty levied on production in excess of 10,000 barrels of crude oil per year, at 9% in the case of onshore areas and 10 % in the case of shallow (less than 200 meters water depth) offshore areas. However, no royalty is levied on production obtained from deep offshore areas, and this is where most companies are planning to start their exploration and later on establish production. On top of that, the oil companies are subject to corporate income tax, to which an additional municipal charge may be added.

All activities related to oil exploration and production may only be performed under concessions "granting exclusive rights without prejudice of any third parties to other activities or resources or to national interests concerning national defense, the environment, navigation and scientific investigation, and management and preservation of maritime resources" (Ministry of Finance, 2013). The rules regarding concessions have been presented in a Table 10 below.

Table 10 Concession granting summary (ENMC, 2017)

Name	Maximum Acreage	Duration	Allowed Activities	Minimum Obligations
Preliminary Evaluation License	35 lots ca. 2800 km^2	6 months	Evaluation of existing data and geological field work	Report results of evaluation
Concession contract	16 lots* ca. 1300 km^2	Exploration period: 8 years* (+ 2 possible 1 year extensions each)	Geological, geochemical and geophysical surveys; exploration and appraisal drilling	Years 1 to 3: negotiable
				Years 4 to 8: 1 well/year**
		Production period: 25 years* (extensible to 40 years)	Development drilling and production	None

* The number of lots and the duration of these periods can be exceeded in deep-offshore concessions.

** The number of wells can be less for deep-offshore concessions.

The Meso-Cenzoic sedimentary basins onshore, and whole offshore area under Portuguese jurisdiction, has been divided into quadrants of 1 degree of latitude by 1 degree of longitude. Those quadrants have been subdivided in lots of 5' of latitude and 6' of longitude (except when intercepted by the coast line, the 200m water depth polygonal line or the outer line of the Economic Exclusive Zone). The lot is the basic unit of the concession area and has an average of about 80km^2 (ENMC, 2017).

The concession granting is happening through a public tender, where the concession is granted to the bidder offering best work programs and benefits (technology transfer programs, execution of special oil geological studies of general interest, etc.). The concessionaire and its contractors are bound to keep all data and information related to the concession confidential for the whole duration of the concession, and shall not disclose any such information without the prior authorization of the Dictorate General for Energy and Geology (DGEG). There is no limit to the number of concession contracts held by any one company at any time.

Table 11 Summary of sliding scale rates of royalties on oil production

Crude oil	Percentage
Onshore fields	0–9%
Annual production up to 300,000 tons (+/- 6,000 bbl/d)	0%
Annual production between 300,000 and 500,000 tons (+/- 6,000 – 10,000 bbl/d)	6%
Annual production in excess of 500,000 tons (+/- 10,000 bbl/d)	9%
Shallow offshore fields (< 200 meters water depth)	0–10%
Annual production up to 500,000 tons (+/- 10,000 bbl/d)	0%
Annual production in excess of 500,000 tons (+/- 10,000 bbl/d)	10%
Deep offshore fields (> 200 meters water depth)	0%

When it comes to payments for surface rentals, the concessionaire should pay a fee stated in the concession agreement, which may vary from €12.50 to €250.00 per year per square kilometer according to the potential of the area and the contractual period (ENMC, 2017). There is also a royalty on the value of the production determined according to the guidelines from Article 51 of Decree-Law No. 109/9, summary of which has been presented in Table 12 above.

The concessionaire is also obliged to pay the corporate income tax at applicable rates, which is levied on its profits. Rates may vary annually in accordance with the provisions of the state budget approved by the parliament. Corporate income tax rate is currently equal to 21% (Stron, 2013). An additional municipal surcharge of 1.5% is levied, while the state surcharge is applied as shown in the Table 13 below.

Table 12 Rates of state surcharge on taxable profits (Stron, 2013)

Taxable Profits	State Surcharge
excess of €1.5 million	3%
excess of €7.5 million	5%
excess of €35 million	7%

There has been a public debate in recent months concerning the possible environmental consequences of oil and gas exploration operations. The members of the parliamentary coalition have highlighted the need of tighter and more precise environmental regulations concerning seismic and drilling operations. Therefore, current legislation will need to be revised, as it dates from 20 years ago, and do not reflect properly the technological advancements of the industry and environment. In such case, a new legislation will need to be put in place, what can take a significant amount of time.

As for the moment, with no proven reserves and no successful discovery of crude oil, the fiscal regime is not well-tailored for a well-established oil production case. The current fiscal instruments are not positioning government in a very much profitable situation. However, a rough estimation of several possible cases of crude oil revenues have been presented in the next subchapter, and was based on the scenarios presented previously in Chapter 2.

Due to a fact, that each project has a specific cost structure and development strategy, some assumptions had to be made. Table 14 presents the assumptions with the average costs associated with production of one barrel of crude oil in Portugal. Those costs have been calculated based on information from Rystad Energy, an independent energy consulting and business intelligence data firm, and interpreted by The Wall Street Journal (The Wall Street Journal, 2016).

Table 13 Assumptions for revenue calculations

Item	Unit	Value
Royalties	%	0.00
Corporate income tax	%	29.50
Surface rental fee	€/km^2/y	250.00
Cost of production of one barrel of oil	$	8.00
Capital spending for one barrel of oil	$	15.00
Transportation cost of one barrel of oil	$	3.00

The royalties have been set to 0%, as due to the information presented in previous subchapter, production on deep offshore fields over 200m depth is exempt from those payments. Corporate income tax has been set to 29.5%. While normal income tax is equal to 21%, it has been assumed that the taxable profits will have an excess greater than $35 million, therefore the governmental surcharge has been assumed to be at maximum of 7% and the municipality surcharge is also assumed to be equal to 1,5%. Taking into account that the surface rental fee is calculated depending on size, depth and potential of the area, it has been assumed that the surface rental fee will be set to maximum of 250 €/km^2 per year. When it comes to cost of production, capital spending and transportation cost per barrel of oil, the values have been assumed to be averages of main global oil producers, whose majority of oil production is off-shore based, and are equal to $8.00, $15.00, and $3.00 respectively (The Wall Street Journal, 2016).

The price per barrel of oil, at which the contractor sells the product, has been assumed to be 75$, based on the data from May 2018 for Brent Oil Price (James Stafford, 2018). Therefore, taking into account the previously assumed costs, the company would make $50 profit per each barrel produced. It is a rough estimation, and is not reflecting the real case scenario, where the initial investments are much higher and the generation of profits take much more time. However, as this analysis is performed to present the order of magnitude of possible governmental revenues, the value of $50 per barrel will be used in further calculations.

When investigating the state revenue, royalties, taxes and surface rental fees are the three main contributing factors. As mentioned before, the deep offshore fields are not subject to royalties fees. The profit taxed by the rate of 29,5%, amounts to a state tax revenue of $14,75 per barrel of oil. This value multiplied by the production scenarios presented in Chapter 2, will constitute the majority of governmental income from oil production.

The surface fee has to be calculated for a specific concession area. Same as in case of environmental analysis the Alentejo Basin was selected for this calculation. The Santola concession consists of 39 lots, area of each of which is 5' of latitude by 6' of longitude'. Assuming 1' latitude to be representing a distance of 1.85km and 1' of longtitude to 1.42km (data for 40 degrees N), the area of one lot corresponds to 17.77 km2. Therefore, the total surface of the concession area is equal to 693.03km^2. With the surface rental fee of 250 € /km2, the contractor will be subject to pay the government a levy of $207,909.00 per year.

3 Results and discussion

This chapter focuses on main impacts on environment caused by activities related to analyzed case studies for imports of crude oil from Brazil and potential off-shore domestic oil production in Portugal. The scenarios for which the analysis has been performed have been explained in more detail in Chapter 2. The comparison between imports and domestic production has been presented, and largest deviations have been explained. The most significant impact categories are highlighted, and the results are normalized to investigate, which of the impact categories within those scenarios is contributing most to the global emissions.

3.1 Environmental impacts

An exemplary process scheme of a production of 1kg of crude oil in Brazil is shown on Figure 5. The data presented on this figure correspond to a Climate Change impact category, with unit of kg of CO_2 equivalent in the bottom of each box signifying the environmental effect of each process, and given the input units per each process on the top of the process boxes.

