# POLITECNICO DI TORINO

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# Modelling the energy risk of oil supply to Italy


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## Abstract

The Italian energy mix is still heavily dependent on fossil fuels, especially natural gas and crude oil. However, the domestic production of oil and gas are scarce and insufficient to cover the demand, therefore almost the totality of fossil fuel has to be imported. This makes Italy one of the most energy dependent country in Europe, with an import dependency of 77%, and the assessment of the supply energy security becomes a crucial aspect. The national energy security is referred to two fronts: the internal front and the external front. The internal front is related with the domestic availability of energy resources and the resilience of the transmission and distribution system, the second one with the security of the corridors through which the energy commodities reach the Italian entry points. The present thesis is focused on the analysis of crude oil and oil products, which account for 33,8% of the total primary energy supply and for 38,2% of the final energy consumption of the country. The aim of the work is to develop a novel modelling approach for quantitatively evaluate the national external energy security, able to support the policy-decision making by assessing the impacts of possible contingencies and the mid/long-terms effects of alternative strategies. For this purpose, an overall analysis of the oil trade is performed by identifying all the supply corridors (open-sea routes and oil pipelines) and by tracking the oil flows from the sources (oil fields) to the national entry points. A database has been built, based on a complete mapping of the oil fields in terms of location, available reserves and annual production and classification of crude oil types, on the technical characterisation of the transport infrastructures (like capacity, length, pressure and diameter of oil pipelines, deadweight tonnage and actual intake of oil tankers, number and time duration of maritime voyages) and on the identification of the Italian entry points. Moreover, ad hoc metrics and integrated indicators have been defined in order to provide an overall measure of the security level, taking into account the international geopolitical situation and the spatial dimension of the energy corridors (including the corridor length, the geopolitical security of the crossed countries and the possible presence of chokepoints and piracy phenomenon). The developed methodology considers a multi-layered risk analysis able to provide a complete overview of the interconnection between geopolitical and energy aspects of the Italian oil supply, taking into account the energy spatial dimension. Several scenarios are implemented and analysed in order to assess the impacts of possible events such as the unavailability of a given infrastructure or the increasing of geopolitical tensions, on the national energy security.

# Contents

# 1. Introduction

The thesis is the result of the collaboration with Eleonora Desogus, student of the Polytechnic of Torino enrolled in the master course of Environmental Protection engineering. The dialogue between the Environmental and the Energy field have allowed to deeply analysed the energy risk of oil supply to Italy under multiple points of view. Moreover, the union of different interests and personal sensibility about the issues we have approached during the work has contributed to the development of a unique product. In particular the collaboration has focused upon the initial characterisation of the Italian oil market and afterward on the theoretical development of the security model. Eleonora, through her experience with GIS software, have managed the geomatics characterization of the oil trade and the selection and analysis of the model input data. On the other hand, I have managed the energy characterization of the oil trade and the model data processing. Once having built the model, each of us have applied it through the analysis of different scenarios reaching separately conclusions. Finally, it should be point out that the general framework of the two thesis is developed according to our personal master course. Eleonora have analysed the role of oil from the point of view of the energy transition whereas I have focused my attention specifically on the energy involved in the oil trade.

## 1.1. Oil role in the global context

Global energy demand continuously increases due to the global improvement of economics condition that is mainly driven by the emerging economies. Indeed, according to Energy Information Administration (EIA), during the last 10 years the primary energy consumption have increased of 6% reaching 105 Mtoe in 2019 and is expected to rise nearly 50% until 2050 [1]. The growth is caused by the non-OECD countries where the strong economic development, the increased access to energy and the high level of birth rate lead to the rising of energy demand. It is expected that Asian developing countries accounts for the two third of the increase in global energy consumption [2]. On the other hand, the developed countries, thanks to the improvements in the energy efficiency and the less growth in energy-intensive industries, will experience a slightly increase of energy consumption. Nowadays, Europe and North America account for the 40% of the global energy demand and the developing economy around 20%. However, according to the descripted trend by EIA, in 2050 the situation should completely reverse. The fossil fuel still dominates the 2019 global energy mix: coal, oil and natural gas account respectively for 11.3%, 32% and 36% [3]. Even if the renewable consumption is spreading thanks to the green policies promoted by the international agreements, their growth is counterbalance by fossil demand of developing countries which cannot afford with expensive investments in sustainable energy production. In particular the oil represents the largest share in the primary energy consumption and will maintain a domination role for many years in future: according to the statistics, in 2050 oil will still account for the 25% [1]. Even if the oil share in the global energy mix will decrease in the next 30 years, the exceptional increasing of the primary energy consumption involves a rising in oil demand in absolute value (+20% in 2050).

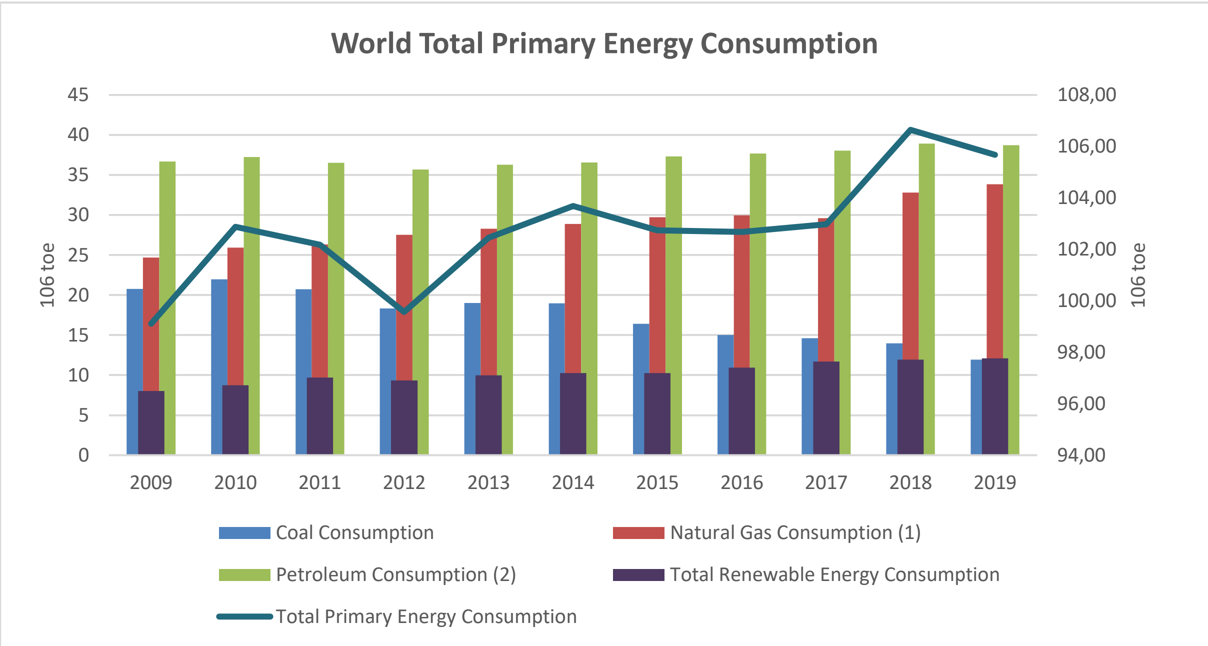


*Figure 1 - World Primary energy consumption (Source: Elaboration based on [3])*

(1)(Excluding Supplemental Gaseous Fuels)

(2) (Excluding Biofuels)

The central role to which the oil is intended is possible because of the great availability of reserve. Although the oil had been exploited for more than 150 years new proven reserves are being discovering because of the novel exploration technologies and the improving of the extraction methods. Since 2009, the proven reserve has increased of 17% reaching 1550 billion of barrel in 2019. Nevertheless, oil reserves are unevenly distributed: Middle East owns more than 48% of total crude reserves and Latin America accounts almost 19% [4]. This aspect deeply affects the price and the oil trade making many countries strong importers of crude due to the lack of local reserves. All the major European countries are substantially devoid of oil reserves and the large share of the imported oil comes from Russia, Kazakhstan and Middle East countries.

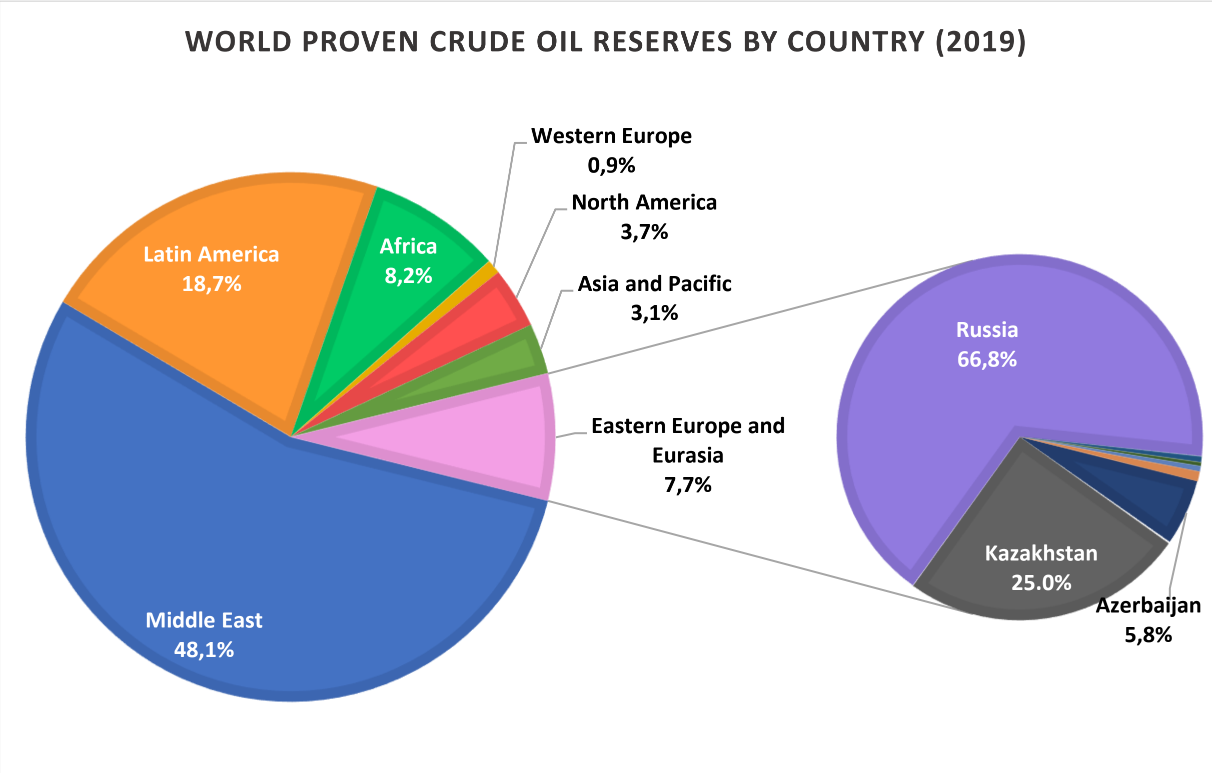


*Figure 2 - World crude oil reserves (Source: Elaboration based on [5])*

The presence of proven reserves is a necessary but not a sufficient condition in order to be an important oil producer. Indeed, also the presence of a sufficiently developed extraction and transport infrastructure are required. The Latin America is an explicative case study: it accounts for the 19% of the total oil reserve but its general underdevelopment does not allow it to be on the same level as USA, Russia, and Saudi Arabia that account for the 40% of the global oil production [1]. The reserve to production ratio (R/P) is a representative index of the described situation because assess the depletion of the oil reserves at the present extraction rate. The global R/P ratio is around 50 years according to British petroleum statistical review [4]. Regionally, South & Central America has the highest R/P ratio (136 years) while Europe has the lowest (11 years) [4]. The highest value of the South and Central America R/P depends on the political instability and the infrastructure underdevelopment of the region that imply a low extraction rate. Instead the middle east, that is characterized by the highest amount of proven reserve, has a R/P equal to 70 years since the production rate is high.

The unevenly oil reserves distribution lead to the transformation of the transnational and intercontinental energy flow in a complex network that couple the production and the consumers countries. The link is represented by a corridor that can be open-sea (i.e. oil tankers) and/or captive (i.e., railways, pipelines). In 2019, approximately 2239 million of crude oil tons have been transported all around the world [4]. Europe, with an overall 522 million of tons imported is the first market of the world immediately followed by the China with 507 million of tons. The main exporters are the Middle East region countries and Russia that account for more the half of total oil trade. It is clear how the issue of corridor security has become a priority, in particular for the regions which are characterized by a great import of a specific commodity, in order to guarantee the national security.

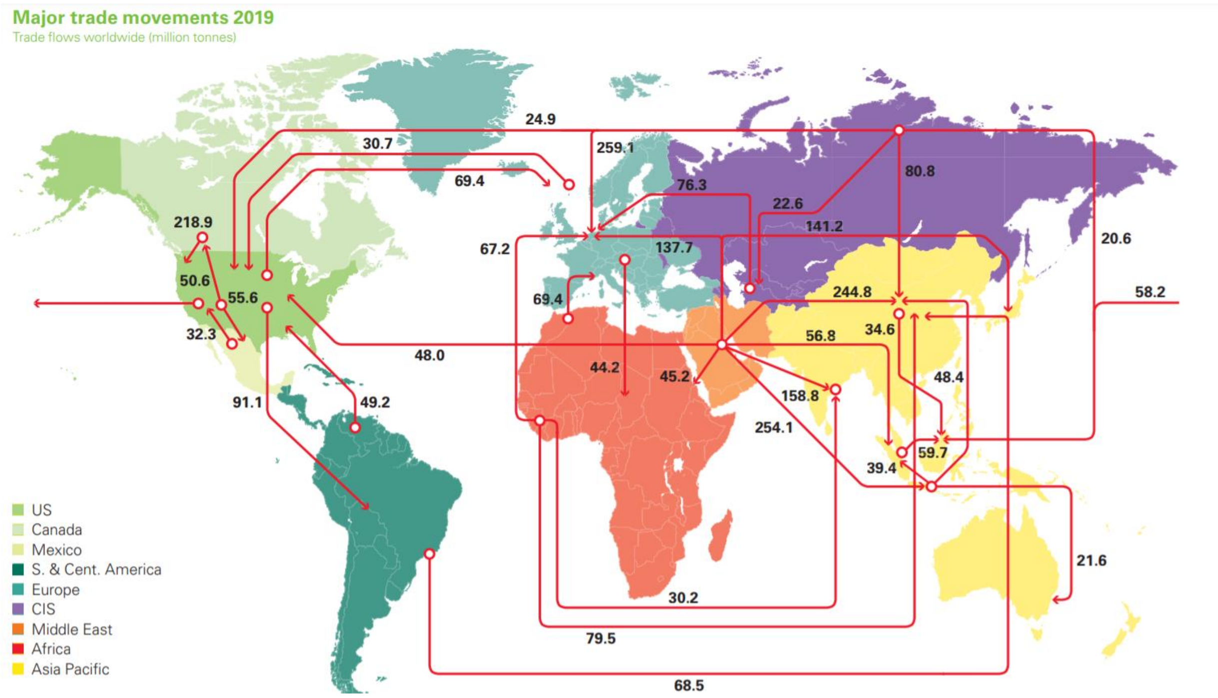


*Figure 3 - International Oil trade (Source: [4])*

## 1.2. Aim of the thesis: analysis of supply oil security in Italy

The national energy security can be defined as the ability to ensure, at affordable prices, availability of the different energy commodity needed to meet the demand for the end users. Therefore, for the countries characterized by high level of import, the reliability of the energy supply must be guarantee by strategical government measures. The political decision-making process is very hard because energy systems are complex and dynamic. Therefore science-based models must be implemented in order to provide a useful tool able to suggest the best political choices to global governments. The key point is that policy, supported by scientific evidence, allow to evaluate the current situation and to estimate the impact of different decisions and alternative options. This tool can be provided by the adaptation of the classical risk analysis, used in the industrial and technological field, for the assessment of the national energy security supply. The novel approach wants to model a multi-layered risk analysis able to provide a complete vision of the interconnection between geomatics, geopolitical and energy aspects.