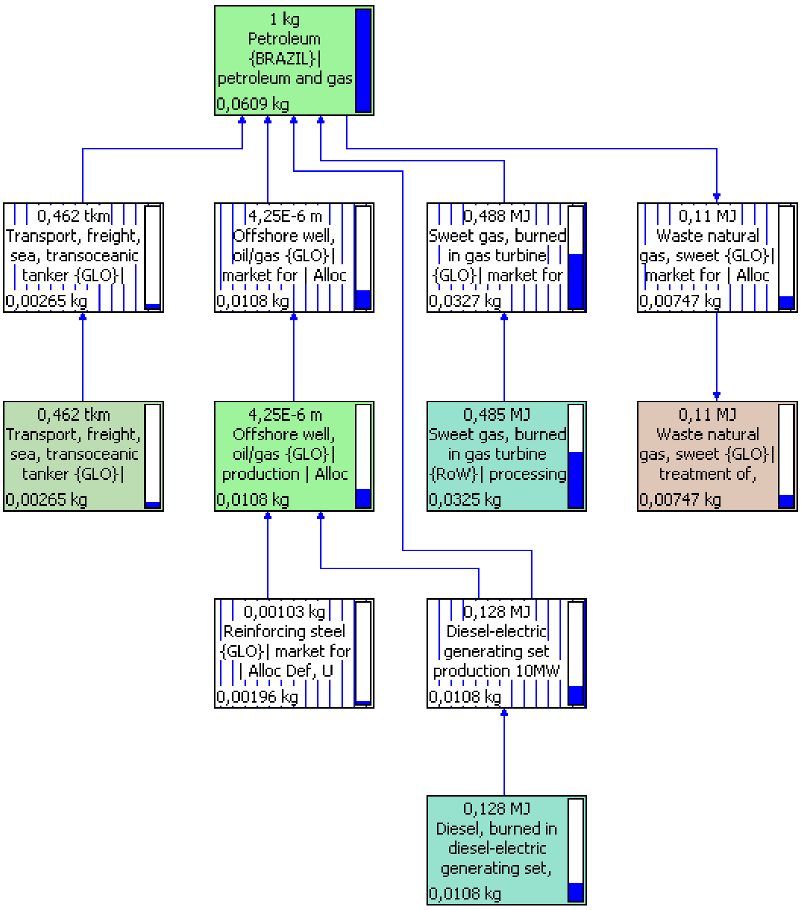
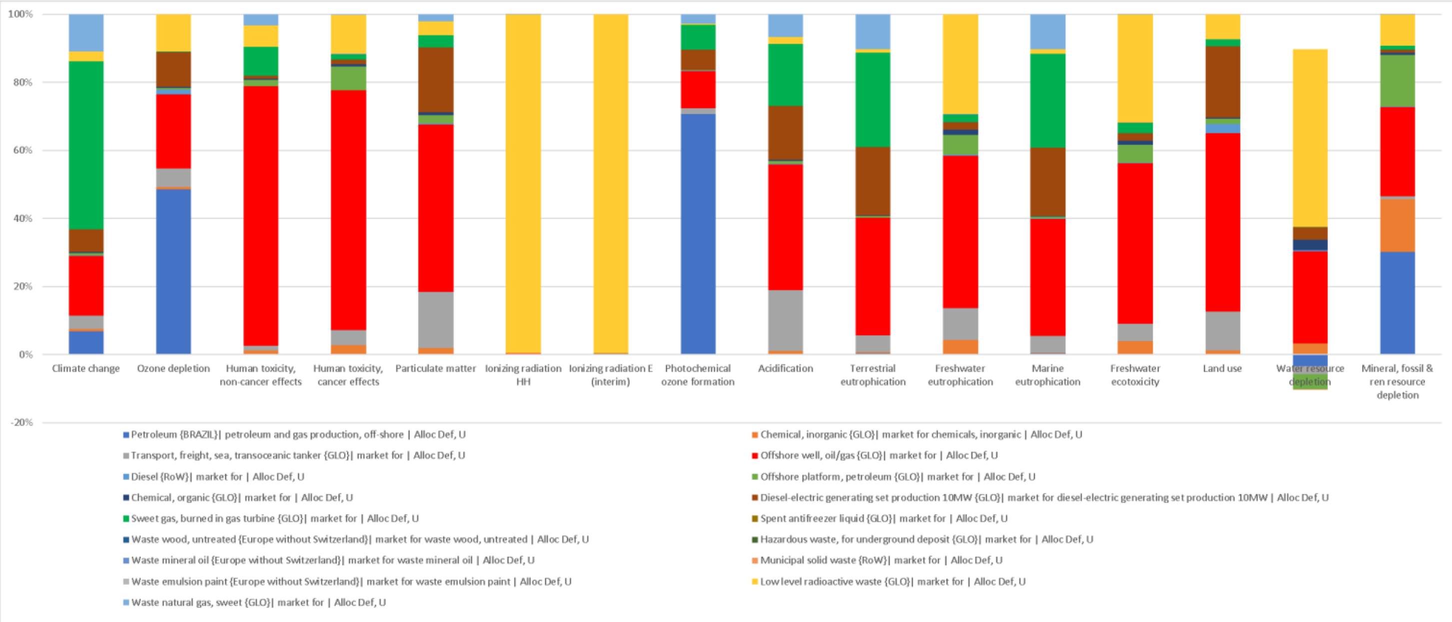


Figure 5 Brazil case study process network scheme example for climate change impact category

It can be observed, that the highest impact corresponds to the process stage representing the sweet gas burning in a gas turbine for on-site electricity production. The unified reference unit is kg CO_2 equivalents for global warming. All the process stages presented in Figure 5, are contributing towards a deep offshore production of a functional unit of 1kg of crude oil, and amount to 0.0609 kg CO2 eq. However, some waste process resulting from a production of oil are also contributing to the climate change impact, one of which is visible at the scheme and it is related to the waste natural gas corresponding to the process of burning of sweet natural gas in production flare.

The contribution of each process step can be presented as a percentage of total environmental impact per category as shown in the Graph 9.



Graph 9 Process contribution share per impact category in Brazil case study (%)

As an example, a case of climate change impact category will be shortly explained. In this category the main contributor is the gas burned in a gas turbine, and its share equals to 49.3% of total impact. The process related to offshore well has the second highest impact of 17.43%, while the next is related to a waste process of natural gas burned in production flare equal to 10.98%. The transport step, which is present only for the Brazil case as the Portuguese case studies have been investigating pipeline as oil transportation technology, constitutes of 3,97% of total impact at climate change.

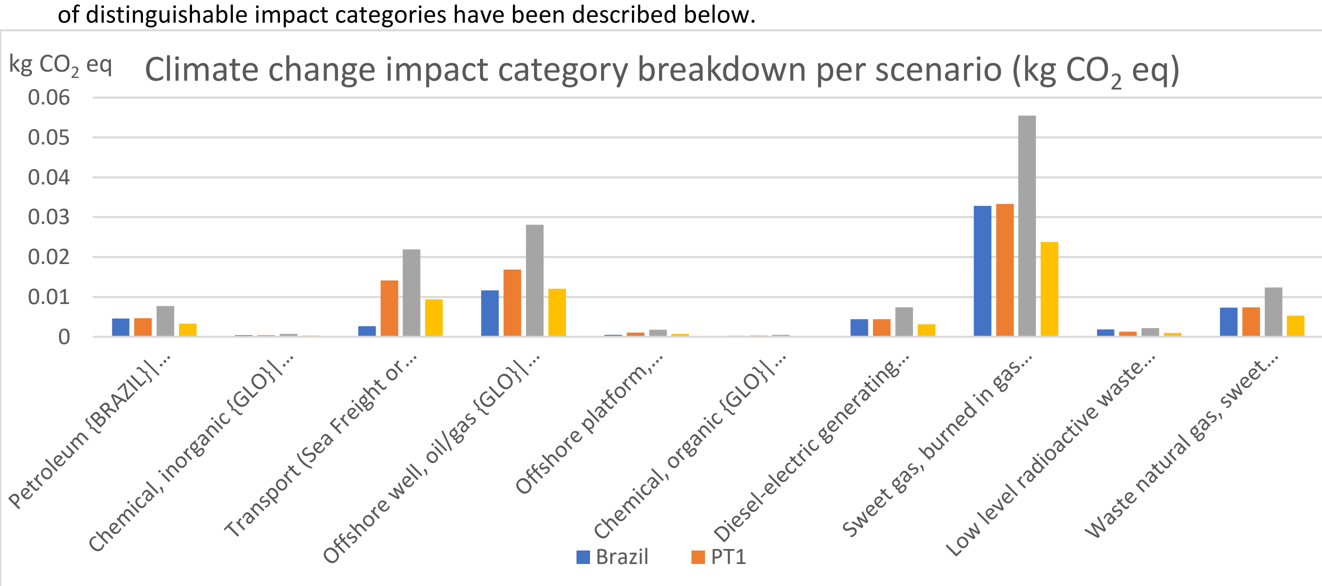
Looking at first column of Graph 9 labeled climate change, it can be observed that the green color amounts for the majority of impact in this major category, and following the legend a gas turbine process step can be deducted. However, it is the red color that is a dominant one in most categories. It corresponds to the process step of the off-shore well, so the drilling activities and related inputs from nature and technosphere. Based on this observation, a direct relation to the wells number and their depth can be aligned with foremost effecting process step for the case of Brazil. The process contribution share per impact category for scenarios related to Portuguese case studies have been presented in Appendix 5. As it can be seen in the Appendix, in cases PT1, PT2 and PT3, for which pipeline has been selected as an oil transport method, most of the categories are dominated by the process corresponding to the offshore well and pipeline. There are only few categories where other processes contribute more, like the major impact category of climate change (the sweet gas dominates in all scenarios), or ionizing radiation, which is in all scenarios (also the reference one) is almost fully composed of low-radioactive waste process.

The result for the scenarios, presented in Table 8, are a percentage of the environmental impact to the reference case (Brazil).

Table 14 Environmental impact analysis results in reference to Brazil case (%)

Impact Category	Unit	Brazil	PT0	PT1	PT2	PT3
Climate change	kg CO_2 eq	0,066619695	105,7%	126,1%	207,6%	89,0%
Ozone depletion	kg CFC-11 eq	7,87393E-09	103,7%	125,3%	206,3%	88,4%
Human toxicity, non-cancer effects	CTUh	1,53987E-08	133,9%	183,3%	299,6%	128,4%
Human toxicity, cancer effects	CTUh	1,75145E-09	133,4%	537,0%	847,8%	363,3%
Particulate matter	kg PM2.5 eq	2,26515E-05	111,0%	173,8%	281,9%	120,8%
Ionizing radiation HH	kBq U235 eq	0,304605461	70,4%	70,7%	117,8%	50,5%
Ionizing radiation E (interim)	CTUe	2,13379E-06	70,4%	70,6%	117,6%	50,4%
Photochemical ozone formation	kg NMVOC eq	0,001320469	104,0%	110,2%	182,8%	78,4%
Acidification	molc H+ eq	0,000396823	103,2%	123,7%	203,3%	87,1%
Terrestrial eutrophication	molc N eq	0,001494714	112,6%	129,5%	213,8%	91,6%
Freshwater eutrophication	kg P eq	4,11461E-06	111,5%	267,0%	426,6%	182,8%
Marine eutrophication	kg N eq	0,000136731	112,7%	131,1%	216,3%	92,7%
Freshwater ecotoxicity	CTUe	0,106492306	114,4%	352,9%	560,3%	240,1%
Land use	kg C deficit	0,053062376	114,5%	170,3%	277,1%	118,8%
Water resource depletion	m3 water eq	1,54629E-05	91,5%	143,7%	233,5%	100,1%
Mineral, fossil & ren resource depletion	kg Sb eq	1,09606E-06	127,7%	279,2%	427,6%	200,5%