The methodology application is particularly interesting for the Italian context given that the level of oil foreign dependency is really high. Therefore, assessing the level of energy supply security become a central theme for the Italian government. The aim of this thesis is to develop a science-based approach able to develop a model which produces an overall energy risk indicator that reflects the actual national energy security. The construction of the model starts from a detailed characterization of the Italian oil market focusing the attention on the corridor through which oil reaches the national borders. The analysis of the infrastructure involved in the oil trade, the tracking of the oil energy flow and the international geopolitical situation poses solid basis that allow the model to takes into account all the most critical parameters. The model provides a quantitative assessment of the Italian energy security in terms of energy loss that represents the energy at risk related to each corridor. The results are easily comprehensible for policy decision-makers and are able to give a complete snapshot about the national oil trade. Finally, the model is also used to assess the impact of possible events such as the unavailability of a given infrastructure or the increasing of geopolitical tensions, on the national energy security and the mid-long-term effects of alternative energy strategies.

## 1.3. Outline of the thesis

In chapter 1, the global energy context is described with a particular focus regarding the role of oil and an overview on the oil reserves and the international trade. The aim of the thesis is explained together with the presentation of the science-based model for quantitative energy security assessment.

Chapter 2 describes the main data providers consulted, underling and justifying the mutual differences. Afterward, a general introduction about the national energy mix, the national oil trade and infrastructure are provided through the conscious use of the source of information. A particular attention is reserved for the analysis of the oil market diversification index (Shannon index) that is a crucial parameter for the national energy security.

Chapter 3 introduce the fundamental basic figures of the risk analysis (probability of failure and consequences) and their application on the national energy security assessment. The concepts of maritime and captive corridor probability of failure are defined together with the identification of the main parameters that can affects each of the two. The logical relations between the elements considered are specified, through the development of the Fault Tree, and the overall mathematical formulation of the failure probability is obtained. Afterward, the corridors are characterized from the energy point of view and the model for quantitative energy security assessment is completed. Finally, the criticalities encountered along the model construction are underlined together with the development of the resolutive assumptions.

In chapter 4, the model is applied firstly to the present (reference scenario: 2019) national oil trade assessing the energy at risk, secondly to realistic scenarios with the aim to forecast possible hazardous events occurrence that can compromise the security of the Italian oil corridor. The scenario settings are defined and the results are compared respect to the reference scenario.

The chapter 5 contains the conclusion of the thesis underling the strength but also the weakness of the model. Finally, several suggestions are proposed in order to improve the model by taking into account also the economical aspect and an optimization algorithm.

# 2. Data collection and analysis

The oil trade characterization process turned out not to be feasible with open-source data alone. First of all because usually the nations are reluctant to share information about the internal infrastructure fearing for their energy security. Moreover, the oil that reaches the Italian entry point is handled both by oil tankers and oil pipelines giving to the system a higher level of dynamism respect to other commodities (such as the electricity or the natural gas that required fixed infrastructure) that consequently increases its complexity. Indeed, the maritime routes are flexible and can be subjected to rapidly variation according to external events. Differently from a pipeline, the pathway of an oil tanker can be modified during the trip or in case of deterioration of trade relation with a trading partner it is possible to compensate the loss of energy by changing the exporting port maintaining always the same infrastructure. The purchasing of several datasets has been required in order to better characterized the dynamicity of the oil system. It is necessary to underline that the data collection is only the starting point of the work: a further process of data analysis has to be performed. Indeed, very often, the data providers present some contradiction and differences that have to be justify and solved with reasoned assumptions.

## 2.1. Dataset and data validation

The main open source data providers are the "Ministero dello Sviluppo Economico" (MiSE) and the "Unione Petrolifera" (UP) that furnish information about the national oil and oil products trade and the refineries activities. Despite the authority of the two institutions several mismatching between the data can be observed in particular regarding the amount of imported commodity. The disagreement can be explained by the different nature of the institutions. MISE is a government department to which all the entities involved in the oil trade have to periodically send their data through the compilation of the so called "bollettini petroliferi". On the other hand, UP is a trade-union association that brings together the main oil companies but does not cover the overall system and moreover does not have the authorities to claim the information from the members. Nevertheless, through the analysis of oil sector experts it is able to provide reliable yearly report with a great added value in particular in the oil transformation field and in the logistic distribution. The data granularity offered by MISE and UP is not sufficient to assess the national energy security because the information about the oil trade are aggregated by country of origins without taking into account the pathway followed. Therefore, MISE and UP are only used to characterized the Italian energy context (chapter 2.2. National Energy mixand chapter 2.3. Oil trade).

The lack of detail in the open source data providers is compensated by the purchasing of Alphatanker and "Energy Web Atlas" (EWA) that are able to frame respectively the maritime routes followed by the oil tankers and the pipelines system. Alphatanker is a dataset that contains all the commercial maritime routes with a very high level of granularity. Each oil tanker's travel is characterized by a set of information that allow to perform a very detailed analysis both from energy and geomatic point of view (i.e. pathway, load/discharge port, vessel DWT, amount of commodity transported, sea duration etc). The data about each individual vessel are useless alone because do not provide a comprehensive overview of the maritime oil trade. Therefore, a two-step bottom-up approach has been used to reduce the granularity level:

1) The single travel is grouped in the corresponding maritime corridor: foreign load port - Italian discharged port
2) The corridors are grouped for exporting country: foreign load country - Italy

The process is partially automatized by a MATLAB code (APPENDIX C: CHARACTERIZATION OF ITALIAN OIL INFRASTRUCTURE). The first step is necessary to perform the risk analysis considering the main maritime corridors that reach the Italian entry point (chapter 3). The second one allows to obtain aggregated data comparable with the granularity of MISE and UP dataset. The graph and the table show the results of the comparison both in term of single exporting country and of total amount of commodity imported.

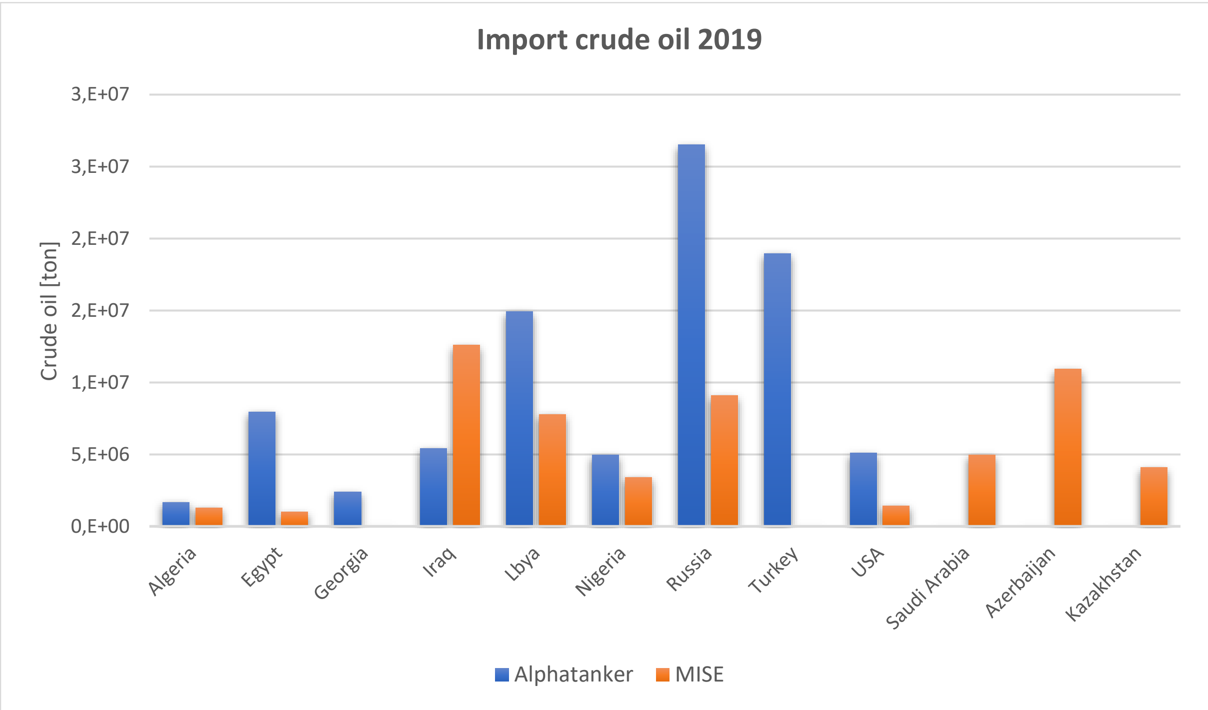


*Figure 4 - Alphatanker and MISE comparison (Source: Elaboration based on [6] and [7] )*

The difference between the two data providers are huge and can be justified by two considerations:

- Alphatanker: reports the amount of commodities load from an exporting port and discharged on the Italian soil;
- MISE: reports only the commodities imported and therefore purchased by Italy from a specific production country;

Consequently, Alphatanker takes into account also the commodities that transit through Italy and that are subsequently exported (therefore not considered by the MiSE). Furthermore, the differences are accented by the fact that some production countries do not have direct access to the sea or do not have sufficient maritime infrastructure, thus they rely on third-country for the exportation. Become of primary importance the characterisation of the oil pipeline infrastructure in order to understand the connection between exporting and production counties. A research about the oil pipelines data provider leads to the identification of EWA as the best products on the market. The analysis of the main pipelines system allows to explain the value reported in Figure 4. For example, since Azerbaijan and Kazakhstan do not have direct access to the Mediterranean Sea, they export the extracted crude oil through the Russian, Georgian and Turkish ports thanks to several captive corridors. In chapter 3.3 the main oil pipelines systems are described and the difference will be justified.

Finally, it is a discrepancy in the nomenclature used by Alphatanker and MiSE regarding the oil products have been detected. A bibliographical research has underlined the lack of an international standard in the identification of the oil product with a specific code therefore, each institution has developed a personal classification. The association between Alphatanker and MiSE is carried out by comparing the properties of the various products such as the distillation temperature, viscosity and field of use with reference to the IPCC guideline for national greenhouse gas inventory [8] and the MiSE "Questionario sul petrolio" [9].

*Table 1 - Classification of oil products (Source: Elaboration based on [7] and [9])*

| ***Terminology*** | | |
|---|---|---|
| *Alphatanker terminology* | *MiSE code* | *MiSE terminology* |
| Ultra low sulfur diesel | *D0* | Benzine |
| Unleaded motor spirit | | |
| Diesel | *F0* | Gasoli |
| Gas oil | | |
| Asphalt and bitumen | *I0* | Bitumi |
| Jet fuel | *E0* | Petroli |
| LPG | *C0* | GPL |
| Naphta | *R1* | Virgin Nafta |
| Fuel oil | *G0* | Olio combustibile |
| Crude oil | *A0* | Greggio |

## 2.2. National Energy mix

According to MiSE statistics Italy's primary energy consumption is driven by oil and natural gas. The remaining shares are coal, net import of electricity and renewable sources. As a consequence, Italy is a net importer of both crude and natural gas and this aspect strongly affects its energy security. The historical data of the Italian total primary energy supply (TPES) highlights that fossil fuels still dominate the energy mix accounting for the 70% of which 34% of oil, 34.5 % of natural gas and 5.4% of solid fuel [10]. Italy, as a UE member, strives to promote measures to increase the share of sustainable renewable energy sources in the energy mix but the transition process from fossil fuels to renewable resources will be very gradual and will require many years. As shown in Figure 5 in the last 10 years the Italian fossil fuels consumption is progressively reduced. In particular oil decreased from 80 million of toe in 2008 to less than 60 million of toe in 2018. Renewable resources have increased their share in Italy's energy consumption from less than 9% in 2008 to over 20% in 2018. Even though the renewable sources show an increasing trend, actually oil maintains a central role in the Italian energy mix such as natural gas. Therefore, the assessment of the oil security supply still represents a critical point for the Italian government in the next future.

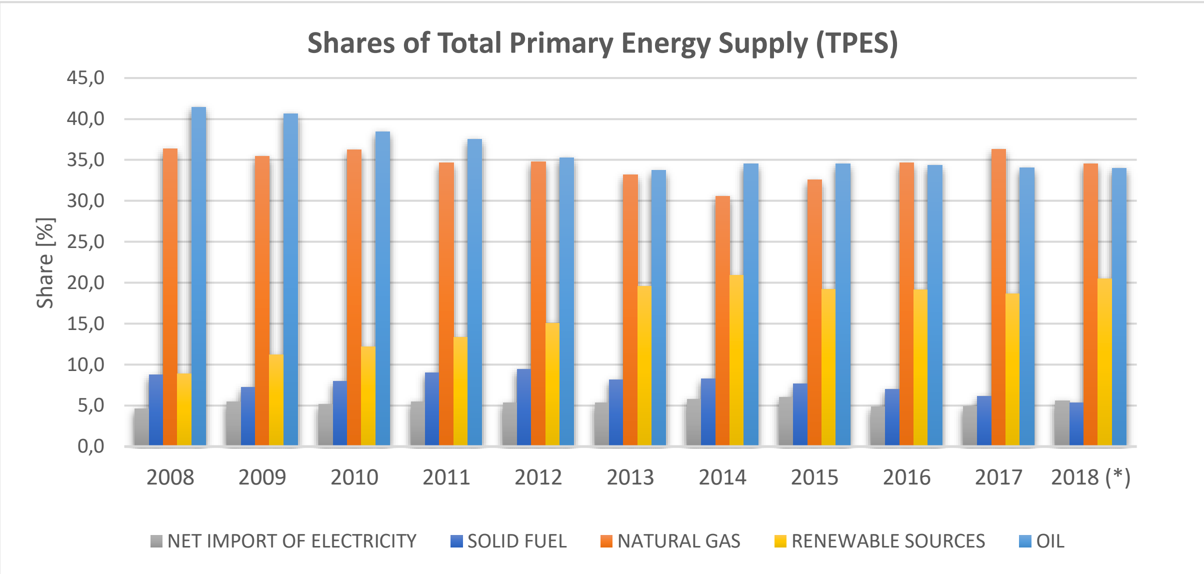


*Figure 5 - Italian total primary energy supply (Source: Elaboration based on [10] )*

The great share of oil in the energy national energy mix is mainly due to its use in the transport sector in the form of petroleum derivates. Whereas, regarding the electricity production its share accounts only for the 3% because the main used energy sources are the natural gas (48.9%) and the renewable sources (23.1%) [2]. The last Bilancio Energetico Nazionale (BEN) [11] in 2018 shows how the commodities consumption strongly depends on the type of sectors:

- Oil: 70% for transport;
- Gas: 62% civil use and 34 % industry application;
- Renewable resources: 84% for civil use;

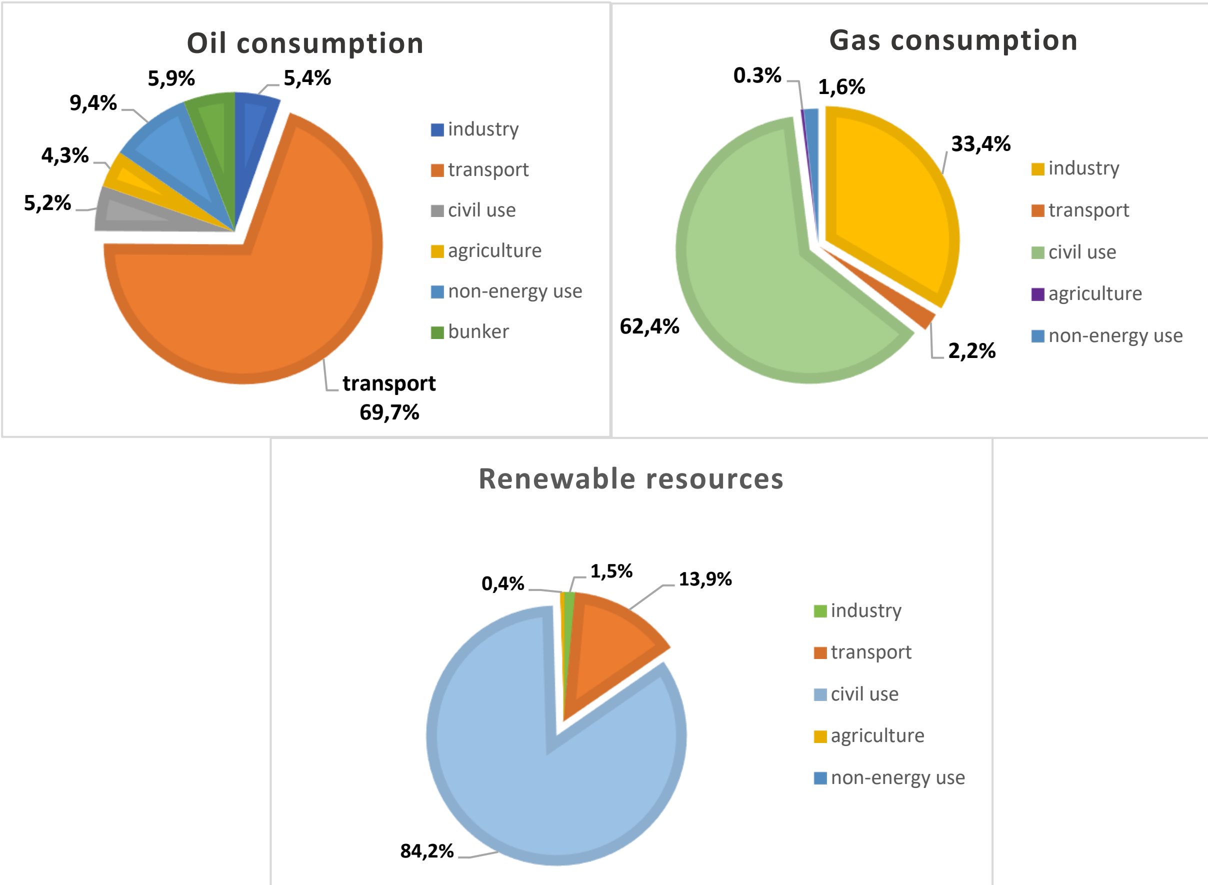


*Figure 6 - Commodity consumption by sector (Source: Elaboration based on [6])*

Nevertheless, the strong Italian dependency from fossil fuel is not compensated by the domestic production. Generally, an oil reserves is classified according to the technical and commercial certainty of extraction using existing technology. The degree of certainty, known as Certainty of Commercial Extraction, is obtained as a result of several geological surveys and cost benefit analyses. According to the degree of this certainty, three distinct categories are defined:

1. Proven reserves [12];
2. Probable reserves [13];
3. Possible reserves [14];

Proved reserves have a 90% or greater likelihood of being present and economically viable for extraction in current conditions. Probable and possible reserves are characterized by a Certainty of Commercial Extraction respectively equal to 50% and 10%. According to the MiSE data, the Italian oil proved reserves are concentrated for 92,5% on-shore.