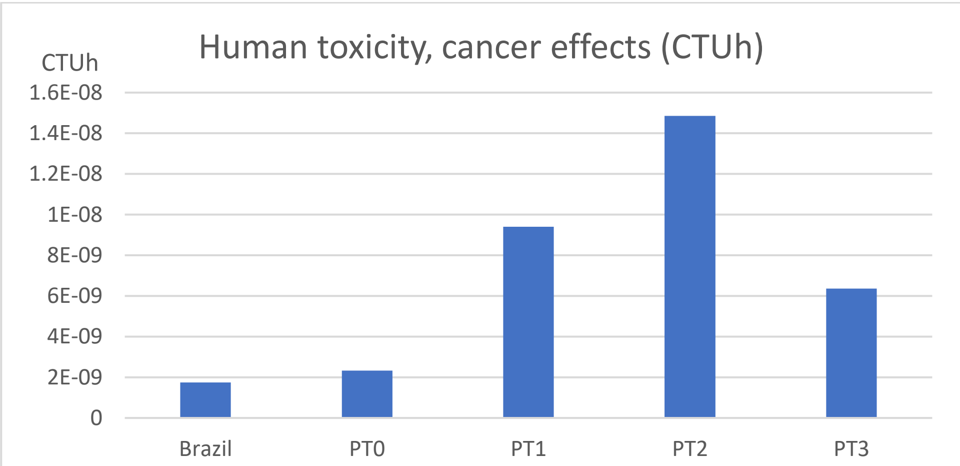
As expected, the results of case PT0 in most impact categories are closest to the current scenario of imports from Brazil, while PT1, PT2 and PT3 are showing extremely different values. Graph 10 shows the process contribution to climate change per main scenarios (without P0, which differs from PT1 only by transportation method). Some of distinguishable impact categories have been described below.



Graph 10 Process breakdown of climate change impact category for main production scenarios

The impact on climate change and ozone depletion are one of the most relevant categories, as they are directly not only affecting the environment, but consequently also the political aspects related to international agreements regarding the emissions. The ratio of impacts for those two categories, are quite similar. Case study PT1 has a higher impact than the reference of Brazil, and is equal in both categories around 125%, while PT2 exceeds the import scenario by a magnitude of 2, doubling the emissions to over 206% in both categories. For PT3 the impact is lower than the reference and amounts to around 89%. The results for climate change are presented in Graph 10. To analyze further, the specific process stage contributions can be investigated. As it was mentioned in above subchapter, the share of sea freight in total climate change contribution for Brazil is equal to 0.00264 kg CO_2 eq, giving around 4% of total impact in this category. While the share corresponding to the process of pipeline transportation in PT1 amounts to 0.014 kg CO_2 eq, giving 16.81% of total climate change impact contribution.

The largest deviation from the reference values per category has been recorded for human toxicity, with emphasis on impacts related to cancer effects. In all three cases the values exceed the reference of Brazil by a minimum of 363,3% for PT3, reaching up to 537,0% and 847,8% for PT1 and PT2 respectively. Graph 11 shows the results for this impact category expressed in Comparative Toxic Unit for human (CTUh), being an estimated increase in morbidity in the total human population per unit mass of a chemical emitted.



Graph 11 Human toxicity, cancer effects category results (CTUh

The largest impact on this category is indicated by the transportation step, where in extreme case of PT2 the pipeline process step contributes to over 73,94% of the result, out of which 28% corresponds to slag from electric steel production to landfill, and therefore to ground water. When investigating the impacts corresponding to water, the eutrophication and eco-toxicity are relevant. In all impact categories, the results are much higher than in case of Brazil, and sub-processes contributing to that are mostly related to infrastructure, so to processes of well and pipeline, are shearing in cases PT1, PT2 and PT3 between 70% to 88% of the impact. In case of PT0, it can be observed that the result is much more similar to the reference case. It is due to a fact that the transport method of finished product is in this case done by sea freight and not by the pipeline. Therefore, for PT0 the impacts of transportation process in any category does not exceed 3,5%, which it reaches for the acidification, and only 0,7% for the impacts on human toxicity. However, the offshore platform in case of PT0 scenario contributes at average in all categories at 43,9%, as it reaches even up to 82,6% for the human toxicity category.

In most of the impact categories, the environmental impact of Portuguese cases PT1 and PT2 is higher, than for a reference case of Brazilian oil production. Only PT3 in some categories is showing results below the reference. It has to be noted, that the simulations have been based on the same process for Norway, the oil composition is the same, there is same technology applied for production (only number of wells and depth of the reservoir varies), there are almost all the same sub-processes as constituents (transportation step is different), the investigated cases and the values are calculated using the scaling factor (ratio of production wells between case study and Norway). Therefore, the main differences between processes are related to different transportation method (what can be seen in case of similarity between import case and case PT0) and distance, different wells depth and their number, and most importantly to different well productivity. It can be seen, that if an optimistic strategy of 35 kboe/d in PT3, the impacts of 8 out of 15 categories are lower than in the reference. However, when the impact category is not production-based but infrastructure based (e.g. toxicity or eco-toxicity), then in such category the use of a pipeline for transportation is a lot less environmentally friendly than a transoceanic tanker, as the difference between the values corresponding to PT0 and PT3 are easily visible and mount to 114,4% and 240,1%, respectively.

The share of global emissions represented by the production activities in each of the scenarios has been presented in Table 10. While investigating the results of normalization, it can be assumed that each of the case studies within the scope of the analysis is playing a minor role in the total global emissions and resource extraction. The highest share of analyzed impacts can be seen within the category “Human toxicity, non-cancer effects”, and in case of three scenarios for Portugal in category “Mineral, fossil & renewable resource depletion”, where the share exceeds 1% of global emissions. However, in other categories the results do not go over a limit of 0,4%, what is a marginal fraction.

Table 15 Scenarios' share in global emissions after normalization

Impact Category	Unit	Brazil	PT0	PT1	PT2	PT3
Climate change	kg CO_2 eq	0,015724%	0,005126%	0,019823%	0,032649%	0,013992%
Ozone depletion	kg CFC-11 eq	0,000668%	0,000214%	0,000838%	0,001378%	0,000591%
Human toxicity, non-cancer effects	CTUh	0,791093%	0,326801%	1,449790%	2,370505%	1,015932%
Human toxicity, cancer effects	CTUh	0,007319%	0,003013%	0,039305%	0,062054%	0,026595%
Particulate matter	kg PM2.5 eq	0,128441%	0,043969%	0,223177%	0,362056%	0,155167%
Ionizing radiation HH	kBq U235 eq	0,143044%	0,031064%	0,101094%	0,168440%	0,072189%
Ionizing radiation E (interim)	CTUe	0,000000%	0,000000%	0,000000%	0,000000%	0,000000%
Photochemical ozone formation	kg NMVOC eq	0,064446%	0,020668%	0,070987%	0,117822%	0,050495%
Acidification	molc H+ eq	0,014159%	0,004509%	0,017512%	0,028790%	0,012339%
Terrestrial eutrophication	molc N eq	0,016743%	0,005817%	0,021687%	0,035796%	0,015341%
Freshwater eutrophication	kg P eq	0,011112%	0,003823%	0,029665%	0,047402%	0,020315%
Marine eutrophication	kg N eq	0,009582%	0,003331%	0,012564%	0,020723%	0,008881%
Freshwater ecotoxicity	CTUe	0,017856%	0,006301%	0,063023%	0,100046%	0,042877%
Land use	kg C deficit	0,002302%	0,000813%	0,003921%	0,006379%	0,002734%
Water resource depletion	m3 water eq	0,000003%	0,000001%	0,000004%	0,000006%	0,000003%
Mineral, fossil & ren resource depletion	kg Sb eq	0,000003%	0,117292%	0,831476%	1,273309%	0,596940%

3.2 Revenue analysis

When investigating oil revenues it must be stated, that for different projects, concessions and companies, the fiscal model will vary. Each specific agreement with the local government may be related to different production incentives, tax deductions or bonuses, etc.. All potential projects will have a different cost of development, production and transportation, and will be subject to a different taxation strategy. In the following analysis, the scenarios PT1, PT2 and PT3 (calculations for PT0 would be same as in case of PT1) from Chapter 2, have been used for an estimation of oil revenues. A rough calculation has been performed to present the magnitude of governments profits, and to propose improvements in the current fiscal regime.

Investigating the PT1 the total annual oil production in year 2030 is equal to 301,125 kboe per year. As the production of crude oil is set to commence in year 2022, between years 2018 and 2020 only the surface rental is taken into account as a source of revenue for the government.

Table 16 Case study PT1 state revenue calculation

Year	No of production wells (-)	production (kboe/d)	Annual revenue ($)	Surface fee ($)	Total revenue ($)
2018	0	0	0,00E+00	2,08E+05	2,08E+05
2019	0	0	0,00E+00	2,08E+05	2,08E+05
2020	0	0	0,00E+00	2,08E+05	2,08E+05
2021	0	0	0,00E+00	2,08E+05	2,08E+05
2022	1	25	1,35E+08	2,08E+05	1,35E+08
2023	5	125	6,73E+08	2,08E+05	6,73E+08
2024	9	225	1,21E+09	2,08E+05	1,21E+09
2025	13	325	1,75E+09	2,08E+05	1,75E+09
2026	17	425	2,29E+09	2,08E+05	2,29E+09
2027	21	525	2,83E+09	2,08E+05	2,83E+09
2028	25	625	3,36E+09	2,08E+05	3,37E+09
2029	29	725	3,90E+09	2,08E+05	3,90E+09
2030	33	825	4,44E+09	2,08E+05	4,44E+09
				Total	2,06E+10

In case study PT1 the total state revenue at year 2030, for which the environmental analysis has been performed, amounts to almost 20,6 billion dollars. In this rough estimation the main assumption is that the fiscal regime will not be subject to any changes. However, as the authorities have recently stated a need of reevaluation of current fiscal instruments regarding crude oil exploration and production activities, Table 16 shows a case study PT1 with a fiscal regime of Norway applied.

The surface fee for Norway is NOK137,000 ($16,900) per square kilometer, and the income tax is much higher than in Portugal, and is equal to 78% (27% corporate income tax and 51% resource rent tax). With this more rigorous fiscal regime the total state revenue for Portugal would amount to almost 54,5 billion dollars, so over 2,6 times higher than with the use of current fiscal instruments.