Table 2 - Oil reserves (Source: Elaboration based on [6])

| *Oil reserves (kton) 2018* | | | | |
|---|---|---|---|---|
| | *Sure* | *Probable* | *Possible* | *% Sure* |
| Land | 70.118 | 81.498 | 53.289 | 92,50 |
| Sea | 5.714 | 3.886 | 254 | 7,50 |
| Total | 75.832 | 85.384 | 53.543 | 100 |

As a consequence, Italian oil extraction installations are mostly located onshore (89,5%) rather than offshore.

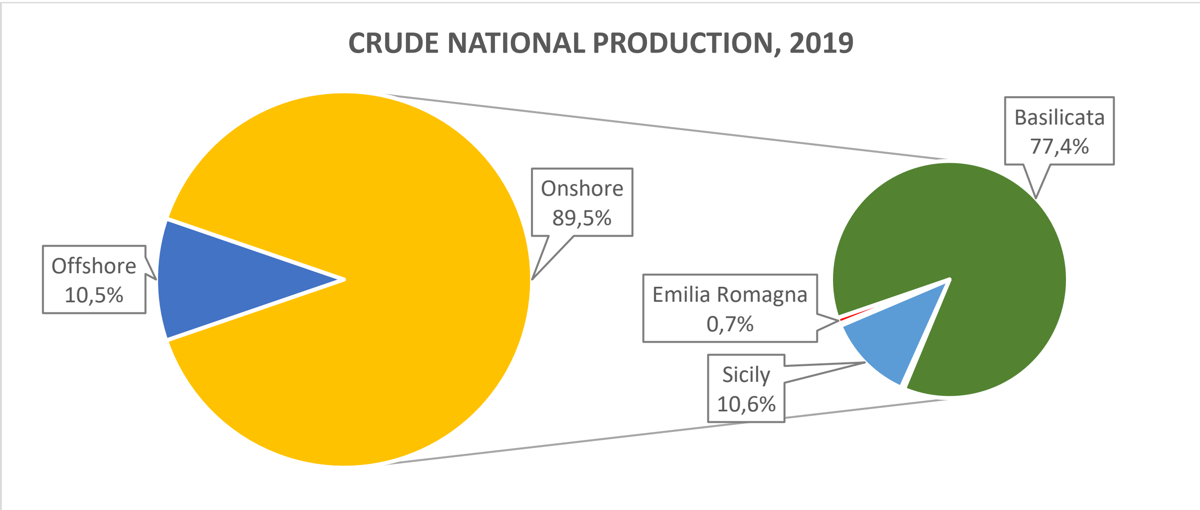


Figure 7 - Crude oil domestic production (Source: Elaboration based on [6])

Basilicata is the region with the highest level of crude production in Italy, with an amount of 3,3 million tons in 2019 reached 77,4 % of total national extraction. The rest of onshore crude production took place in Sicily (10,6%), Emilia Romagna (0,7%), Piedmont (0,4%) and Molise (0,3%). Offshore extraction, which always played a less relevant in national crude production, further decreased in recent years. In 2019 accounted only for 10,5%.
Historical data highlight that the level of domestic crude production experienced a constant increase between 2009 and 2014. Afterward, the domestic output of crude oil dropped, reaching an all-time low of 3,75 million tons in 2016. Subsequently the minimum peak, the production slightly increased until 2018 before experiencing another decrease in 2019 amounting to 4.2 million tons.

## 2.3. Oil trade

According to the last data recorded by MiSE and UP, Italian imports of crude oil and oil products, equal to 80 million tons (Mt), decreased overall by 1.1% compared to 2018. With regard to crude oil, in 2019 the annual oil import reaches 63.14 Mtoe slightly increased by 1,8% compared to 2018. The import was well distributed with the Middle East accounting for almost 28%, Africa and Asia respectively for 27% and 24%, Europe for 17% and America for 4%.

Anyway, these shares varied over the years [15]. The Figure 8 shows two particular trends which represents the evolution of African and Middle Eastern crude import by 2015 to 2019.

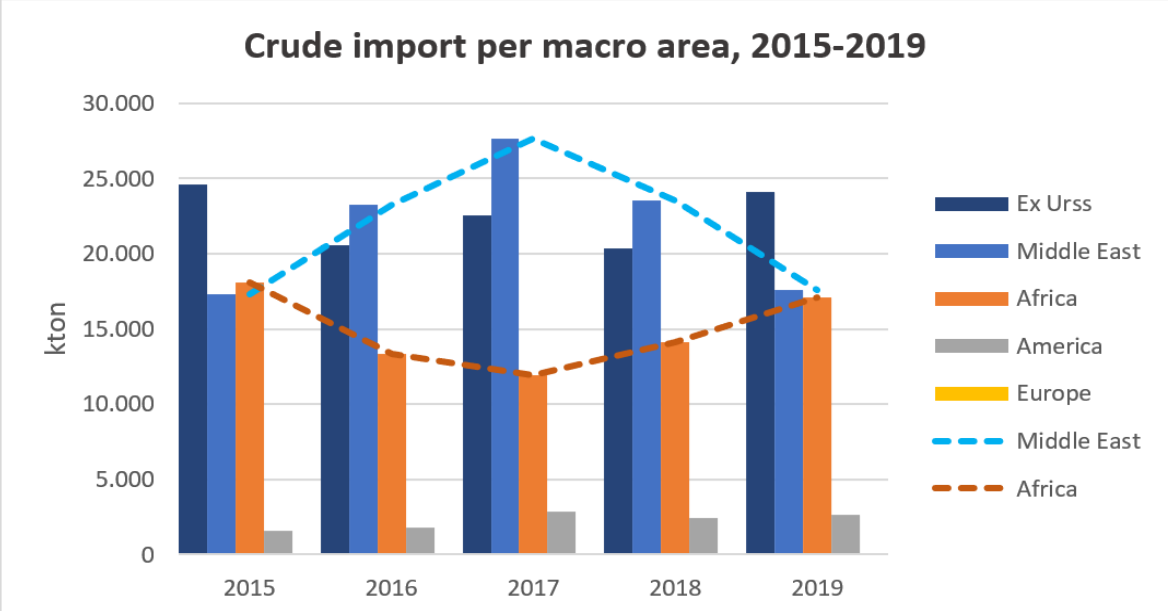


*Figure 8 - Crude import diversification (Source: Elaboration based on [15] )*

The increase in imports of African crudes recorded in 2019 (+ 43% compared to 2017) in contrast with the decrease of crude import from Middle East (-36% compared to 2017) deserves particular attention. The 2017 was the most critical year because it was characterized by the greatest imbalance between Italian oil suppliers in terms of crude import. Indeed, the northern Africa tension and political instability have shifted the Italian import toward more reliable country in the middle east area. After 2017 the oil supply share begins to rebalance and, at the present moment, the disparities have been reduced. Thanks to these variations, a better balance has been achieved between the three main macro-areas of crude supply (URSS 38%; Middle East 28%; Africa 27%). The index of foreign dependence denotes to what extent Italy depends on the oil import by comparing the national oil production and the total import [16]:

$$D = \left(1 - \frac{P}{C}\right) * 100 \qquad [\%]$$

Where:

- D: foreign dependence
- P: self-production of crude
- C: total oil consumption

The Figure 9 clearly shows that Italy have been always characterized by a high value of foreign dependence index because national crude production is far less than total oil demand.

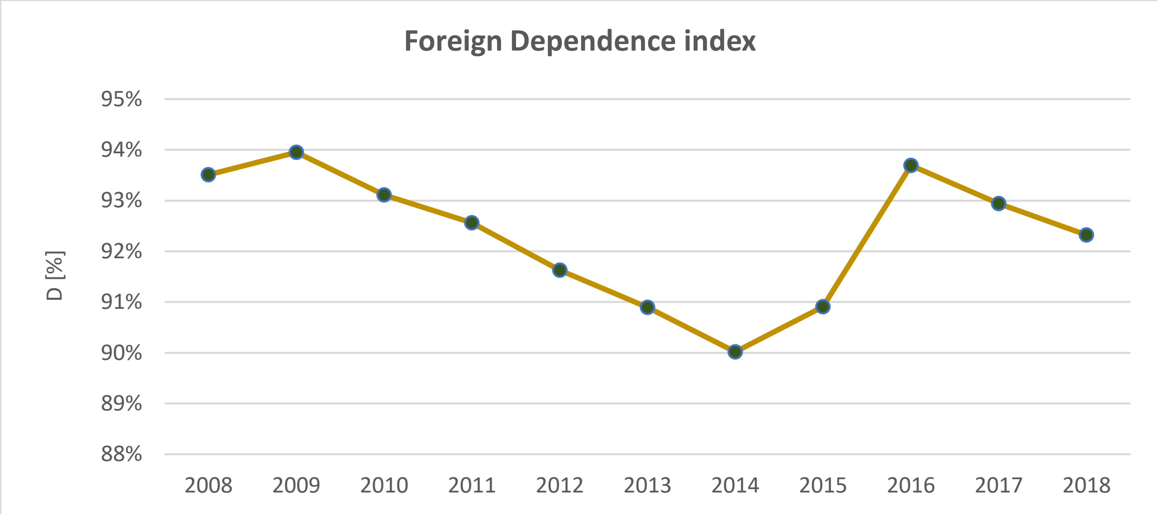


*Figure 9 Foreign dependence index (Source: Elaboration based on [16])*

Therefore, due to the strong dependence on foreign countries, Italy needs a good level of differentiation of the "sources" in order to minimize risks of national energy system related to oil supply. A more detailed analysis of the Italian oil trade is performed by considering each single supplier country. In 2019 Iraq overtook Azerbaijan with 12.6 Mtoe (+36.8% than 2018), whereas Azerbaijan accounted for 10.9 Mtoe, Russia for 9.1 Mtoe, Libya for 7.8 Mtoe, Saudi Arabia for 5.0 Mtoe and Kazakhstan for 4.1 Mtoe [16]. The final balance of 2019 shows 24 overall supplier countries and 73 different types of crude oil. Nevertheless, the Italian import is far from be balanced: the top three exporters (Iraq, Azerbaijan and Russia) supply 51.7% of the total crude demand [6].

Compared to crude, imports of oil products are lower. In the 2018, the semi-finished and petroleum products imports (17.2 Mt) fell by 10.2% respect the previous year. The decrease affected imports from the Middle East (-26%, from 26.7 Mt in 2018 to 19.7 Mt in 2019) and America (-9.7%). Positive changes were recorded in purchases from Europe (+ 18.7%), Africa (+ 15.6%), and Asia (+ 3%). Furthermore, finished products experienced a fluctuating trend last years, whereas semi-finished products were characterized by a steady decrease [6] [16].

*Table 3 Crude oil and Oil product import variation (Source: Elaboration based on [6] and [16] )*

| ***Italian import*** | | | | | | |
|---|---|---|---|---|---|---|
| *Import [Mtoe]* | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| *Crude* | 53,8 | 62,5 | 60,9 | 66,3 | 62,1 | 63,1 |
| *Semi-finished products* | 5,9 | 6,1 | 6,2 | 3,7 | 3,2 | 2,53 |
| *Finished products* | 12,5 | 13 | 15,5 | 16 | 17 | 15,9 |

According to MiSE and UP, products import recorded in 2019 was mainly composed by:

- gas oil (38,6%);
- petroleum (21,0%);

- LPG (18,0%);

The products import is more balanced than crude: indeed Africa, Middle East, Europe and North America account almost for the same percentage.

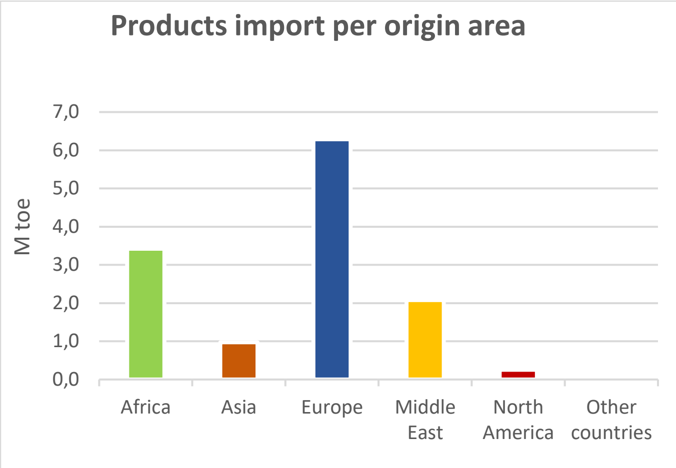


*Figure 11 - Oil products import per origin area (Source: Elaboration based on [16])*

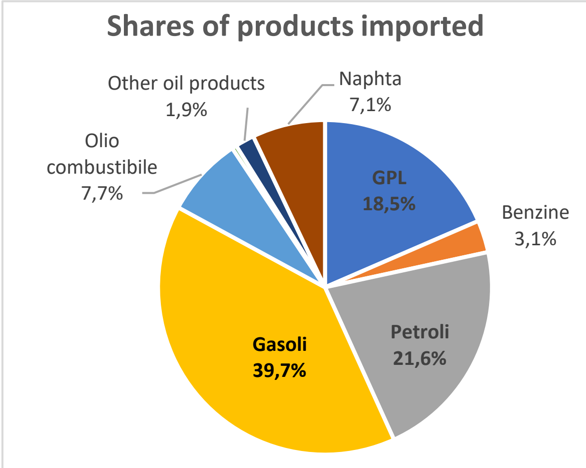


*Figure 10 - Oil products import per typology (Source: Elaboration based on [16])*

The previous analysis about the oil and oil products imports underlines a common feature typical of developed countries poor of national primary resources like Italy. On one hand, Italy is a net importer of crude due to the scarce domestic reserves, on the other, Italian refining activity produce several oil products which are partly exported and partly satisfy internal demand. In this way is possible to damp the cost of oil purchasing by implementing a manufacturing process that is able to create an added value respect the raw material. In particular gasoline and gas oil are the most exported commodity, followed by fuel oil (Figure 12). The first imported of Italian oil products is Europe, which accounts for over 65% (Figure 13). The export of crude oil is almost negligible.

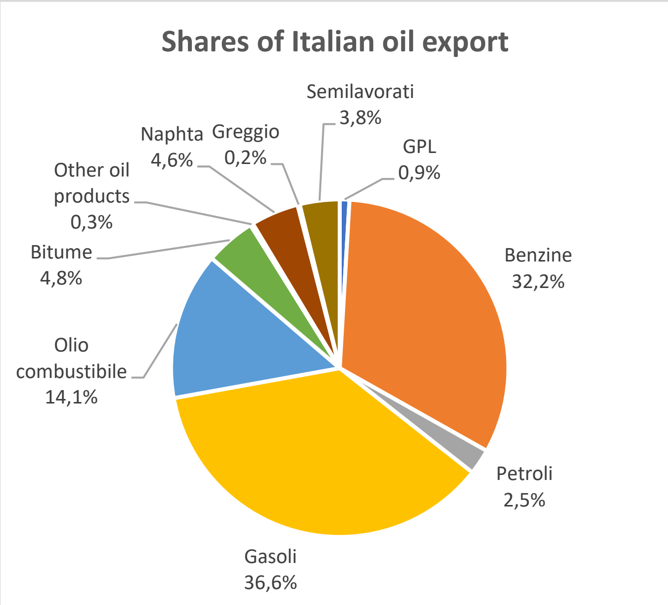


Figure 12 - Italian oil export per typology (Source: Elaboration on [16])

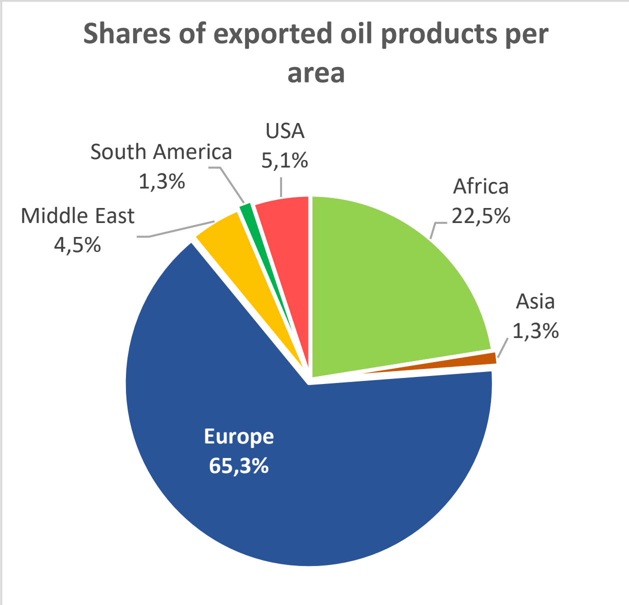


Figure 13 – Italian oil export per area (Source: Elaboration on [16])

## 2.4. Shannon index

A central element which deserves particular attention is the diversification of the energy mix and suppliers commonly measured by aggregated indicators known as “diversity” indicators. In the energy security framework, the concept of diversity includes three key properties [17]:

1. Variety: it refers to the number of categories which can be related to the type of commodity or the supplier. The greater the variety, the greater the overall diversity of the supply system;

2. Balance: it refers to the spread of elements across categories. The higher is the spread, the greater is diversity;

3. Disparity: it indicates the level of difference between the categories. For instance, a system whose categories in terms of primary energy sources are all fossil sources such as Oil, Coal and Natural gas is less heterogeneous than a system with Oil, Nuclear and Hydro [18];

One of the most common diversity indicators is the Shannon index. Several types of Shannon indices are used but, according to the aim of the thesis, only an overall diversification indicator will be introduced for the characterization of the national energy security related to oil supply. The index $S_i$ couples the geographical origins of the crude and the amount of commodity imported in order to assess the oil supplier diversification degree:

$$S_i = -\sum_j h_k l\, n(h_{ij})$$

Where:

- $m_{ij}$ is the share of imports of commodity i from supplier j respect the total import of commodity $i$;
- $S_i$ is Shannon index referred to the commodity $i$;

The calculation of the Shannon index is applied by using two different datasets:

- MiSE dataset which provides information about imported commodities: each exporting country is considered as a different supplier;

- Alphatanker dataset which provides information about discharged in port commodities. Two level of detail can be taken into account:

  - Level 1: each load port is considered as a different supplier;

  - Level 2: load ports belonging to the same country are grouped together and each country is considered as a supplier;

In the first level, the Shannon index reflects the actual diversification degree of maritime imports taking into account the share of commodity coming from each load port. On the other hand, the level 2 has a lower granularity but it allows to compare Alphatanker and MiSE data. For this reason, specific cross-analysis were performed in order to link every commodity classified by Alphatanker to a MiSE code. Internal exchanges are excluded from calculation because not required for external risk assessment. In general, the best condition occurs when these two conditions are met:

- High number of suppliers;

- Not excessive disparities between shares of imported commodity coming from different suppliers;

Thus, the higher is $S_i$ more balanced is the supply of commodity i and, in case of failure of a corridor, more easily would be mitigate the loss of energy by increasing importation from others alternative corridors. However, $S_i$ alone is not sufficient to give a comprehensive view of the market diversification because commodities with greater number of suppliers turn out to be respect to commodities with few suppliers. In order to compare correctly different commodities is necessary to normalize $S_i$. Indeed, the ratio between $S_i$ and its maximum value $S_i^{max}$ is considered to evaluate the quality of commodity's diversification:

$$H = \frac{S_i}{Si^{\max}}$$

$$S_i^{max} = -\ln\left(\frac{1}{N}\right)$$

Where:

- $S_i^{max}$ is the maximum Shannon index related to commodity i. It occurs when all the suppliers provide the same amount of commodity $i$;
- N is total amount of suppliers;
- H is the normalized Shannon index;

After the normalization, three values are obtained: $H_1$ and $H_2$ linked to Alphatanker data and $H^*_2$ based on MSE data. By comparing $H_1$ and $H_2$ two possible phenomena can be observed in Table 4:

- Case 1: $H_1 > H_2$ means that Shannon index based on load countries accounts lower number of suppliers thus, many load ports belong to the same load country and, as a consequence, there are more load ports than load countries. Moreover, grouping major load ports of the same country may increase disparity between shares of import from different supplier;
- Case 2: $H_1 < H_2$ means that, even if the number of suppliers decreases, grouping minor load ports balances gap between share of importations. In this way, considering single load country as a unique supplier leads to a better distribution of commodity supply;
- Case 3: H=0 means that there is only one supplier; this is the most critical situation because in case of failure of a corridor there is no alternative supplier (asphalt, bitumen and vacuum gas oil);

*Table 4 - Shannon index for crude oil and oil products supplier (Source: Elaboration based on [6] and [7] )*

| ***Shannon index*** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **N° suppliers** | *n° load ports* | | *n° load countries* | | | | *n° oil producing countries* | |
| ***Alphatanker terminology*** | ***$S_1$*** | ***$H_1$*** | ***$S_2$*** | ***$H_2$*** | ***MISE code*** | ***MISE terminology*** | ***$S_2$**** | ***$H_2$**** |
| *Ultra low sulfur diesel* | 2,1 | 92,4 | 1,8 | 86,4 | *D0* | Benzine | 2,3 | 87,2 |
| *Unleaded motor spirit* | 2,1 | 99,9 | 1,7 | 96,1 | | | | |
| *Diesel* | 1,2 | 89,7 | 1,2 | 89,7 | *F0* | Gasoli | 2,6 | 80,6 |
| *Gas oil* | 1,4 | 74,4 | 1,0 | 73,7 | | | | |
| *Asphalt and bitumen* | 0,0 | 0,0 | 0,0 | 0,0 | *I0* | Bitumi | 1,3 | 83,8 |
| *Jet fuel* | 1,9 | 93,6 | 1,8 | 93,0 | *E0* | Petroli | 2,2 | 82,3 |
| *LPG* | 1,7 | 51,7 | 1,5 | 54,4 | *C0* | GPL | 1,7 | 52,8 |
| *Naphta* | 1,4 | 71,7 | 1,3 | 72,4 | *R1* | Virgin Nafta | 1,7 | 68,9 |
| *Fuel oil* | 2,6 | 92,1 | 1,9 | 78,3 | *G0* | Olio combustibile | 1,7 | 82,0 |
| *Crude oil* | 3,3 | 72,1 | 2,3 | 65,6 | *A0* | Greggio | 2,4 | 75,5 |

Differences between $H_2$ and $H_2$* lie in the fact that the number of load countries do not correspond to the number of producing countries neither the amount of imported commodity according to the matching process perform between Alphatanker and MiSE. Indeed, Alphatanker accounts the total amount of commodity discharged in Italian ports even if only transiting whereas MiSE accounts the imported quantity destined for national use.

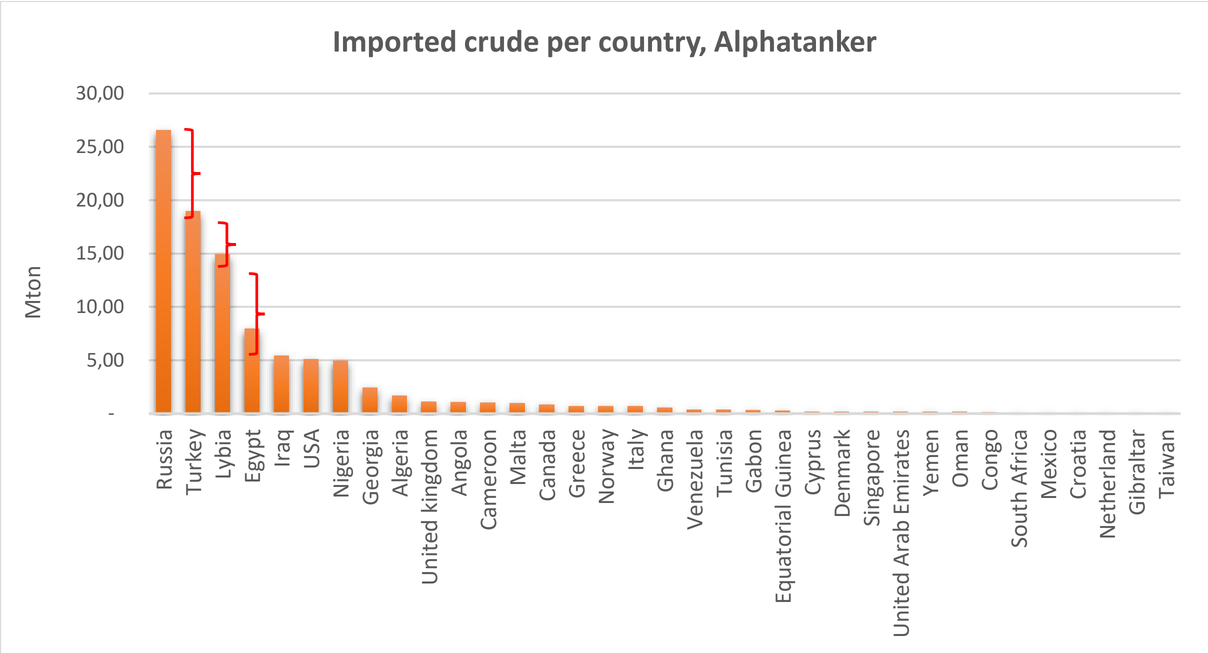


*Figure 14 - Italian crude oil import per country (Source: Elaboration based on [7] )*

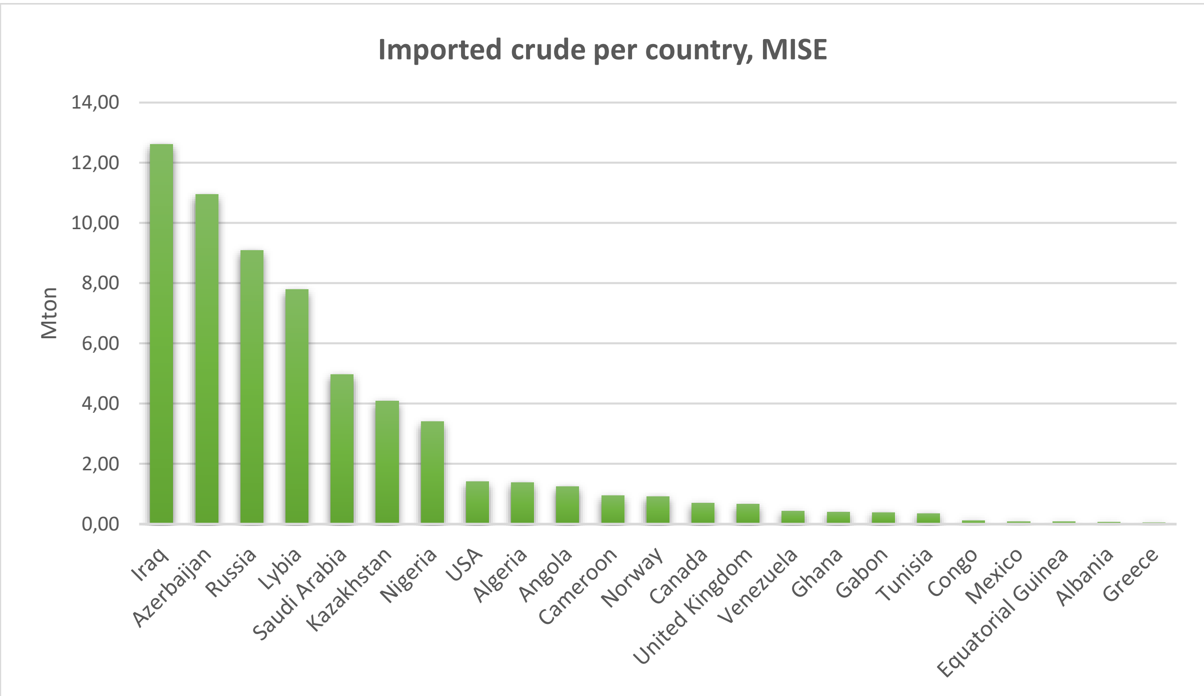


*Figure 15 - Italian crude oil import per country (Source: Elaboration based on [6] )*

As well as, radar graphics reported in Figure 16 and in Figure 17 evidence that the overall distribution of oil commodity importations according to MiSE is more balanced. For instance, bitumen and asphalt come solely from Spain according to Alphatanker instead according to MiSE, they come from five different countries. Thus, $H_2$ is equal to zero whereas $H^*_2$ is equal to 83,8. These differences highlight that oil products, unlike crude, are transported mainly by trucks or by trains rather than by oil vessels and hence Alphatanker is not well representative of the oil product market.

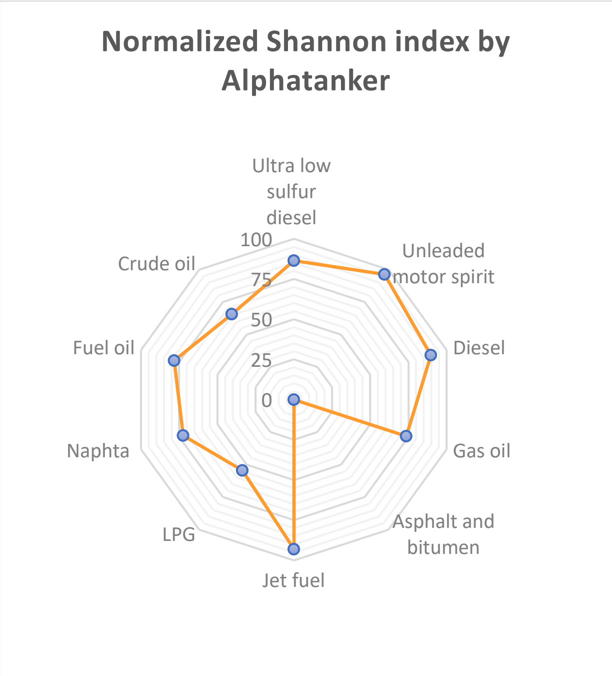


*Figure 17 – Normalised Shannon index* (**$H_2$**) *according to Alphatanker (Source: Elaboration based on [7] )*

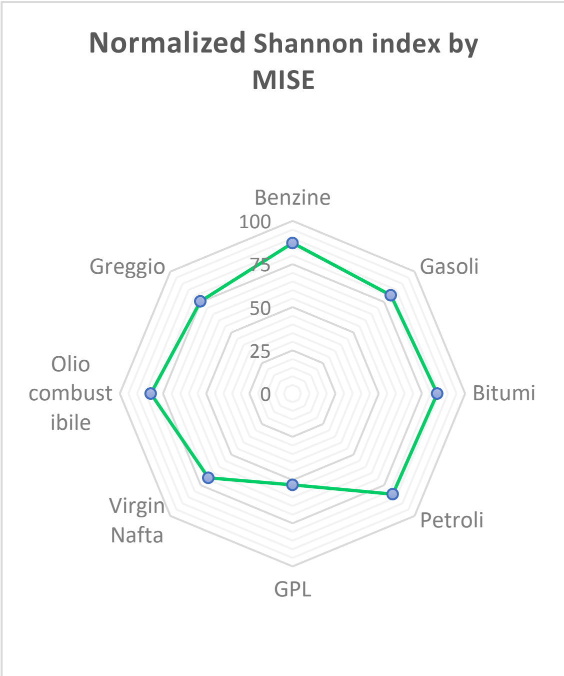


*Figure 16 - Normalised Shannon index* (**$H_2$***) *according to MiSE (Source: Elaboration based on [6] )*

## 2.5. National oil infrastructure

Three main infrastructures are involved in the oil supply: refineries, oil pipelines and ports. Unlike natural gas, the role of maritime trade in the oil supply is fundamental. In case of long distances, crude is generally transported by oil vessels whereas oil products both by vessels, tank vehicles or trains. The strategic position in the Mediterranean Sea makes Italy a "pivotal" country for oil trade between North Africa, Middle East, Asia, Europe and United States. Furthermore, at the present moment, all the oil pipelines that have represented an import channel toward Italy have been shut-down therefore all the Italian entry point consist of ports. The only exception is represented by the oil pipeline TAL (Trans-Alpinen Leitung) but it exports crude oil from the port of Trieste to foreign refineries therefore does not constitute an import corridor. The presence of the TAL, with its 40.2 Mton of crude oil flow [19], partially explains the gap between the data registered by MiSE and Alphatanker (Figure 4). Indeed, MiSE does not include the crude oil in transit in the national territory instead Alphatanker registers the quantity because it is discharge in an Italian port. Therefore, Trieste becomes the busiest

Italian port for the crude oil supply: in 2019 the discharged crude amount accounted for 40.5% of the total.