Table 17 Revenue calculation for case study PT1 with Norwegian fiscal regime

Year	No of production wells (-)	production (kboe/d)	Annual revenue ($)	Surface fee ($)	Total revenue ($)
2018	0	0	0,00E+00	6,62E+05	6,62E+05
2019	0	0	0,00E+00	6,62E+05	6,62E+05
2020	0	0	0,00E+00	6,62E+05	6,62E+05
2021	0	0	0,00E+00	6,62E+05	6,62E+05
2022	1	25	3,56E+08	6,62E+05	3,57E+08
2023	5	125	1,78E+09	6,62E+05	1,78E+09
2024	9	225	3,20E+09	6,62E+05	3,20E+09
2025	13	325	4,63E+09	6,62E+05	4,63E+09
2026	17	425	6,05E+09	6,62E+05	6,05E+09
2027	21	525	7,47E+09	6,62E+05	7,47E+09
2028	25	625	8,90E+09	6,62E+05	8,90E+09
2029	29	725	1,03E+10	6,62E+05	1,03E+10
2030	33	825	1,17E+10	6,62E+05	1,17E+10
				Total	5,45E+10

Table 17 is showing estimates of total state revenues for all three study cases (PT1, PT2 and PT3) taxed using current regime and the one based on Norwegian system. The lowest state revenue has been calculated for the present taxation strategy in case study PT2, which is characteristic for low well productivity. The largest state revenues have been achieved with Norwegian taxation and highest well productivity. It highlights the fact, that not only the environmental impact is directly connected to the well productivity, but also the economic impact is related to well productivity as well.

Table 18 Revenue estimation for case studies PT1, PT2 and PT3 per Norwegian fiscal regime ($)

Year	PT1 ($)		PT2 ($)		PT3 ($)	
	Current Regime	Norwegian Regime	Current Regime	Norwegian Regime	Current Regime	Norwegian Regime
2018	2,08E+05	6,62E+05	2,08E+05	6,62E+05	2,08E+05	6,62E+05
2019	2,08E+05	6,62E+05	2,08E+05	6,62E+05	2,08E+05	6,62E+05
2020	2,08E+05	6,62E+05	2,08E+05	6,62E+05	2,08E+05	6,62E+05
2021	2,08E+05	6,62E+05	2,08E+05	6,62E+05	2,08E+05	6,62E+05
2022	1,35E+08	3,57E+08	8,10E+07	2,14E+08	1,89E+08	4,99E+08
2023	6,73E+08	1,78E+09	3,23E+08	8,55E+08	1,13E+09	2,99E+09
2024	1,21E+09	3,20E+09	5,66E+08	1,50E+09	2,07E+09	5,48E+09
2025	1,75E+09	4,63E+09	8,08E+08	2,14E+09	3,02E+09	7,97E+09
2026	2,29E+09	6,05E+09	1,05E+09	2,78E+09	3,96E+09	1,05E+10
2027	2,83E+09	7,47E+09	1,29E+09	3,42E+09	4,90E+09	1,30E+10
2028	3,37E+09	8,90E+09	1,53E+09	4,06E+09	5,84E+09	1,54E+10
2029	3,90E+09	1,03E+10	1,78E+09	4,70E+09	6,78E+09	1,79E+10
2030	4,44E+09	1,17E+10	2,02E+09	5,34E+09	7,73E+09	2,04E+10
Total	2,06E+10	5,45E+10	9,45E+09	2,50E+10	3,56E+10	9,42E+10

As a conclusion, the Portuguese fiscal regime needs to be reevaluated to maximize the gains within the resource rental. Norwegian tax fees cannot be directly a good example for a developing case of Portugal, as Norway has few decades of established oil production, and does not need to lure new investors towards large endeavors in deep offshore exploration. Nevertheless, the huge differences in state revenues show, that policymakers have to design a fiscal regime for the oil sector that will attract investment as well as secure a reasonable share of economic rent for the government.

Taking into account all the possible fiscal instruments described in this chapter, some recommendations can be made. There is no one optimal regime suitable for all projects in all countries. There is much difference between countries or even basins, when it comes to exploration, development and production costs. The chemical size, composition and quality of oil reserves may somehow vary. Investors apply different negotiation strategies for countries with a proven track record of successful projects, than in case of countries with short or even non-existing history of successful discoveries.

It is however possible, to outline some desirable features while designing a fiscal regime for oil sector. It would be in country's best interest to secure some up-front payment (e.g. in form of royalties), but in case of Portugal it may be hard due to no record of successfully developed projects. In such situation, most accurate would be a resource rent based tax system. It must be kept in mind, that all the investment decisions are made with regard to market price per barrel of crude oil.

As it was highlighted in above chapters, the off-shore oil exploration is connected with high investment costs, therefore the recent slump in the sector is not dictated only by the design of unfavorable fiscal regimes, but also by the global situation at the oil market. The fiscal terms are directly affecting investment environment, and for this reason it is important to try to mitigate the uncertainty of high political, market and commercial risk, while developing a fiscal strategy. Therefore, if the country wishes to maximize its profit, while increasing the number of investors within its territory, the authorities must be flexible and adjust the fiscal regime to the environment and to the specific conditions of all undertaken projects.

In March 2018, renewable energy sources made up 103,6% of mainland Portugal's monthly electricity use, according to information reported by Routers (Reuters, 2018). Portugal has been one of the top countries regarding renewable energy generation for some time now. In 2016, Portugal ran on solar, wind and hydropower energy for 107 hours (The Guardian, 2017). Therefore, with such an efficient and well-designed renewable energy system producing over 100% of energy need, at times, and still being on the rise, Portugal has a strong position on the energy market. However, those numbers are related only to energy needs related to electricity production, and is only viable at specific times with favorable weather conditions.

Portugal does not produce oil or natural gas, therefore country is highly dependent on imported fossil fuels. Even with 100% of electricity needs met with renewables at times there are still many fossil dependent parts of the industry, which in 2014 constituted to 74,3% of total primary energy supply (TPES), with 45,1% corresponding to oil (IEA, 2016). As it was mentioned before, Portugal imported 10,5 Mtoe of oil in 2014. Therefore, there is a steady and relatively high demand on oil in Portugal, which is for now purely dependent on imports. With local oil production the money spend on imports, could stay domestically improving the trade balance, and therefore the economy even more.

With electricity sector being on the rise, and already reaching 100% of the demand for a month, oil money could be invested into sectors still very much dependent on fossil fuels, to accelerate the transition towards the low-carbon economy. Therefore, one of the methods of transition acceleration, Portugal could subsidize the electric vehicles (EV's) sector development. The transport sector consumes 59,8% of oil in Portugal, industry accounts for 19,0%, while 6,9% is refined and used by the energy sector's own use (IEA, 2016). Over 55% of energy-related CO_2 emissions in Portugal have been of oil origin.

Following the example of Norway, Portugal could use its potential oil reserves as a pathway to a generate funds for a low-carbon, sustainable future. In 1990 Norwegian authorities established an oil fund (Government Pension Fund Global), to invest the surplus revenues of domestic oil producing activities, which in 2017 reached over 1 trillion dollars and is the largest sovereign-wealth fund recording over $130 billion of income per year (The Economist, brak daty). This gives a staggering amount of around $192,000 for every citizen of Norway. However, in case of Norwegian pension fund, the investment is being made in global assets of various international companies. In 2017 the fund had shares in 9,146 companies. The largest contributors to the fund's returns are Apple, Microsoft, Tencent and Amazon. With good investment strategy Portugal could benefit from its oil revenues, and with time grow the fund to be as large as the Norwegian sovereign-wealth fund.

Portugal has an established fund of it's own, namely the Portuguese Carbon Fund (FPC), established in 2006 by Decree-Law 71/2006 of 24 March 2006. The fund raises its own income, by collection of taxes on heating oil, diesel oil, low-efficiency lightbulbs (paid by manufacturers and retailers). However, its main revenue stream comes from auctioning allowances under the European emissions trading system (EU ETS). It also supports projects in Portugal leading to reduction of greenhouse gasses emissions, projects to improve emissions accounting methodologies or innovative renewables projects under the NER300 EU programme (carbon capture and storage project, or new renewable energy systems) x24. It also invests in electric mobility programs (Mobi.E Project), promoting the demand for electric vehicles (EV's).

While investigating the issue, it may seem that the oil sector may be destructive to the goals of the FPC fund. However, with well-designed fiscal regime and good management of oil revenues, this could significantly accelerate the transition towards low carbon economy in Portugal. Oil sector, if well controlled and sanctioned, with new technological advancements should be a safe and profitable solution, giving a large boost towards the goals of FPC fund. As the exploration and production concessions are given for a limited period of time, the release of new concessions can be stopped at certain time, when the revenues generated by the oil sector will be no longer feasible in regards to the environmental impact of those activities. Money gained through oil exploration and production activities can be a milestone towards a development of new technologies and a whole new sustainable infrastructure. The real energy transition cannot happen without considerably large investments, and those need to be backed with funds.

4 Conclusions and future work

As it was presented in the introductory Chapter 1 to this work, fossil fuels are still dominant source of energy, and will be in the upcoming decades. Therefore, the sector will be still growing and the companies, both local and foreign, should be interested in investment in the area in case of successful discovery of crude oil in the Portuguese offshore basins. However, it is very much dependent on fiscal regime that will be established by the local authorities in the coming years and on the fluctuating crude oil prices, which are dictating the decisions related to such high investment initiatives.

In the environmental impact analysis results it has been presented, that the impacts associated with local crude oil exploration and production will be very much dependent on the quality, quantity and productivity of established production. In Chapter 3 the results show, that in cases such as PT0, with inputs very similar to the reference case of Brazil (mainly the average well productivity equal to 25 kboe/d) the environmental impact is almost the same as in reference averaging 107,5% within 16 environmental impact categories. However, even in a situation of higher well productivity and faster development of the reservoir leading to larger amount of production wells, if a pipeline will be introduced instead of sea freight as in case of PT3, the average impact throughout all categories will be higher reaching over 130,2% with highest impacts on human toxicity reaching up to a 363,3% of reference value for case of imports from Brazil. Those deviations are highly connected to the infrastructure (wells, platforms or pipelines), so it can be highlighted that a more precise analysis would have to be performed with more specific inputs from companies planning to develop the reservoir. There are many variables, which may lead to different outcomes regarding the environmental impact of the exploration and production projects. It can be concluded, that with high well productivity and with low infrastructure employment the production of oil in Portugal would have similar impacts on environment in comparison to imports from Brazil.