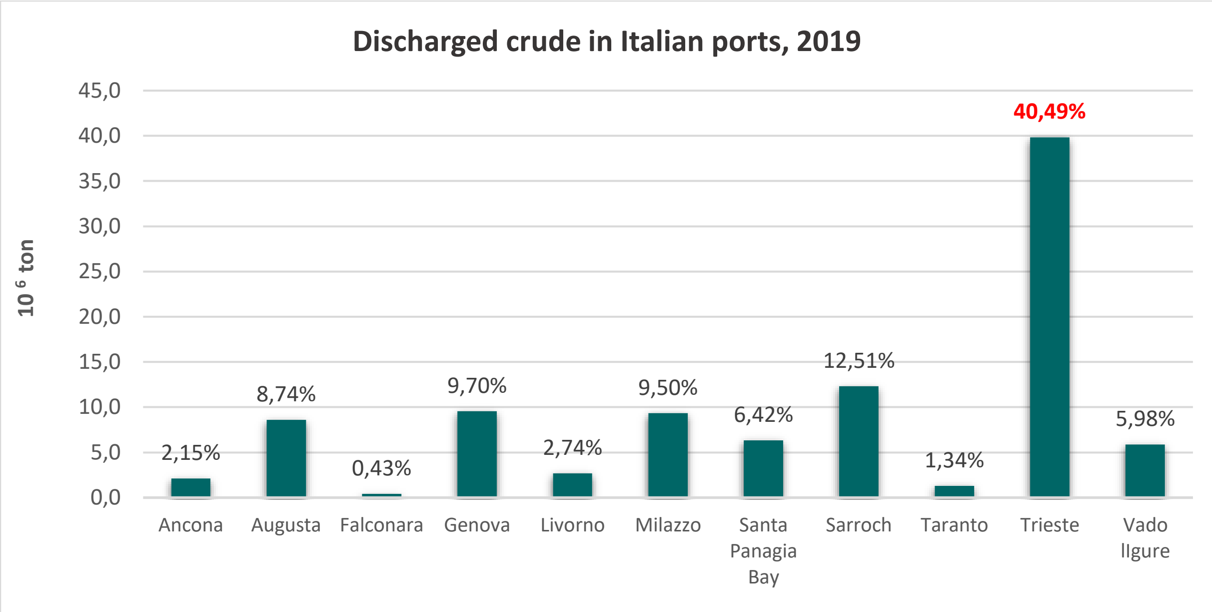


*Figure 18 - Discharged crude oil in Italian ports (Source: Elaboration based on [7] )*

On the other hand, the maritime traffic of petroleum products is better distributed: Naples accounts for 15,4% of the total supply of refined products (Figure--), followed by Marghera (13,3%) and San Leonardo (10,4%).

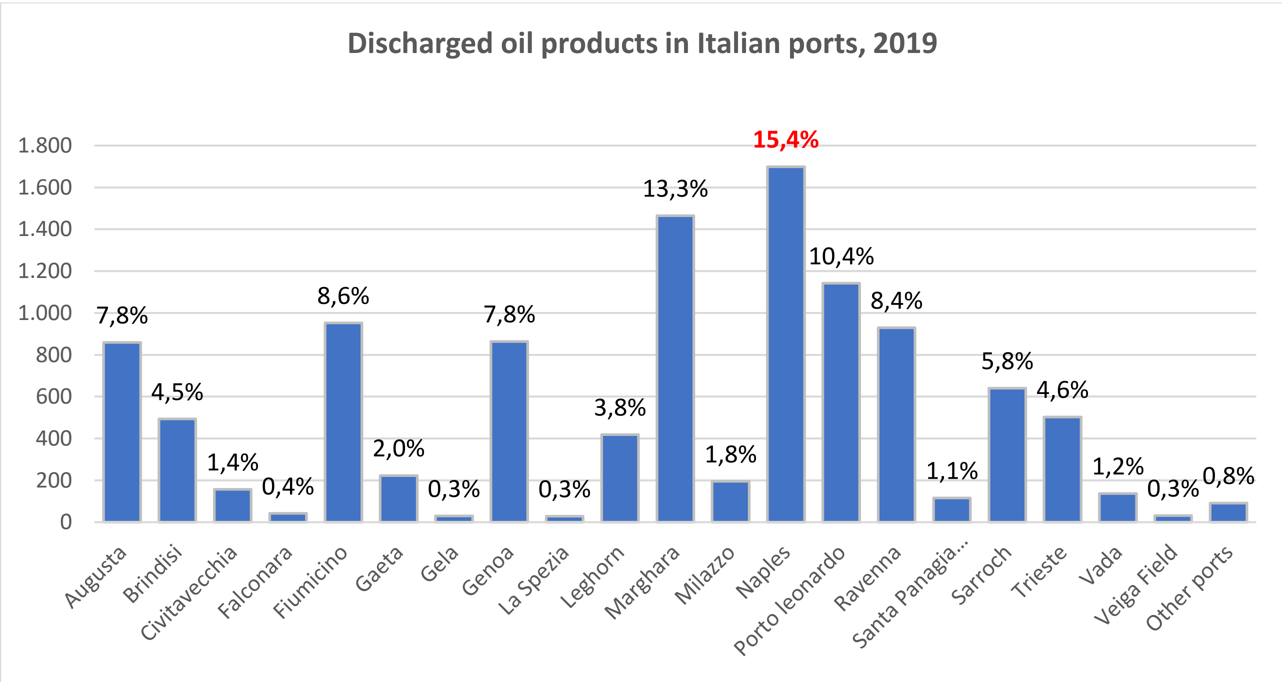


*Figure 19 - Discharged oil products in Italian ports (Source: Elaboration based on [7] )*

Usually ports near to refineries are characterized by a more intense oil traffic. It is an example the port of Sarroch, Milazzo, Genoa and Augusta which are all connected to a nearby refinery:

- Saras, near the port of Sarroch;
- ENI-KUPIT, near the port of Milazzo;
- IPLOM Busalla, near the port of Genoa;
- SONATRACH Augusta, near the port of Augusta;

Actually, the amount of crude oil and petroleum products discharged in port are sent via pipeline to national or foreign refinery for further treatments or are collected in tanks and stored in specific areas within the port called "coastal deposits" waiting to be sent to final consumers by tank trucks or tanker trains. Two distinguish procedure interest the unloading process *[20]*:

1. Unloading "at anchor": the ship does not dock in the port but is connected to an arm that directly transfers the liquid commodity to nearby refineries (eg: from the port of Sarroch to Saras refinert or from the port of Milazzo to the ENI-KUPIT refinery) or foreign refineries through an oil pipeline (eg: from the port of Trieste to German, Austrian and Czech refineries). Crude oil generally follows this path and, once refined, is exported by sea or by land (pipeline, road, rail);
2. Unloading “in port”: the ship docks and unloads liquid commodity. Once discharged it can follow two alternative paths: collected in cisterns, loaded onto tank trucks and tanker trains and transported by road and rail, or stored inside the port’s "coastal deposits". There are some ports whose main function is store imported commodity acting as a logistic point of collection for the subsequent sorting and internal distribution by road or rail.

Once crude oil and petroleum products are within the Italian territory, internal transport from the port to the refinery or to the final consumers generally takes place in three ways:

- by pipelines;
- by road through vehicles;
- by railway through tank trains;

Over the past 10 years has been recorded a progressive decline in demand for refined products (Figure 20). For this reason, Due to the overcapacity, several refineries such as Cremona, Rome and Mantua have been converted into logistics hubs whereas Gela and Porto Marghera refineries were converted into biorefineries by ENI. Since 2008, the number of 16 refineries has been reduced to 11.

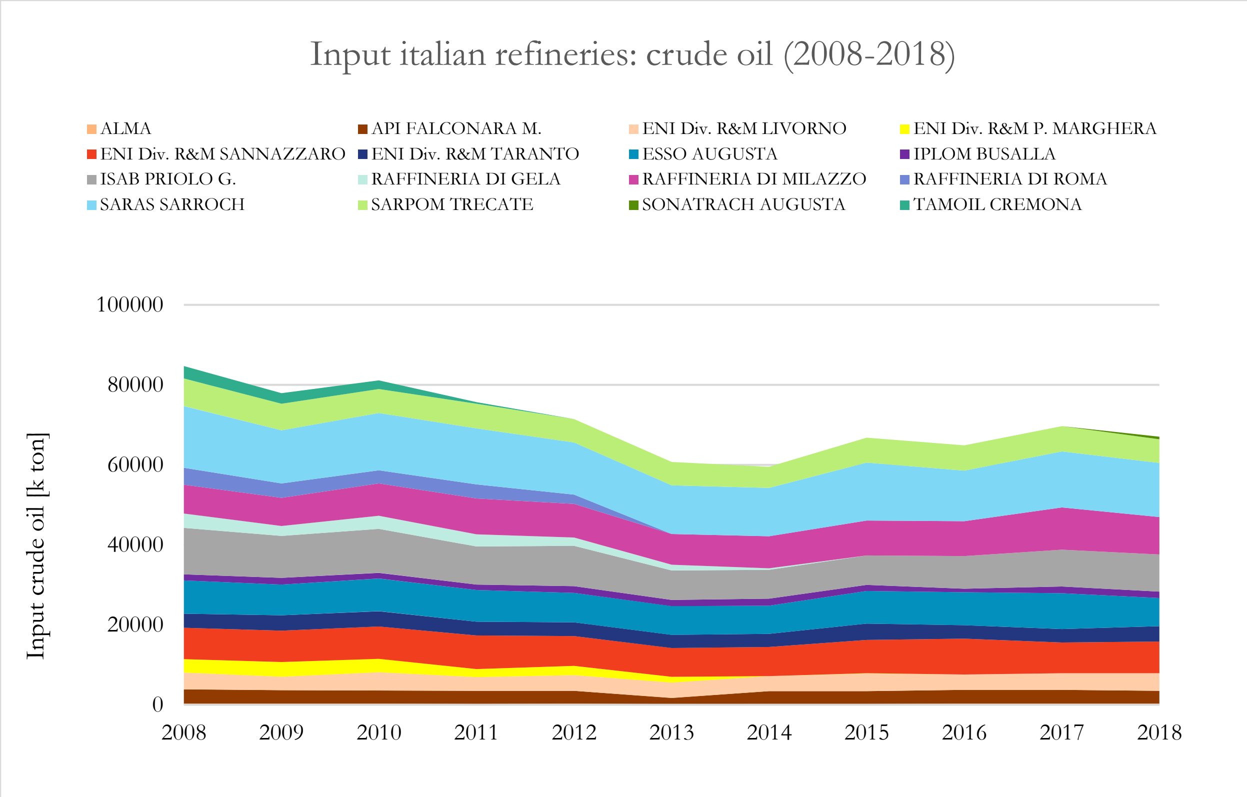


*Figure 20 - Refineries activity (Source: [16])*

Currently, the refineries operating in Italy are those described below and represented in Figure 21 [15]:

- the Sarpom refinery in Trecate (NO) of ExxonMobil / Esso Italiana, in operation since 1952. Its position in the middle of the Milan-Turin-Genoa industrial triangle makes it a strategic point for fuelling in Po area;
- the refinery of Sannazzaro de 'Burgondi (PV), managed by ENI, in operation since 1963;
- the Busalla (GE) refinery, in operation since 1943, now owned by Iplom. It specializes in the production of bitumen, diesel and fuel oil;
- the refinery in Livorno, founded in 1973 and currently managed by Eni which is planning to convert it into a plant for the transformation of hard plastics into biomethanol;
- the Ravenna refinery, managed by Alma Petroli;
- the Falconara Marittima (AN) refinery established in 1933 and currently 99% controlled by Api;
- the Taranto refinery, active since 1964 and currently managed by ENI;
- in Sicily: the former Augusta ESSO refinery which at the end of 2018 was purchased by SONATRACH; Priolo Gargallo refinery is owned by ISAB, Milazzo refinery is owned 50% by Eni and 50% by Kuwait Petroleum Italia;
- in Sardinia, the Sarroch refinery, currently owned by Saras;

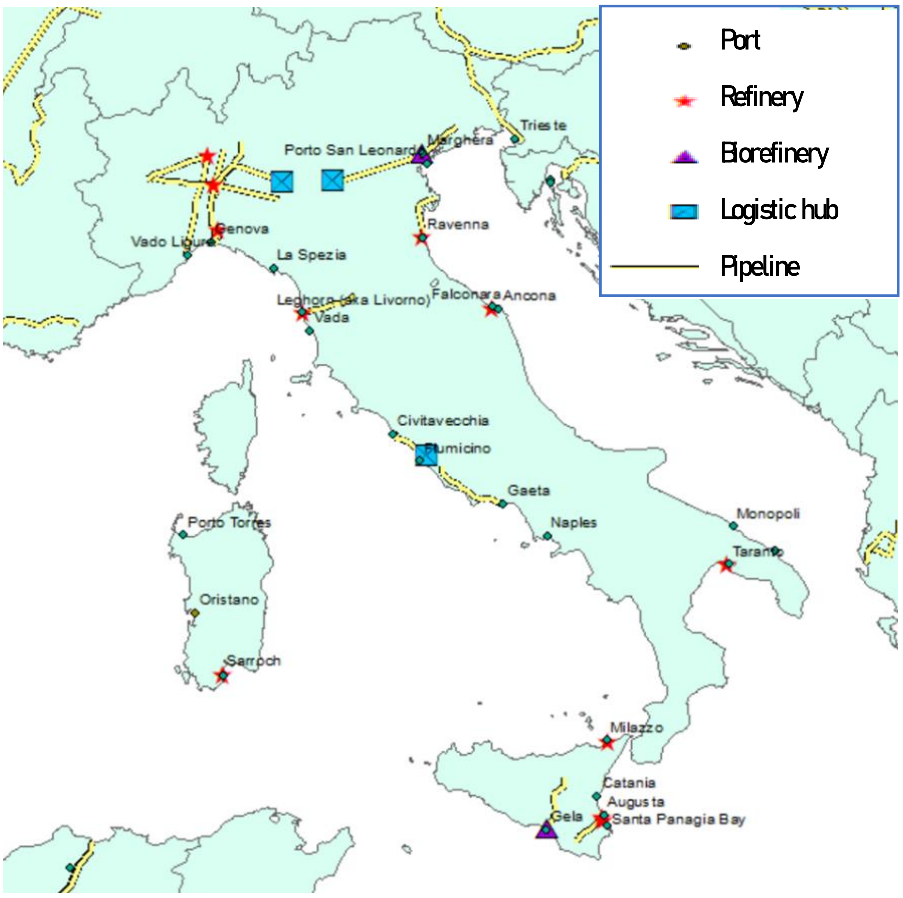


*Figure 21 - Italian oil infrastructure (Source: Elaboration through GIS based on [7], [16] and [21] )*