There is a huge chance for Portuguese government to collect a significant share of the oil profits, and to invest in low carbon solutions development. With good management of revenues, and taking a lesson from countries with well-established oil revenue streams (e.g. Norway), Portuguese economy can be on the rise in the upcoming decades. Within the investigated scenarios and corresponding assumptions, and with regard to current fiscal regime, the state revenues have been estimated to reach from 20,6 to 35,6 billion dollars in year 2030. However, if the taxation system would shift to a similar one to the Norwegian, the total revenues for the same period of 13 years would range between 54,5 and 94,2 billion dollars. Such amount could be distributed between different goals and areas of state business, however to facilitate a smooth transition from potential oil-related economy in the future towards a low-carbon sustainable system, investment in funds such as Portuguese Carbon Fund should be made, as it would not only increase the competitiveness of Portuguese economy, but also allow to put a timeline for oil exploration and production activities in Portugal.

At this stage, there is so little data available to public information, and there are so many variables influencing the results, that it is impossible to say, if it is better to import oil or produce oil locally in long term by using only such a simple analysis. However, as it was presented in this work, with favorable natural and economic environment for crude resources development, Portugal may feel a recognizable change in the following years. Taking into account the economic benefits associated with domestic crude oil production, it is surely worth to be prepared for a successful discovery, and have all the instrument in place to fully benefit from this opportunity.

The future work in this topic should be performed on impacts on a local scale, and not global or state centered. Domestic crude oil production can affect mostly local communities and businesses, therefore a social impact analysis should be performed. It would also be good to repeat a similar study to the one contained in this work, but at a point in which more data is available for precise investigation of both environmental and economic impacts. Also, there should be a larger transparency within the crude oil exploration and production projects, what would not only accelerate external bodies to investigate the possible outcomes of such actions, but could also ease current negative public reception of any domestic crude initiatives.

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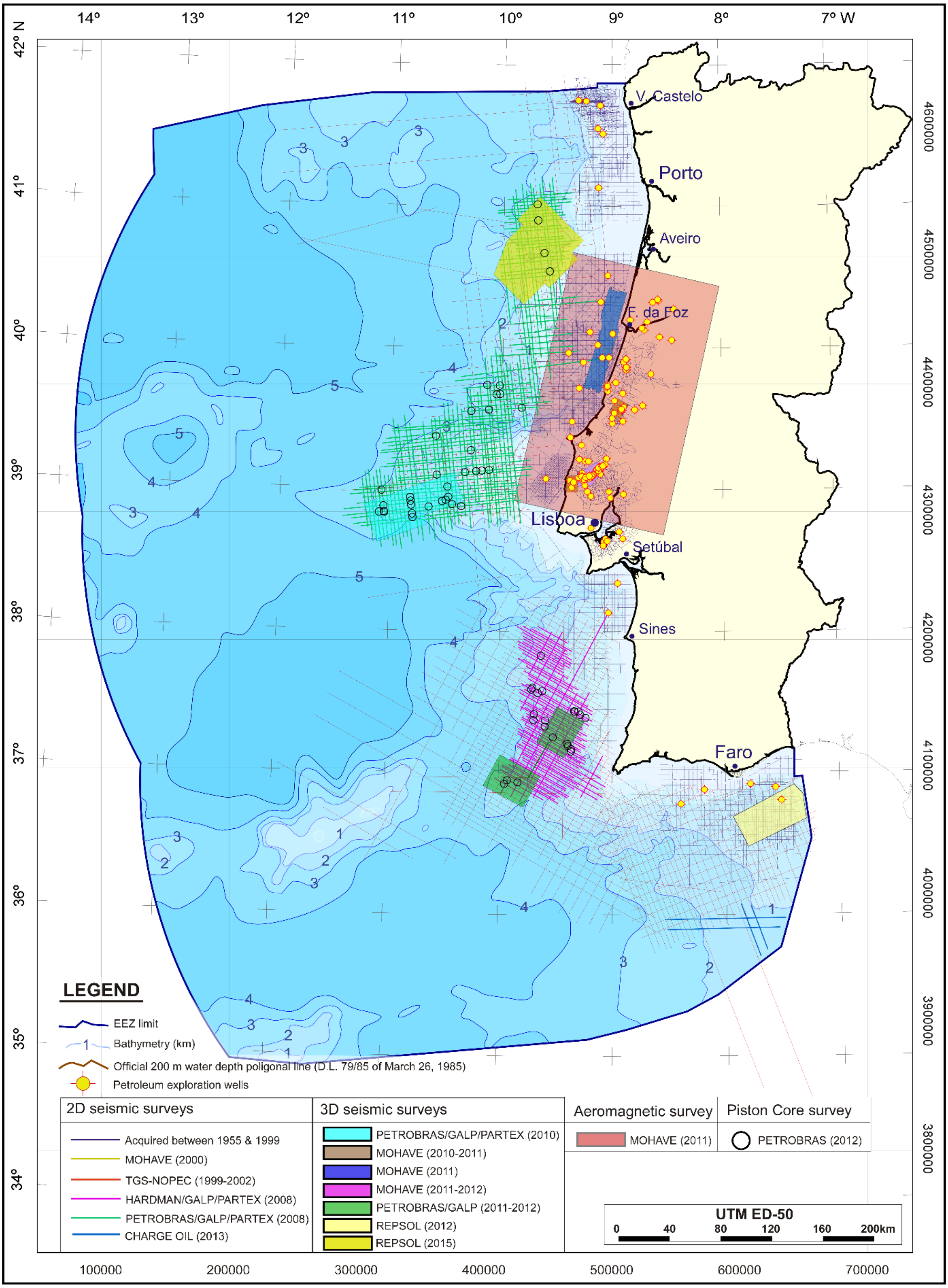
Appendix 1



14°
13°
12°
11°
10°
9°
8°
7° W
42° N
41°
40°
39°
38°
37°
36°
35°
34°
V. Castelo
Porto
Aveiro
F. da Foz
Lisboa
Setúbal
Sines
Faro
4600000
4500000
4400000
4300000
4200000
4100000
4000000
3900000
3800000
100000
200000
300000
400000
500000
600000
700000
LEGEND
EEZ limit
Bathymetry (km)
Official 200 m water depth poligonal line (D.L. 79/85 of March 26, 1985)
Petroleum exploration wells
2D seismic surveys
Acquired between 1955 & 1999
MOHAVE (2000)
TGS-NOPEC (1999-2002)
HARDMAN/GALP/PARTEX (2008)
PETROBRAS/GALP/PARTEX (2008)
CHARGE OIL (2013)
3D seismic surveys
PETROBRAS/GALP/PARTEX (2010)
MOHAVE (2010-2011)
MOHAVE (2011)
MOHAVE (2011-2012)
PETROBRAS/GALP (2011-2012)
REPSOL (2012)
REPSOL (2015)
Aeromagnetic survey
MOHAVE (2011)
Piston Core survey
PETROBRAS (2012)
UTM ED-50
0
40
80
120
160
200km

Appendix 2

TYPE
6th generation ultra deepwater drillship

DESIGN
Samsung

SHIPYARD
Samsung Heavy Industries

YEAR OF BUILT
2010

CLASSIFICATION
ABS ✠A1, Drilling unit, (E), ✠AMS, ✠ACCU, ✠CDS, ✠DPS-3, SH-DLA

FLAG
Bahamas

WATER DEPTH
Up to 12,000 ft (3,658 m)

DRILLING DEPTH
35,000 ft (10,660 m)

STATION KEEPING
DP class 3

MAIN DIMENSIONS
Length overall: 228 m
Breadth, moulded: 42 m
Depth, moulded: 19 m
Operating draft: 12 m
Displacement: 96,000 t

CAPACITY
Variable deck load: 20,000 t

POWER SYSTEM GENERATORS
Six (6) STX 16V32/40, 8,000 kW each approximate total power generation of 48,000 kW

THRUSTER
Six (6) azimuthal thrusters, 4,500 kW each

DERRICK
Double Derrick NOV
Height 200 ft
Static hook load 2,000,000 lbs each rig simultaneius capacity 2,000 kips + 1,000 kips

MOTION COMPENSATOR ON DERRICK
Each rig is equipped with Croen motion compensator and Active Heave compensator

DRAWWORK
Two (2) NOV SSGD-5750, 5,750 HP each

TOP DRIVE
Two (2) NOV HPS-03 1000 2AC KT RD, rated capacity 1,000 st
Maximum continuous torque 94,000 ft.lbs
Working Pressure 7,500 psi

ROTARY TABLE
One (1) NOV RST 755, opening 75.1/2",
rated capacity 1,000 st
One (1) NOV RST 605-2G, opening 60.1/2",
rated capacity 1,000 st

MUD PUMPS
Four (4) NOV 14-P-220
2,200 HP each
Fluid end working pressure 7,500 psi WP

MUD TANKS
Total capacity above 12,300 bbl

BOP
18.3/4" - 15,000 psi
Two (2) annular preventers
Six (6) ram cavities
Drill Pipe and Casing (up to 13.3/8") shearing capability

DIVERTER
20" - 500 psi

RISERS
21.1/12" OD, 90 ft length

CRANES
Four (4) NOV knuckle boom cranes, rated capacity 85 st

CREW FACILITIES
Air conditioned living quarters for 200 people

HELIDECK
Suitable for Sikorsky S-61 N

REMARKS
Two (2) NOV Vertical Column type capable to handle from 3.1/2" D.P. to 13.3/8" casing

IACMS: Integrated, automated control and monitoring system.
The drillship is designed to function as an integrated unit allowing all systems including propulsion, power management, power generation, fluid flow systems, fluid storage systems and drilling systems to be monitored and controlled via a single integrated monitoring and control network.

Equipped with EWT (Extended Well Testing)

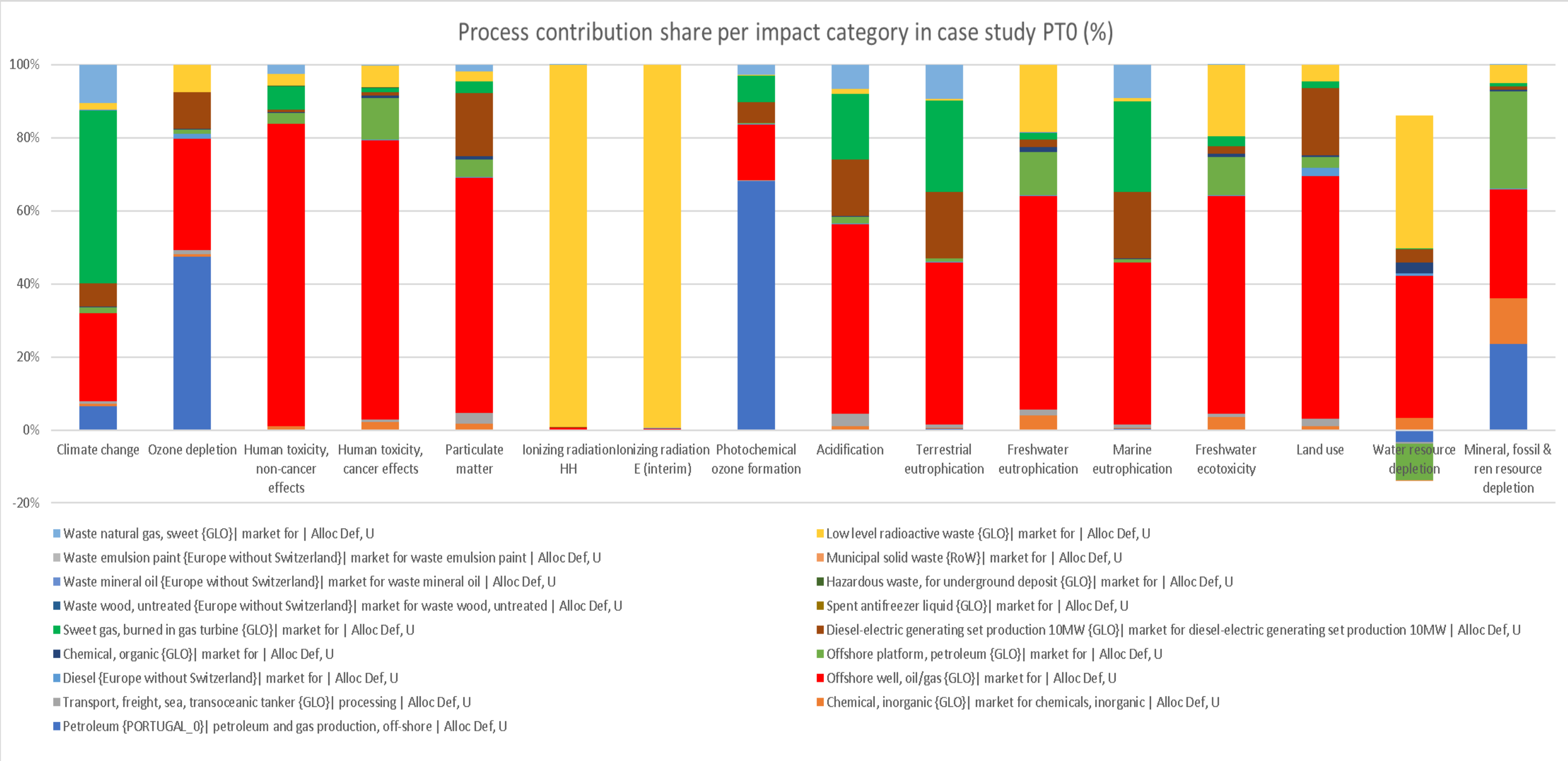
Appendix 3

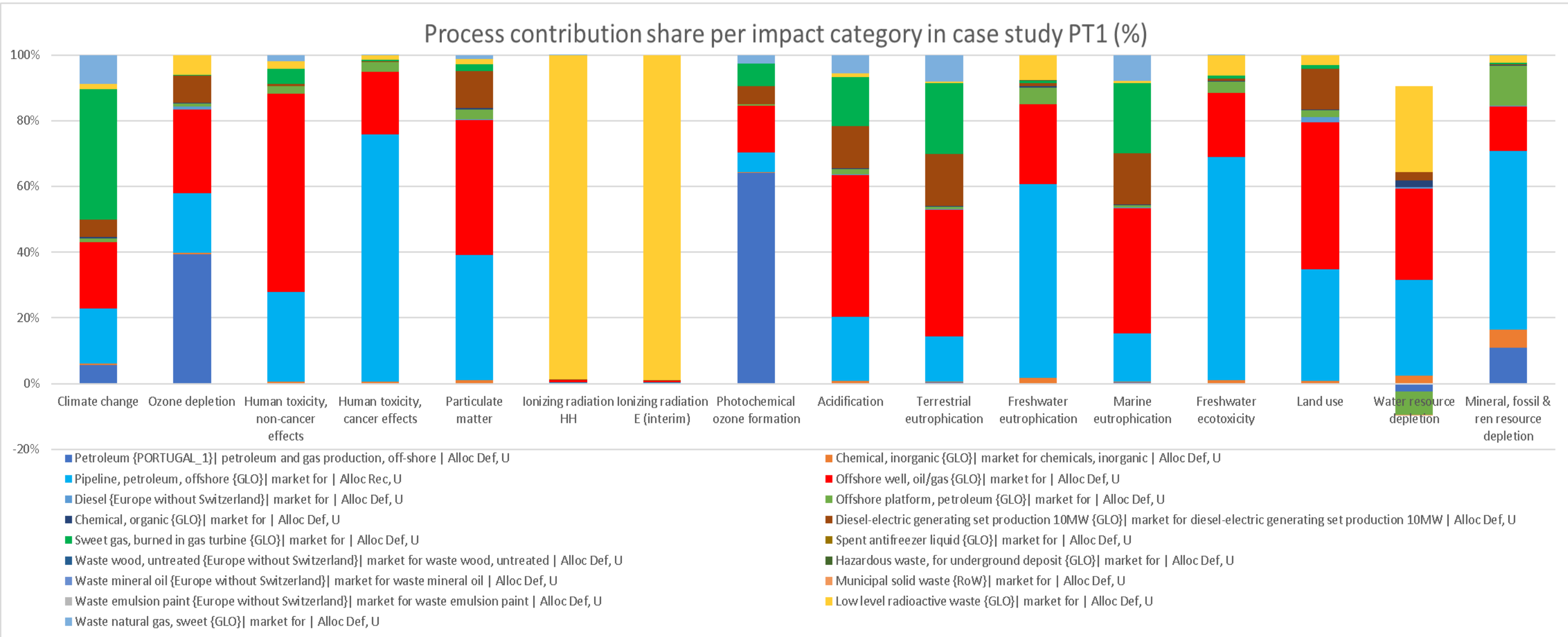
Impact category	Total	Petroleum {BRAZIL}| petroleum and gas production, off-shore | Alloc Def, U	Chemical, inorganic {GLO}| market for chemicals, inorganic | Alloc Def, U	Transport, freight, sea, transoceanic tanker {GLO}| market for | Alloc Def, U	Offshore well, oil/gas {GLO}| market for | Alloc Def, U	Diesel {RoW}| market for | Alloc Def, U	Offshore platform, petroleum {GLO}| market for | Alloc Def, U	Chemical, organic {GLO}| market for | Alloc Def, U	Diesel-electric generating set production 10MW {GLO}| market for diesel-electric generating set production 10MW | Alloc Def, U	Sweet gas, burned in gas turbine {GLO}| market for | Alloc Def, U	Spent antifreezer liquid {GLO}| market for | Alloc Def, U	Waste wood, untreated {Europe without Switzerland}| market for waste wood, untreated | Alloc Def, U	Hazardous waste, for underground deposit {GLO}| market for | Alloc Def, U	Waste mineral oil {Europe without Switzerland}| market for waste mineral oil | Alloc Def, U	Municipal solid waste {RoW}| market for | Alloc Def, U	Waste emulsion paint {Europe without Switzerland}| market for waste emulsion paint | Alloc Def, U	Low level radioactive waste {GLO}| market for | Alloc Def, U	Waste natural gas, sweet {GLO}| market for | Alloc Def, U
Climate change	0,066619695	0,004608644	0,000412227	0,002649949	0,011612288	8,3546E-05	0,00046208	0,00028634	0,004385072	0,03286208	3,23514E-07	8,61504E-08	7,183E-06	6,17427E-05	1,9483E-06	2,77652E-07	0,0018659	0,00732
Ozone depletion	7,87393E-09	3,82353E-09	5,73157E-11	4,23795E-10	1,72067E-09	1,0296E-10	3,891E-11	2,0783E-11	8,08297E-10	9,3301E-12	5,35165E-15	5,64929E-15	6,4858E-13	9,11272E-14	2,1147E-14	9,67695E-15	8,676E-10	0
Human toxicity, non-cancer effects	1,53987E-08	4,35126E-11	1,4694E-10	2,07948E-10	1,17347E-08	9,3967E-12	2,8514E-10	4,2391E-11	1,4455E-10	1,2966E-09	3,85934E-14	3,63943E-14	1,9139E-12	1,54315E-12	1,2343E-12	2,6914E-14	9,731E-10	5,097E-10
Human toxicity, cancer effects	1,75145E-09	1,01669E-12	4,81046E-11	7,74607E-11	1,23208E-09	2,5112E-12	1,1983E-10	1,1585E-11	2,50072E-11	2,6306E-11	8,36542E-15	1,59903E-15	1,7536E-12	7,4261E-13	7,0523E-14	6,53575E-15	2,007E-10	4,304E-12
Particulate matter	2,26515E-05	7,82482E-09	4,1094E-07	3,74785E-06	1,11409E-05	8,4988E-08	5,252E-07	2,0842E-07	4,31864E-06	7,9742E-07	2,35182E-10	2,10402E-11	9,1703E-09	3,31435E-09	1,0399E-10	5,67379E-11	9,303E-07	4,661E-07
Ionizing radiation HH	0,304605461	3,08212E-08	3,42708E-05	0,000241292	0,000746812	3,7112E-05	5,6238E-05	1,1551E-05	0,000292687	7,8482E-06	2,67068E-09	3,1744E-09	3,7712E-07	3,67556E-08	9,7464E-09	3,8029E-09	0,3031758	1,357E-06
Ionizing radiation E (interim)	2,13379E-06	0	1,29742E-10	1,26858E-09	4,43629E-09	2,5326E-10	1,9071E-10	4,5847E-11	1,98837E-09	1,5865E-11	1,48479E-14	1,62774E-14	1,7888E-12	1,59484E-13	5,3429E-14	1,67858E-14	2,125E-06	0
Photochemical ozone formation	0,001320469	0,00093295	1,19883E-06	2,19286E-05	0,000144248	5,1376E-07	1,9539E-06	1,0454E-06	7,76328E-05	9,8562E-05	4,02889E-10	2,19456E-10	4,058E-08	5,90856E-09	1,093E-09	2,20168E-10	4,16E-06	3,623E-05
Acidification	0,000396823	8,0199E-07	3,48237E-06	7,10766E-05	0,000146186	1,0085E-06	3,1057E-06	1,5028E-06	6,27342E-05	7,2227E-05	1,43197E-09	1,97556E-10	5,3029E-08	6,83089E-09	1,0569E-09	4,626E-10	7,899E-06	2,674E-05
Terrestrial eutrophication	0,001494714	4,61686E-06	5,46851E-06	7,44701E-05	0,000515505	1,1696E-06	6,8582E-06	2,5197E-06	0,000301936	0,0004127	1,03305E-09	7,13585E-10	1,1676E-07	2,71636E-08	4,1585E-09	7,34388E-10	1,54E-05	0,0001539
Freshwater eutrophication	4,11461E-06	0	1,79813E-07	3,82087E-07	1,84503E-06	9,9451E-09	2,4136E-07	5,8435E-08	9,57932E-08	8,4967E-08	8,3391E-11	5,25989E-12	3,4165E-09	4,03255E-09	7,0904E-11	2,57388E-11	1,21E-06	0
Marine eutrophication	0,000136731	4,32442E-07	4,29943E-07	6,60755E-06	4,71165E-05	1,0875E-07	6,5975E-07	2,1381E-07	2,75881E-05	3,7693E-05	1,06178E-10	3,39196E-10	1,0984E-08	2,18521E-09	4,3154E-10	6,98079E-11	1,812E-06	1,406E-05
Freshwater ecotoxicity	0,106492306	2,16589E-07	0,004215541	0,005490998	0,050126565	0,00020405	0,00562439	0,00124943	0,002379087	0,00318179	6,84569E-07	8,15227E-07	6,012E-05	3,71794E-05	0,00010733	5,72996E-07	0,0338062	7,332E-06
Land use	0,053062376	0	0,000637014	0,006058928	0,02783916	0,0014123	0,00078631	0,00023109	0,011076774	0,00106468	2,86483E-07	2,05088E-07	3,1761E-05	1,44899E-06	4,642E-07	1,77059E-07	0,0039218	0
Water resource depletion	1,54629E-05	-6,56223E-07	6,4131E-07	-4,64403E-07	5,25484E-06	8,4605E-08	-8,696E-07	5,6357E-07	7,03631E-07	2,3279E-08	4,35269E-13	3,55465E-11	3,9164E-09	-7,61141E-10	-4,159E-10	4,35117E-10	1,018E-05	0
Mineral, fossil & ren resource depletion	1,09606E-06	3,30039E-07	1,70712E-07	8,92962E-09	2,87621E-07	1,1099E-09	1,6636E-07	6,6868E-09	1,06509E-08	1,253E-08	3,87531E-13	1,29116E-12	3,3588E-10	2,74714E-11	2,1941E-11	2,62126E-12	1,001E-07	8,882E-10