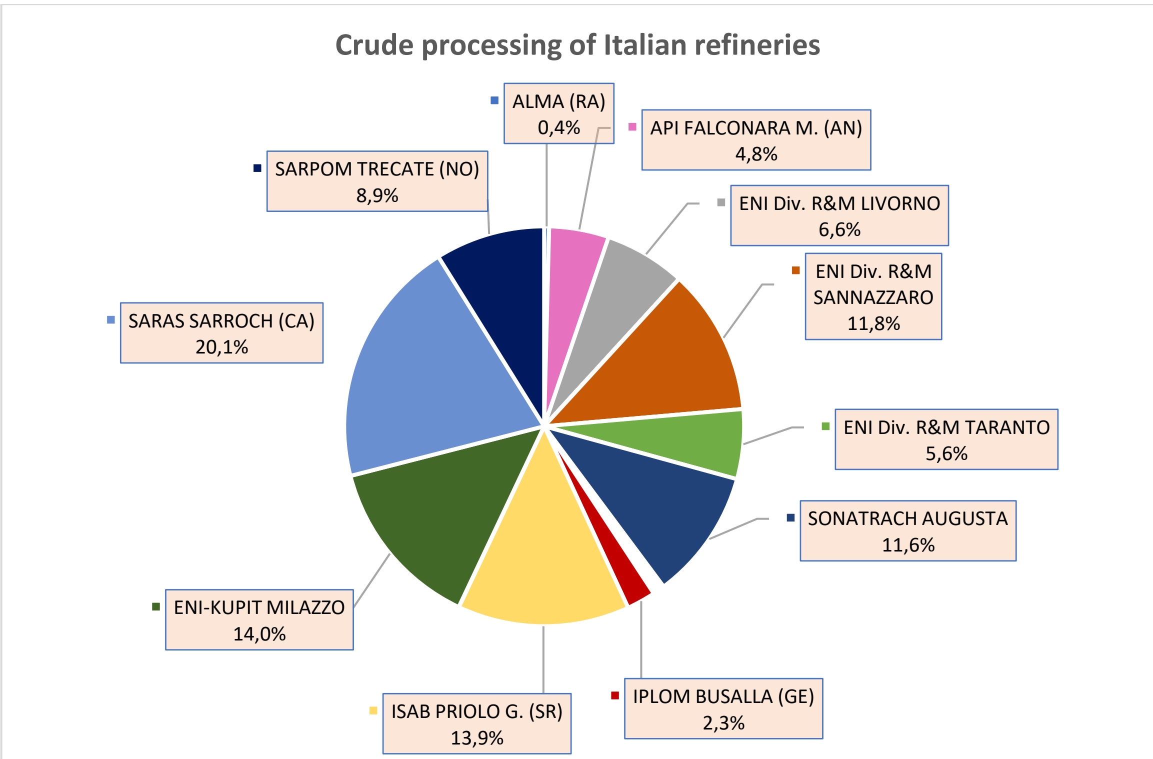


*Figure 22 - Percentage processing of crude oil by refineries (Source: Elaboration based on [16] )*

Data published in the annual report of Unione Petrolifera, show that the most active refineries in the crude processing were: the Saras Sarroch refinery (20.1%), the Milazzo ENI-KUPIT refinery (14.0%), the ISAB Priolo G. refinery (13.9%), the ENI Div.R & M Sannazzaro refinery (11.8%) and the Augusta SONATRACH refinery (10.6%).

# 3. Risk Analysis

The risk analysis can be defined as a "systematic use of available information to identify hazards and to estimate the risk to individual, property and the environment" [22]. The risk analysis is a proactive approach because deals only with potential accident and not with the causes and the circumstance of events. The IEC 60300-3-9 standard define the risk as the "Combination of the frequency, or probability of occurrence and the consequence of a specified hazardous event" [23].

$$Risk = \xi(\varepsilon) * C(\varepsilon)$$

The probability of an event $\varepsilon$ is a number between 0 and 1 that express the likelihood of occurrence of the specific event. If $\xi$ =1, the event will certainty occur, while for $\xi$ =0 the event will not occur. The consequences of an event $\varepsilon$ are the impact that $\varepsilon$ has on our system that can involve damage to people, property, the environment and so on. The accidents can be classified into three main categories [24]:

- Accidents of category 1: high frequency and low consequence accidents. These hazardous events occur so often and regularly that is possible to predict the number of similar accidents in the near future.
- Accidents of category 2: occurs less often than the category 1 but have a higher impact. To estimate such events is not sufficient to base the assessment on the number of past accidents but it is necessary to perform a more detailed analysis on the causes and consequences.
- Accident of category 3: High impact and low probability accidents. For these events it has no meaning to base the analysis on the historical data. It is necessary to carry out a detailed analysis of each component of the system.

Since the aim of the dissertation is the assessment of the Italian energy security the generic risk definition is adapted. The hazardous event is a maritime or a pipeline accident that involves the loss of a certain amount of commodity. The risk analysis could be qualitative or quantitative, depending on the objective of the analysis. In our case it is chosen a quantitative approach so that we are able to numerically quantify the security of the Italian energy supplies. The maritime and pipeline accidents are included into the second category. Indeed, they are not so frequent and a risk analysis only based on the historical data will be found meaningless. Therefore, a detailed analysis on the causes and the consequences of a hazardous event must be carried out.

## 3.1. Model implementation on the Italian oil corridors

Before applying the risk definition to the national energy security assessment, a briefly introduction about the energy security is necessary. The country's energy security depends on two different "fronts" [25]:

- Internal front
- External front

The first is related to the quantification of the availability of the national resource and on the resilience of the transmission and distribution system against possible internal attacks. Instead, the external one includes the geopolitical security of the commodity source country and the security of the corridor that links the source country with the national entry point. Therefore, the *National energy security index* $R_n$ [25] can be define as:

$$R_n = W_1 * R_{int} + W_2 * R_{ext}$$

Where $W_1$ *and* $W_2$ are defined on the basis of the percentage import dependency *X.* Since the aim of the thesis is to assess the external risk, the internal risk index has been disregarded and the analysis is performed only on the external risk.

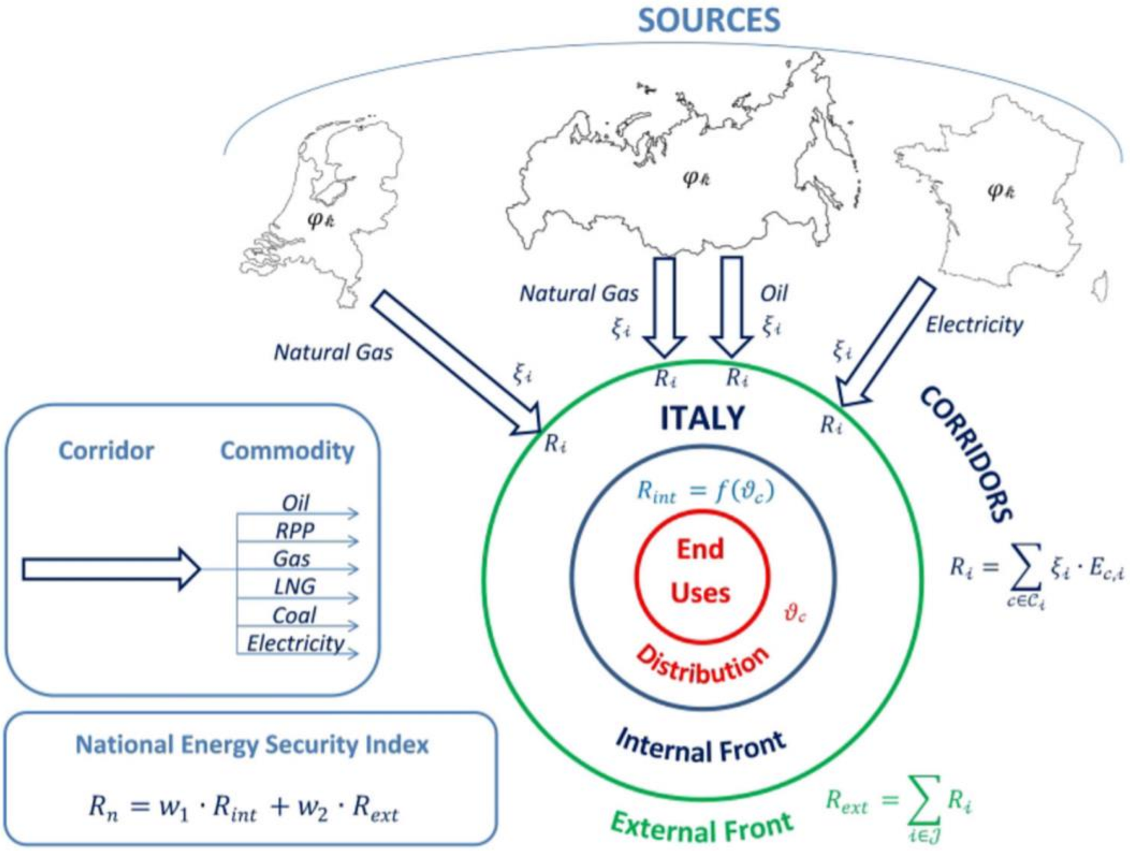


*Figure 23 National Energy Security Index [25]*

The external risk $R_{ext}$ related to a commodity $c$ is defined as the sum of the risk of all the corridor $i$ that reaches a national entry point. The corridor is the pathway that the commodity has to travel in order to reach the Italian entry point from the foreign production field.

$$R^c{}_{ext} = \sum_{i \in I} R^c{}_{ext_i}$$

The risk of the single oil corridor depends on two independent components:

- The maritime route risks ($R^c{}_{opensea}$)
- The captive corridor risks ($R^c{}_{captive}$)

The maritime risk is related to the sea trade of oil and oil product performed through the oil tankers from the foreign load port to the Italian entry point. Instead, the captive risk depends on the pipelines infrastructure that links the oil field with refineries and/or exporting port. The oil corridor risk assessment depends on the quantification of the probability of failure ($\xi_i$) and on the energy transported ($E_i^c$). The risk represents the amount of energy that is subjected to risk of loss:

$$R^c{}_{ext_i} = \xi_i * E^c{}_i$$

The failure probability of a corridor $\xi_i$ is obtained through a fault tree in which all the sensitive parameters (nodes) are linked with Boolean operators. The analysis is carried out in a reverse mode by assessing the probability of success $\omega_i$ in cross the corridor and afterward calculating the complement to one.

$$\omega_i = 1 - \xi_i$$

The top event is the success probability of cross the entire corridor $i$ and depends on the predecessor nodes that are the success of crossing the open sea $\left(\omega_{\text{opensea}}\right)$ and the captive ($\omega_{\text{captive}}$) corridors. The *AND* operator express an independent relation between nodes instead the *OR* operator express a dependent relation. For example, the probability of cross the open sea and captive route are independent from each other because both of them have to be accomplished in order to successfully reach the destination. Therefore, a *AND* operator links the two nodes and the product is performed between the two different occurrence probability.

$$\omega_{\text{i}} = \omega_{\text{opensea}} * \omega_{\text{captive}} = [(1 - \xi_{openSea}) * (1 - \xi_{captive})]$$

The growing of the fault tree from the top to the roots, allows to construct the final formula for the assessment of the corridor failure probability.

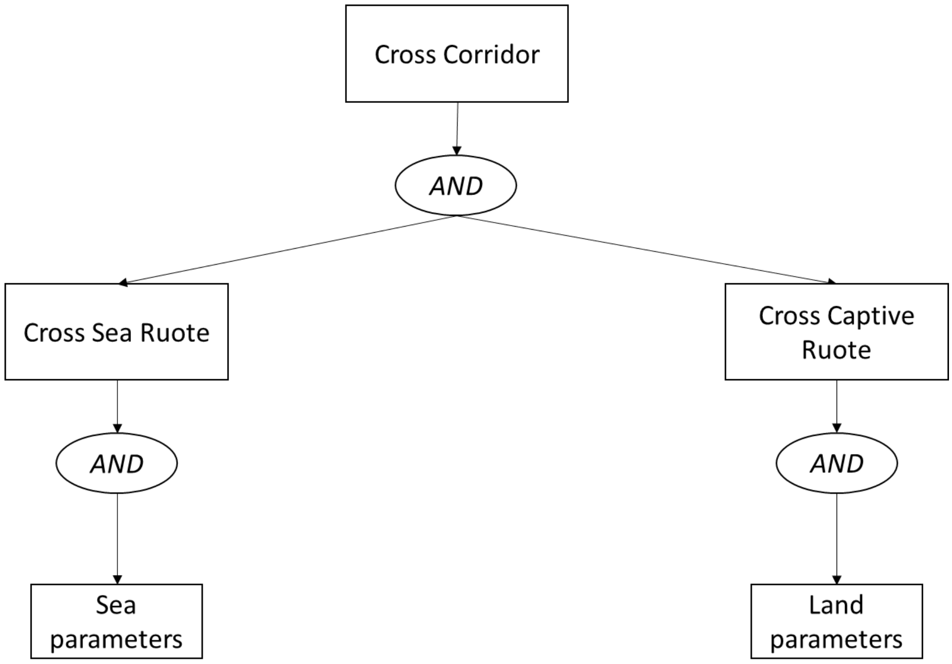


*Figure 24 - Fault tree of the probability of failure*

Since the probability of failure of the captive and open sea corridor depends on different variables, separate mathematical models are required. In 3.2.1 and in 3.3.1 the two models are deeply analysed.

After having obtained the general failure probability it is necessary to apply it for each corridor. According to the fault tree, the corridor analysis has to start from the Italian entry point that represent the occurrence of the top event and afterward, it is necessary to coming back in the oil supply chain until the production field. The purchasing of Alphatanker and EWA database have allowed to characterized the overall corridor:

- Alphatanker provides the routes followed by the oil tankers
- EWA provides the main pipelines systems that link the field of production to the exporting ports.

Once rebuilt the corridor with the going backward process, each corridor's section has to be associated with a pair of values: the failure probability and the energy transported. In this way the final risk index can be computed.

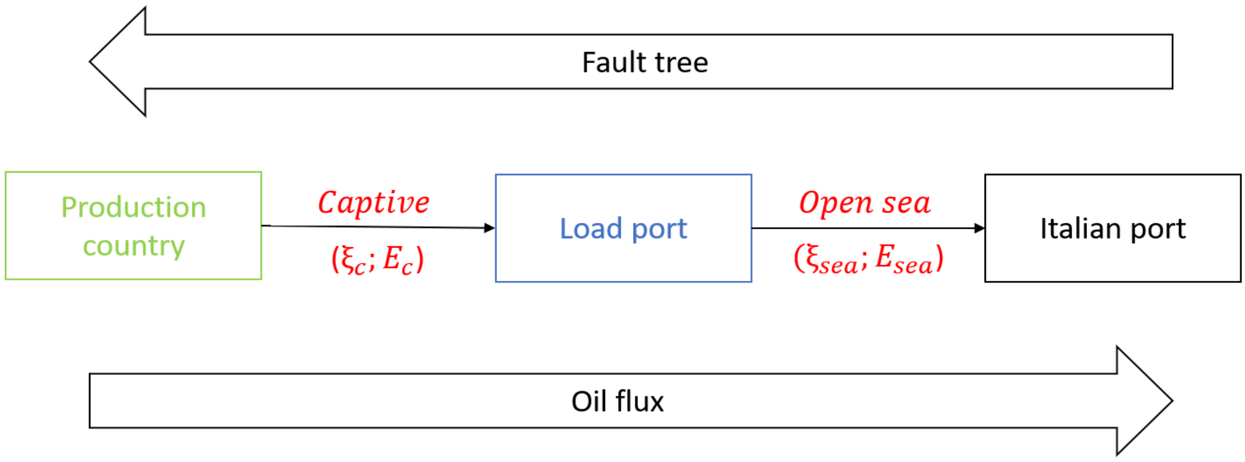


*Figure 25 - Backward process*

## 3.2. Open sea corridors

The analysis of the maritime corridors is critical for the Italian energy security since all the crude oil and the large part of oil products are imported by sea. The transport is carried out by the oil tankers that are classified as “bulk cargo”, ships designed for the carriage of unpackaged goods. There are two basic type of oil tankers: the crude tankers and the product tankers. In addition, they are also classified according to the deadweight tonnage (DWT) that is a measure of the vessel’s weight carrying capacity [26].