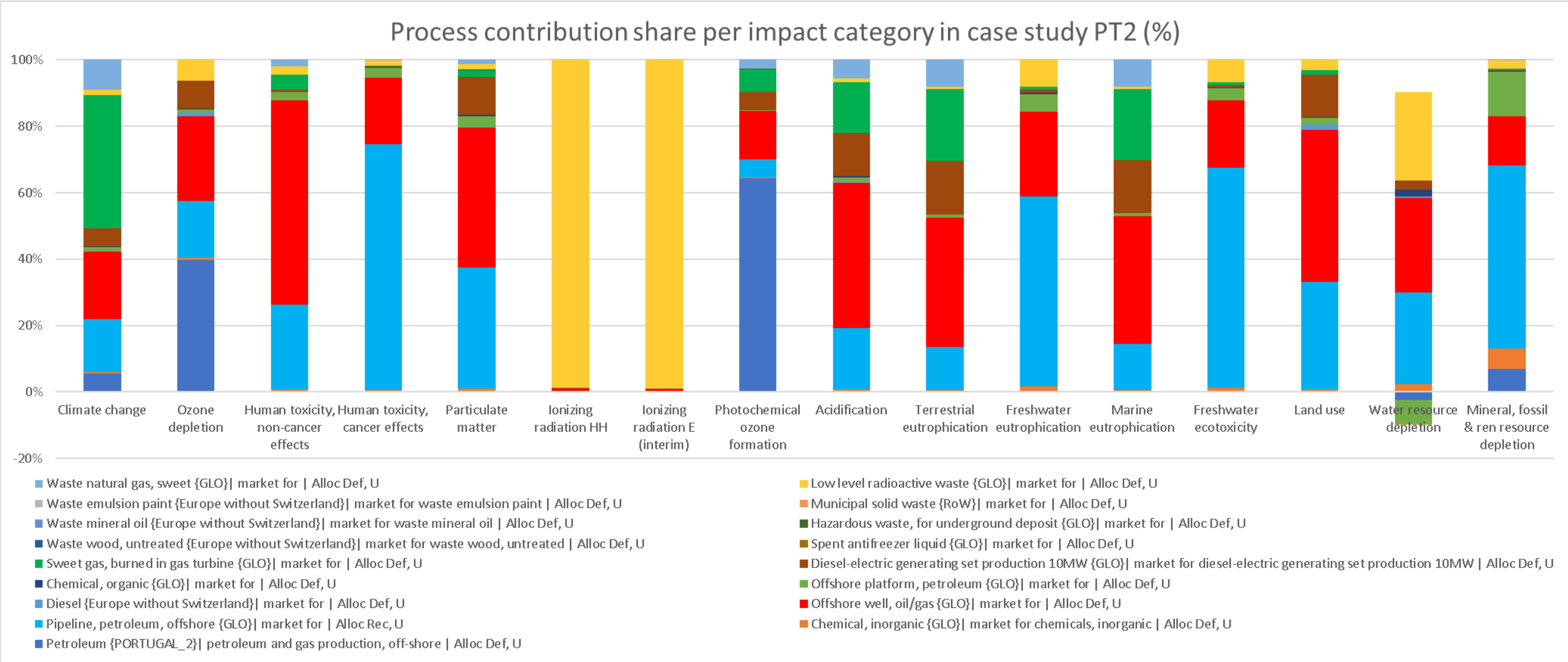
Appendix 4

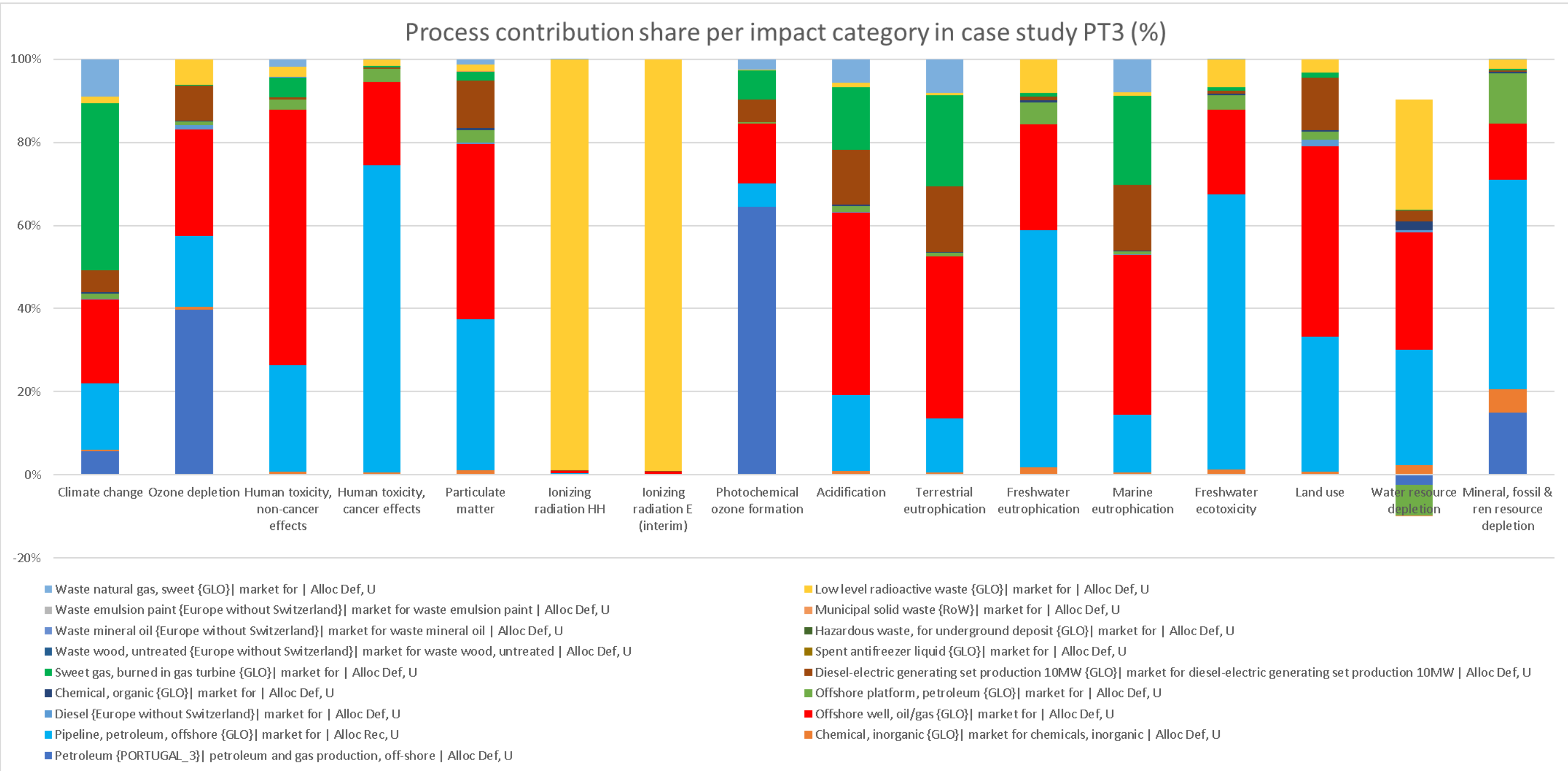
Impact Category	Brazil	PT0	PT1	PT2	PT3
Climate change	0,066619695	0,070396336	0,08398713	0,138331036	0,059284754
Ozone depletion	7,87393E-09	8,16559E-09	9,8697E-09	1,62408E-08	6,96034E-09
Human toxicity, non-cancer effects	1,53987E-08	2,062E-08	2,82203E-08	4,61421E-08	1,97752E-08
Human toxicity, cancer effects	1,75145E-09	2,33675E-09	9,40526E-09	1,48489E-08	6,36383E-09
Particulate matter	2,26515E-05	2,51357E-05	3,93587E-05	6,3851E-05	2,73647E-05
Ionizing radiation HH	0,304605461	0,214424853	0,215274231	0,358684643	0,153722426
Ionizing radiation E (interim)	2,13379E-06	1,50128E-06	1,50573E-06	2,509E-06	1,07529E-06
Photochemical ozone formation	0,001320469	0,001372731	0,001454501	0,002414115	0,001034621
Acidification	0,000396823	0,000409646	0,000490811	0,000806891	0,000345811
Terrestrial eutrophication	0,001494714	0,001683418	0,001936155	0,003195699	0,001369586
Freshwater eutrophication	4,11461E-06	4,58808E-06	1,09843E-05	1,75519E-05	7,52226E-06
Marine eutrophication	0,000136731	0,000154057	0,000179279	0,000295701	0,000126729
Freshwater ecotoxicity	0,106492306	0,121811432	0,375863008	0,596669031	0,25571577
Land use	0,053062376	0,060775835	0,090381845	0,147040778	0,063017539
Water resource depletion	1,54629E-05	1,41468E-05	2,22252E-05	3,61102E-05	1,54758E-05
Mineral, fossil & ren resource depletion	1,09606E-06	1,39946E-06	3,0605E-06	4,6868E-06	2,19722E-06

Appendix 5


Process contribution share per impact category in case study PT0 (%)
100%
80%
60%
40%
20%
0%
-20%
Climate change
Ozone depletion
Human toxicity, non-cancer effects
Human toxicity, cancer effects
Particulate matter
Ionizing radiation HH
Ionizing radiation E (interim)
Photochemical ozone formation
Acidification
Terrestrial eutrophication
Freshwater eutrophication
Marine eutrophication
Freshwater ecotoxicity
Land use
Water resource depletion
Mineral, fossil & ren resource depletion
Waste natural gas, sweet {GLO}| market for | Alloc Def, U
Low level radioactive waste {GLO}| market for | Alloc Def, U
Waste emulsion paint {Europe without Switzerland}| market for waste emulsion paint | Alloc Def, U
Municipal solid waste {RoW}| market for | Alloc Def, U
Waste mineral oil {Europe without Switzerland}| market for waste mineral oil | Alloc Def, U
Hazardous waste, for underground deposit {GLO}| market for | Alloc Def, U
Waste wood, untreated {Europe without Switzerland}| market for waste wood, untreated | Alloc Def, U
Spent antifreezer liquid {GLO}| market for | Alloc Def, U
Sweet gas, burned in gas turbine {GLO}| market for | Alloc Def, U
Diesel-electric generating set production 10MW {GLO}| market for diesel-electric generating set production 10MW | Alloc Def, U
Chemical, organic {GLO}| market for | Alloc Def, U
Offshore platform, petroleum {GLO}| market for | Alloc Def, U
Diesel {Europe without Switzerland}| market for | Alloc Def, U
Offshore well, oil/gas {GLO}| market for | Alloc Def, U
Transport, freight, sea, transoceanic tanker {GLO}| processing | Alloc Def, U
Chemical, inorganic {GLO}| market for chemicals, inorganic | Alloc Def, U
Petroleum {PORTUGAL_0}| petroleum and gas production, off-shore | Alloc Def, U


Process contribution share per impact category in case study PT1 (%)
100%
80%
60%
40%
20%
0%
-20%
Climate change
Ozone depletion
Human toxicity, non-cancer effects
Human toxicity, cancer effects
Particulate matter
Ionizing radiation HH
Ionizing radiation E (interim)
Photochemical ozone formation
Acidification
Terrestrial eutrophication
Freshwater eutrophication
Marine eutrophication
Freshwater ecotoxicity
Land use
Water resource depletion
Mineral, fossil & ren resource depletion
Petroleum {PORTUGAL_1}| petroleum and gas production, off-shore | Alloc Def, U
Chemical, inorganic {GLO}| market for chemicals, inorganic | Alloc Def, U
Pipeline, petroleum, offshore {GLO}| market for | Alloc Rec, U
Offshore well, oil/gas {GLO}| market for | Alloc Def, U
Diesel {Europe without Switzerland}| market for | Alloc Def, U
Offshore platform, petroleum {GLO}| market for | Alloc Def, U
Chemical, organic {GLO}| market for | Alloc Def, U
Diesel-electric generating set production 10MW {GLO}| market for diesel-electric generating set production 10MW | Alloc Def, U
Sweet gas, burned in gas turbine {GLO}| market for | Alloc Def, U
Spent antifreezer liquid {GLO}| market for | Alloc Def, U
Waste wood, untreated {Europe without Switzerland}| market for waste wood, untreated | Alloc Def, U
Hazardous waste, for underground deposit {GLO}| market for | Alloc Def, U
Waste mineral oil {Europe without Switzerland}| market for waste mineral oil | Alloc Def, U
Municipal solid waste {RoW}| market for | Alloc Def, U
Waste emulsion paint {Europe without Switzerland}| market for waste emulsion paint | Alloc Def, U
Low level radioactive waste {GLO}| market for | Alloc Def, U
Waste natural gas, sweet {GLO}| market for | Alloc Def, U


Process contribution share per impact category in case study PT2 (%)
100%
80%
60%
40%
20%
0%
-20%
Climate change
Ozone depletion
Human toxicity, non-cancer effects
Human toxicity, cancer effects
Particulate matter
Ionizing radiation HH
Ionizing radiation E (interim)
Photochemical ozone formation
Acidification
Terrestrial eutrophication
Freshwater eutrophication
Marine eutrophication
Freshwater ecotoxicity
Land use
Water resource depletion
Mineral, fossil & ren resource depletion
Waste natural gas, sweet {GLO}| market for | Alloc Def, U
Waste emulsion paint {Europe without Switzerland}| market for waste emulsion paint | Alloc Def, U
Waste mineral oil {Europe without Switzerland}| market for waste mineral oil | Alloc Def, U
Waste wood, untreated {Europe without Switzerland}| market for waste wood, untreated | Alloc Def, U
Sweet gas, burned in gas turbine {GLO}| market for | Alloc Def, U
Chemical, organic {GLO}| market for | Alloc Def, U
Diesel {Europe without Switzerland}| market for | Alloc Def, U
Pipeline, petroleum, offshore {GLO}| market for | Alloc Rec, U
Petroleum {PORTUGAL_2}| petroleum and gas production, off-shore | Alloc Def, U
Low level radioactive waste {GLO}| market for | Alloc Def, U
Municipal solid waste {RoW}| market for | Alloc Def, U
Hazardous waste, for underground deposit {GLO}| market for | Alloc Def, U
Spent antifreezer liquid {GLO}| market for | Alloc Def, U
Diesel-electric generating set production 10MW {GLO}| market for diesel-electric generating set production 10MW | Alloc Def, U
Offshore platform, petroleum {GLO}| market for | Alloc Def, U
Offshore well, oil/gas {GLO}| market for | Alloc Def, U
Chemical, inorganic {GLO}| market for chemicals, inorganic | Alloc Def, U


Process contribution share per impact category in case study PT3 (%)
100%
80%
60%
40%
20%
0%
-20%
Climate change
Ozone depletion
Human toxicity, non-cancer effects
Human toxicity, cancer effects
Particulate matter
Ionizing radiation HH
Ionizing radiation E (interim)
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Waste wood, untreated {Europe without Switzerland}| market for waste wood, untreated | Alloc Def, U
Sweet gas, burned in gas turbine {GLO}| market for | Alloc Def, U
Chemical, organic {GLO}| market for | Alloc Def, U
Diesel {Europe without Switzerland}| market for | Alloc Def, U
Pipeline, petroleum, offshore {GLO}| market for | Alloc Rec, U
Petroleum {PORTUGAL_3}| petroleum and gas production, off-shore | Alloc Def, U
Low level radioactive waste {GLO}| market for | Alloc Def, U
Municipal solid waste {RoW}| market for | Alloc Def, U
Hazardous waste, for underground deposit {GLO}| market for | Alloc Def, U
Spent antifreezer liquid {GLO}| market for | Alloc Def, U
Diesel-electric generating set production 10MW {GLO}| market for diesel-electric generating set production 10MW | Alloc Def, U
Offshore platform, petroleum {GLO}| market for | Alloc Def, U
Offshore well, oil/gas {GLO}| market for | Alloc Def, U
Chemical, inorganic {GLO}| market for chemicals, inorganic | Alloc Def, U