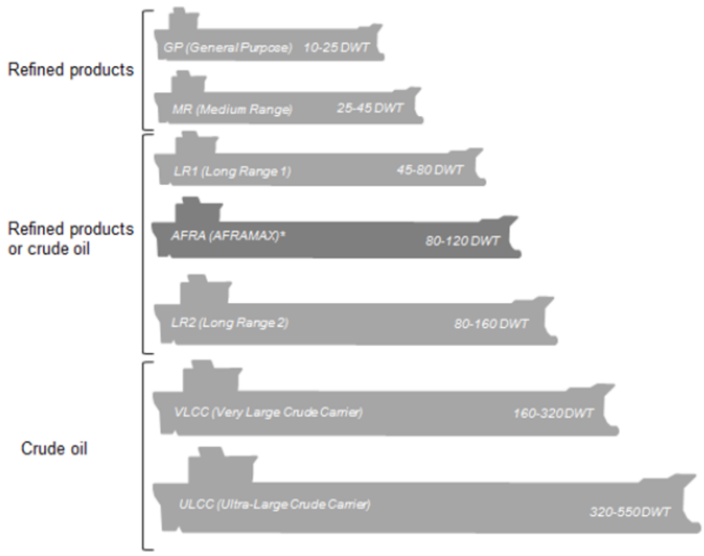


*Figure 26 - Oil tankers classification (Source: [26])*

The process of characterization of the maritime route is performed in two steps. Firstly, all the maritime routes, obtained from Alphatanker, are grouped by Italian discharge port and are characterized with several parameters.

*Table 5 - Livorno oil corridor characterization (Source: Elaboration based on [7] )*

| ***Livorno – CRUDE SUPPLY 2019*** | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Country* | *Load port* | *Crude intake [ton]* | *Intake per country [ton]* | *Sea Duration [day]* | *% load* | *Specific load* | *Power (TOE/year)* |
| Egypt | Sidi Kerir | 1,567,944 | 1,567,944 | 5.19 | 0.71 | 78,397 | 1,567,944 |
| Greece | Kali Limenes | 77,593 | 77,593 | 4.10 | 0.69 | 77,593 | 77,593 |
| Libya | Az Zawiyah | 85,054 | 162,683 | 6.65 | 0.74 | 85,054 | 85,054 |
| | Marsaxlokk | 77,629 | | 9.49 | 0.72 | 77,629 | 77,629 |
| Russia | CPC Terminal | 85,133 | 85,133 | 14.87 | 0.74 | 85,133 | 85,133 |
| Turkey | Ceyhan | 719,013 | 719,013 | 6.19 | 0.71 | 79,890 | 719,013 |
| ***Total*** | | ***2,695,410*** | | [-] | [-] | [-] | [-] |

Where:

- *Intake* is the amount of crude arriving from a single load port;
- *Intake per country* is the total amount of crude arriving from load ports which belong to the same load country;
- *Sea duration* is the average time for oil tanker to reach the discharge port;
- *Intake/DWT* is the average filling percentage of oil tankers;
- *Intake/n° trip* is the average amount of commodity transported by a single trip;
- *Power* is the ratio between the amount of transported crude over year. The conversion factor used to obtain the MWh relies on the lower heating value (LHV) of the crude oil;

Secondly, the corridor georeferencing process have to be carried out in order to takes into account the spatial dimension that has a fundamental role in the risk analysis. This process allows to geographically characterize the corridors in terms of length and pathway (Figure 27 and Figure 28). Considering that the total number of corridors is huge (433), the process of digitalization is restricted to the ones with the highest intake. In particular the cut off threshold is set to 1% of the total transported commodity per year. The distinction between the *total intake* and the *external intake* are the internal commodity exchange (from an Italian port to another Italian port) that have to be disregarded for the national energy security assessment.

*Table 6 - Corridor digitalization process (Source: Elaboration based on [7])*

| ***Corridors digitalization process*** | | | |
|---|---|---|---|
| *Crude Oil* | | *Oil Products* | |
| Cut-off threshold [%] | 1 | Cut-off threshold [%] | 1 |
| N digitalized routes | 24 | N digitalized routes** | 30 |
| $N_{TOT}$ routes | 211 | $N_{TOT}$ routes | 222 |

| | | | |
|---|---|---|---|
| Intake digitalized [ton] | 54,032,629 | Intake digitalized [ton] | 4,682,201 |
| Total intake [ton] | 98,420,089 | Total intake [ton] | 10,604,868 |
| Share digitalized [%] | 54.9 | Share digitalized [%] | 44.2 |
| External Intake digitalized [ton] | 54,032,629 | External Intake digitalized [ton] | 3,806,707 |
| Total External intake [ton] | 97,726,794 | Total External intake [ton] | 8,149,760 |
| External Share digitalized [%] | 55.3 | External Share digitalized [%] | 46.7 |

**eight corridors with a share lower than 1% have been added in order to have at least one corridor for each products type.

This choice derives from the necessity to lighten both the manual tracing and the computational process considering that increasing the number of digitalized corridors does not change in a sensible way the final results. Indeed, are the main corridors that more affect the Italian energy security. Nevertheless, as shown in Table 6 the share considered is not sufficient to obtain reliable results. Therefore, a route grouping process is carried out (chapter3.4.2).

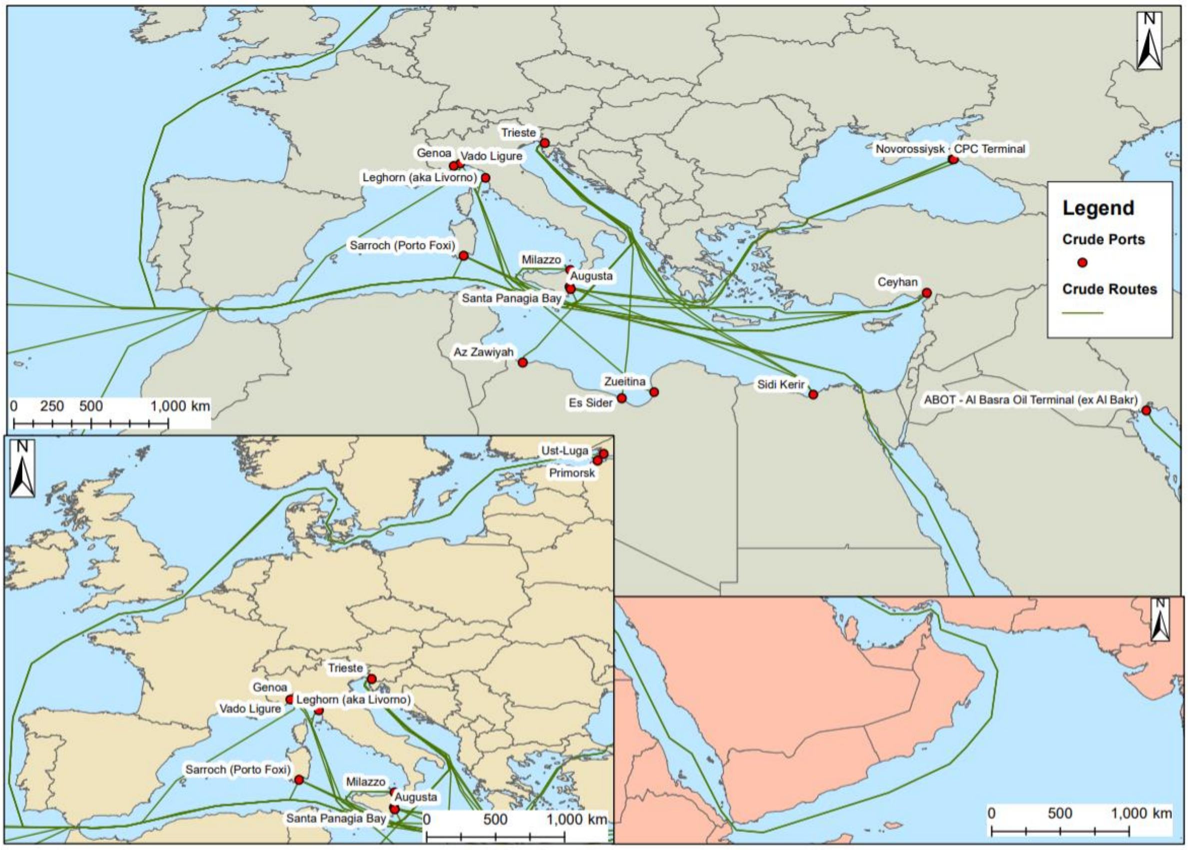


*Figure 27 - Crude oil maritime corridors (Source: Elaboration through GIS based on [7] )*

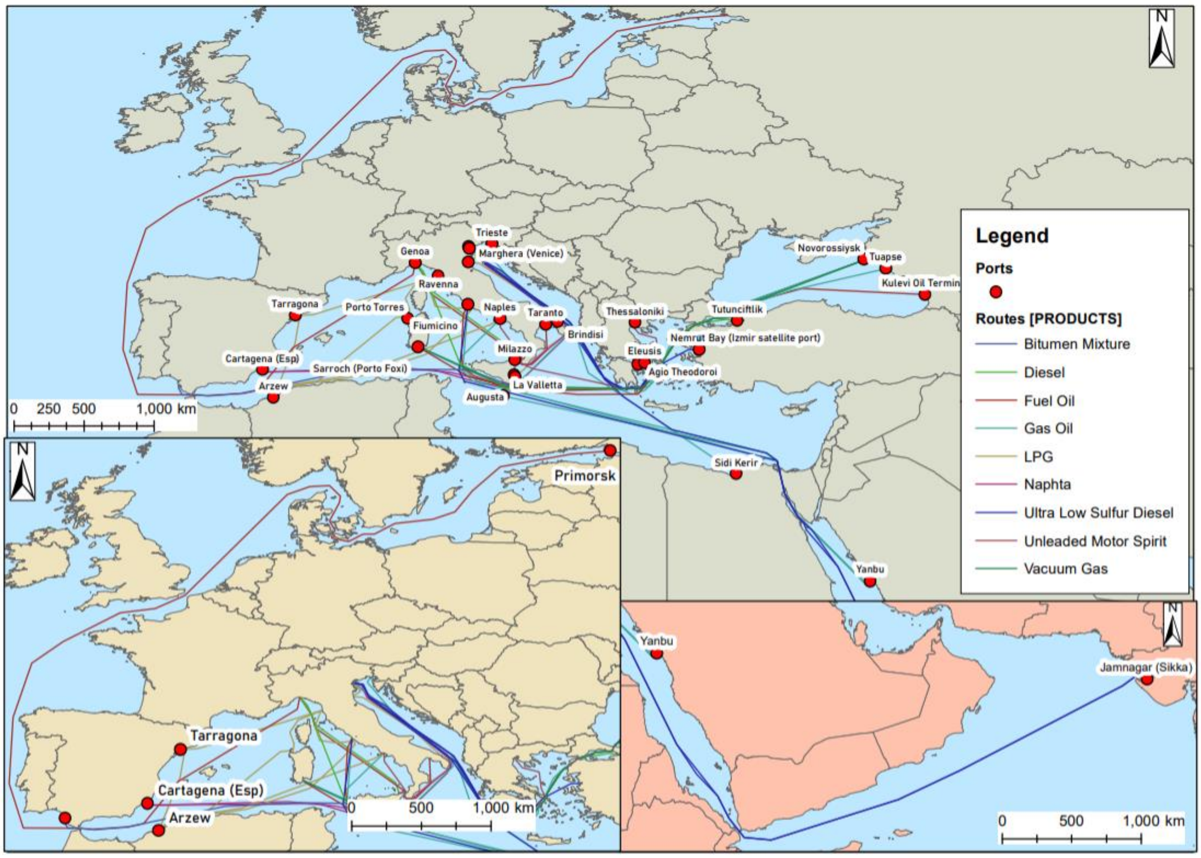


*Figure 28 - Oil products maritime corridors (Source: Elaboration through GIS based on [7] )*

### *3.2.1. Maritime threats*

The investigation of the possible causes that can lead to a corridor failure have brought to the identification of the following parameters:

a) Shipping in a country national water and in the international water;

b) Piracy and armed robbery;

c) Chokepoints disruption;

d) Ships failure;

The navigation is globally ruled by the "United Nations Convention on the Law of the Sea" [27], signed in the 1982 at Montego Bay, Jamaica. Nowadays, 164 countries have ratified the treaty. The convention's aim is to establish the authority on the maritime zones to coastal country through a systemic zoning of the sea. The classification includes:

1. Territorial water: 12 M from the coast;
2. Contigue zone: 24 M from the coast;
3. Exclusive economic zone: 200 M from the coast;
4. Continental platform: until 350 M or until 100 M from the isobath of 2500m;

5. International water: over the ZEE or the Continental platform;

The navigation rules that affect the formulation of the maritime risk can be resumed into 3 principal points:

1. All the ships have the right of free navigation in all the maritime zones;
2. Transit fees can be imposed only for services received;
3. The coastal country has the right to apply every measure to guarantee the respect of its law until the ZEE and, in case of war, can lock the navigation in its water;

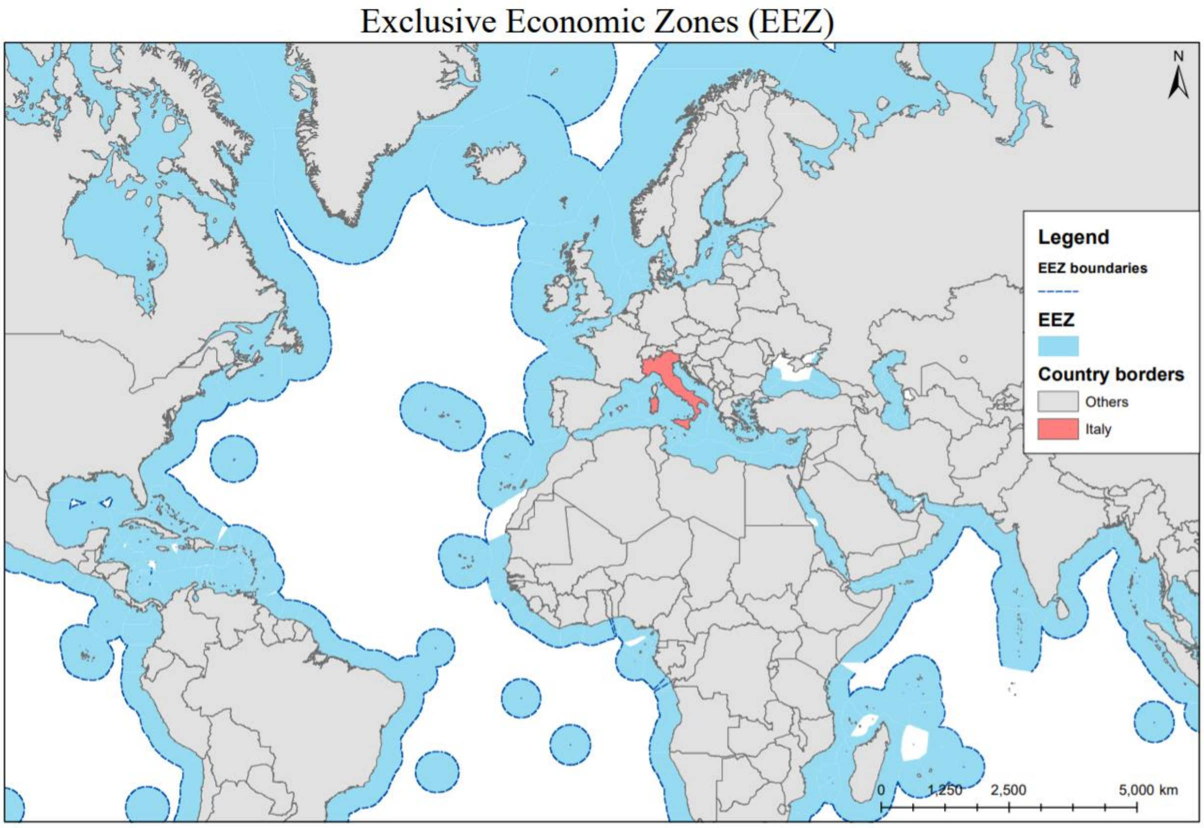


*Figure 29 - Mapping of international EEZ (Source: Elaboration based [28])*

Therefore, the probability of failure of the corridor crossing a EEZ strongly depends on the geopolitical stability of the coastal country. This aspect is described by several indexes available in the literature. In this dissertation is used the Worldwide Governance Indicator (WGI) [29] which provides aggregate and individual governance indicator for more than 200 country over the period 1996-2018 (Appendix D: Geopolitical and maritime security assessment). In particular the final composite index, ranging from 0 to 100, is obtained as the average of six minor index:

- Voice and Accountability: citizens' participation in the selection of the government, freedom of expression, free media, freedom of association
- Political stability and absence of violence: political instability and/or politically motivated violence
- Government effectiveness: quality of the public services, civil services, credibility of the government

- Regulatory quality: ability of the government to implement policies and regulation that promote private sector development
- Rule of law: quality of contract enforcement, properties right, police, court, probability of crime and violence
- Control of corruption: capture the perception of the extent to which power is exercised for private gain

The final index is obtained by the average between the minor index considered with the same weight:

$$\varphi_k = \sum_{j=1}^{6} \frac{WGI_j}{6}$$

Where:

- $\varphi_k$ geopolitical risk of the country;

The presence of criminal activity in the sea have to be taken into account because can lead to an oil tanker's seizure and therefore to the failure of the corridor. The definition of piracy and armed robbery are provided by the *International Maritime Bureau (*IBM) [30]:

- Armed robbery: act of violence, depredation […] committed within territorial sea;
- Piracy: act of violence, depredation […] committed within the EEZ or the international water;

The *IBM* is a specialized department of the international chamber of commerce that try to fight against all the crimes related to the maritime trade. It reports in real time all the piracy and armed robbery event all over the world. Although it stores all the data collected for each year it does not provide a security index. A piracy index can be found in "The state of maritime piracy" [31], a publication of "stable sea programme" promoted by "One Earth Future". It is an international foundation that develops programs designed to foster sustainable peace (Appendix D: Geopolitical and maritime security assessment). The index of piracy and armed robbery ranges between 0 and 100: 100 corresponds to the absence of any piracy and armed robbery attacks whereas 0 corresponds to the maximum frequency of piracy and armed robbery attacks. The index is built by considering only the attacks until 1000 km from the coast and giving more weight to the nearest ones. An empirical function is developed to rescale all the distance between 0 and 1 giving more weight to the nearest ones through logarithmic dependence.

$$Transformed\ Event\ Distance = \frac{Ln\left(\frac{distance}{100} + 1\right)}{Ln(\frac{1000}{100} + 1)}$$

The piracy and armed robbery index ($\eta_c$) is calculated taking into account the nearest 25 attack:

$$\eta_c = \frac{\sum_{i=1}^{25} Transformaed\ event\ distance_i * (25 - i)}{\sum_{i=0}^{25} (25 - i)}$$

Each attack is multiplied by the inverse weight so that the nearest have more influence respect the further. The choice to consider 25 events derive from the observation that the final result does not change in a significant way if the number of attacks considered increase. Finally, the results are displayed through a graphical world representation. The more critical countries are those in the Asiatic archipelagos, the territorial water of Somalia and Yemen and in the west side of Africa. It is clear the relationship between the piracy and the level of poverty that push the local people to commits oil tankers seizures and sailor kidnapping.

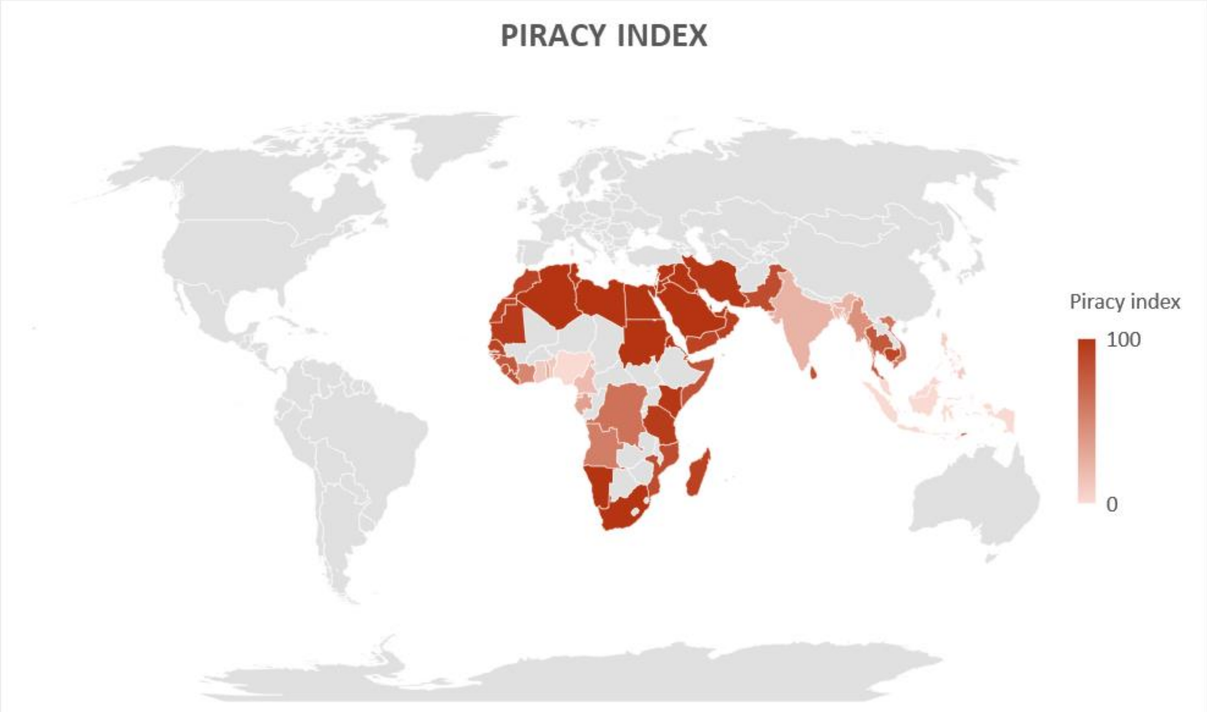


*Figure 30 - Piracy index, GIS elaboration*

The presence of a strait strongly affects the probability of failure of maritime routes because force all the ships to travel in the narrow chokepoint or, in case of straits disruption, to find an alternative route. Two type of chokepoint are defined in literature [32]:

- Conventional chokepoint: a narrow channel that joints two larger adjacent bodies of water in a natural way
- Non-conventional chokepoints which are characterized by high ships traffic because of their strategic locations even though they are not really straits

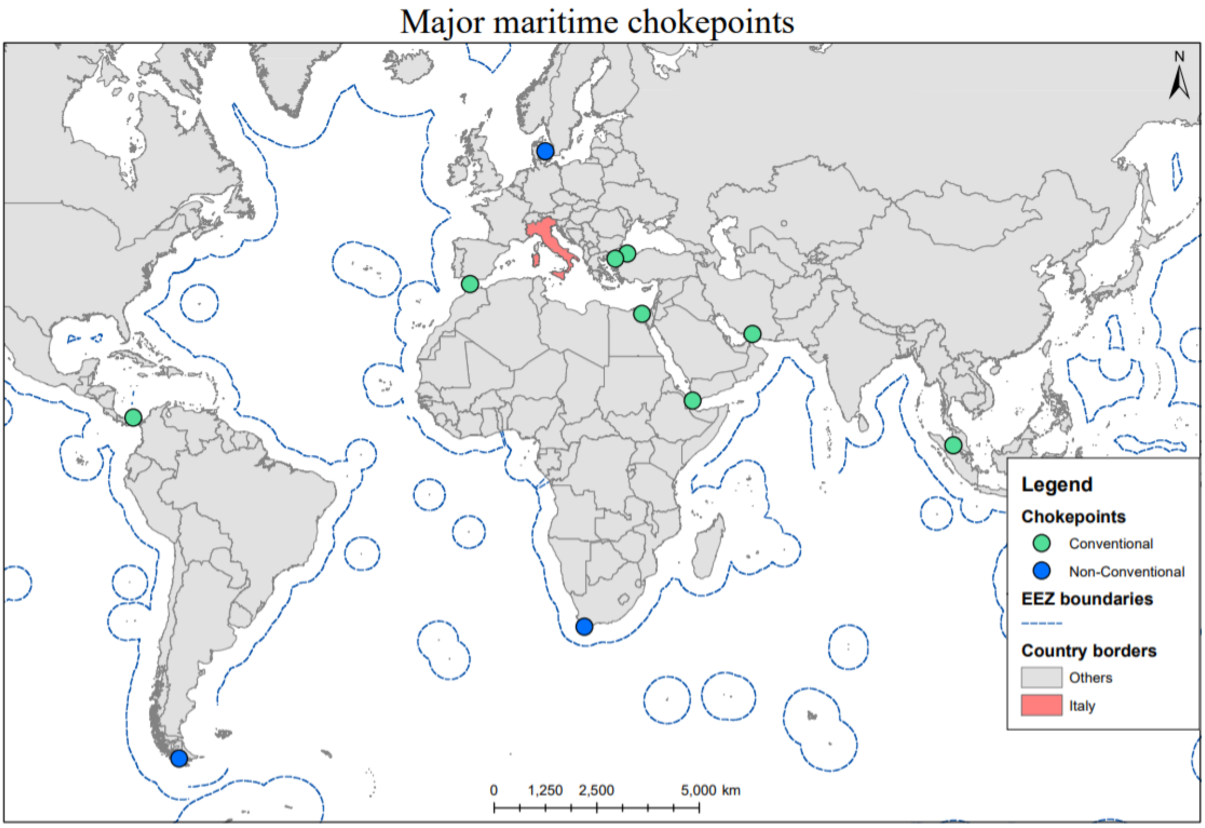


*Figure 31 - Major maritime chokepoints (Source: Elaboration based on [32] )*

According to Figure 32 the most critical chokepoints for Italian crude oil supply are the strait of Gibraltar, the Turkish straits, the Suez Canal, the strait of Bab-el-Mandeb, the straits of Hormuz and the straits of Malacca. The sovereign countries have to deal with the safety of the maritime traffic and usually a Traffic Separation Scheme (TSS) is imposed in order to reduce the risk of collision and to rule the ships movement [33].

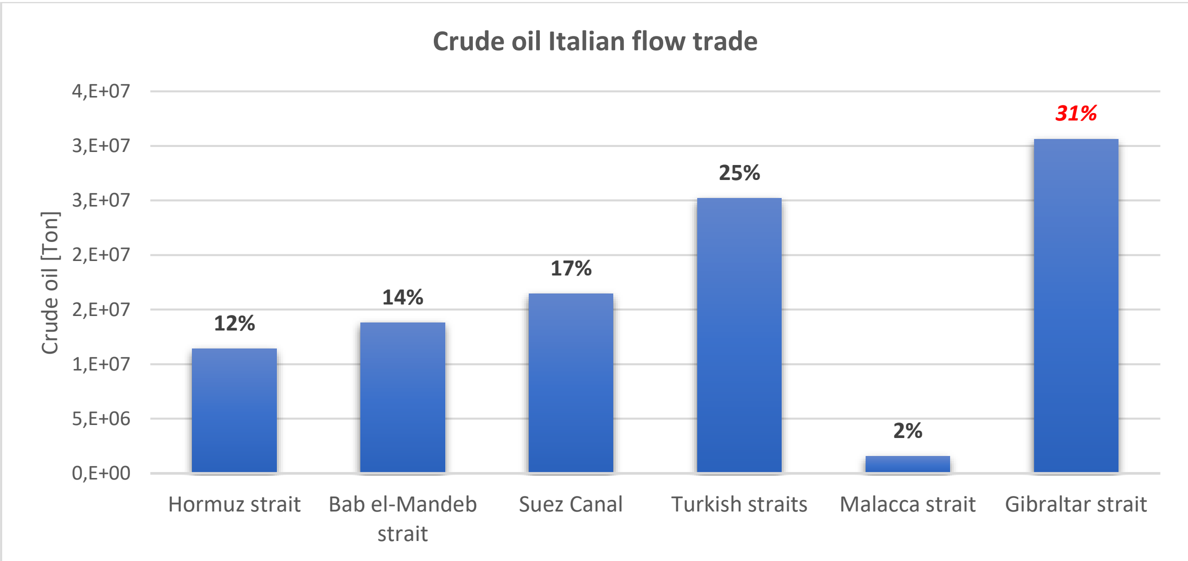


*Figure 32 - Italian oil trade through chokepoints (Source: Elaboration based on [7])*

The chokepoint disruption is defined as the ships inability to cross it. The causes of a failure belong to the geopolitical field: war, embargo, international tension and so on. Therefore, it depends on the geopolitical risk of the sovereign countries that control the strait and on the eventually presence of piracy and armed robbery.

$$\xi_{choke} = f(\varphi_c; \eta_c)$$

The failure of a chokepoint can be defined as a "High-Impact Low-Probability" (HILP) event since it is a very rare event with a great impact in case of occurrence. It is included inside the accident of category 3 [24] differently respect to the maritime accidents.

The ship failure analysis is performed by using the data published by Allianz [34], the largest insurance company in the maritime field. According to Allianz, the loss of a ship can be due to:

- Foundered
- Wrecked/stranded
- Fire/explosion
- Machinery damage
- Collision

The resume of the main ship accidents in the last decade grouped per area of happening is reported in Appendix D: Geopolitical and maritime security assessment. This parameter is not taken into account for the risk analysis model given that the very low number of ship failure respect to the total maritime traffic and the absence of correlation between geographical area and the failure.

### *3.2.2. Quantification of maritime probability of failure*

The probability of a maritime corridor failure is a number between 0 and 1 that express the likelihood that the commodity does not reach the destination. The mathematical formulation derives from the fault tree that takes into account all the relevant parameters identified in 3.2.1.

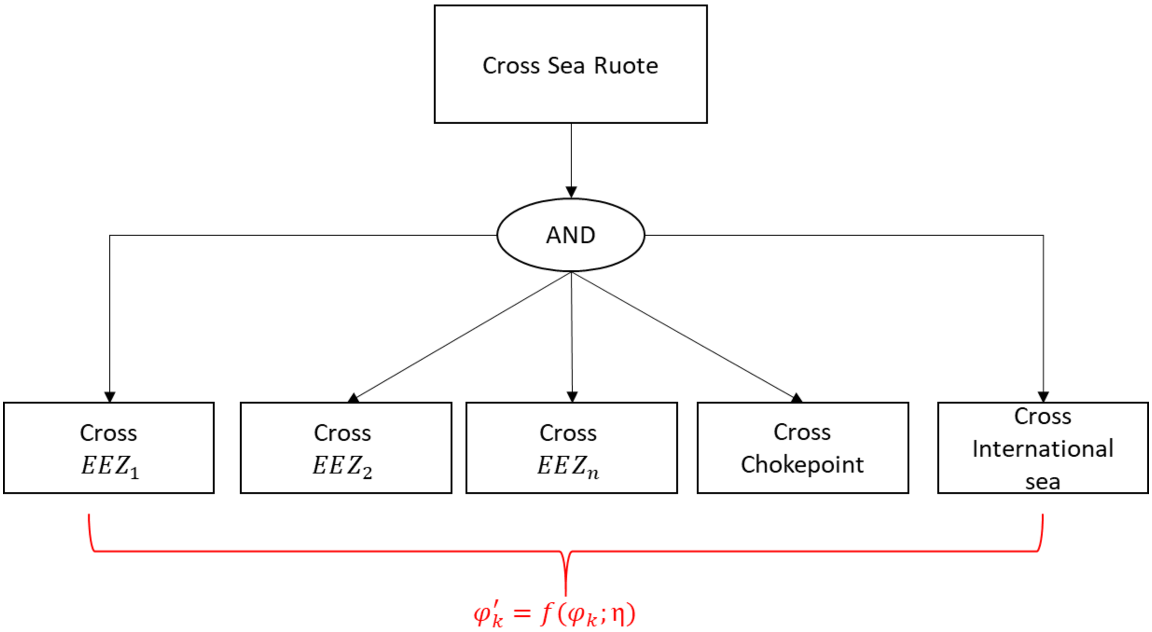


*Figure 33 – Fault tree of open-sea corridor probability of failure*

The two factors that have to be considered are WGI and the piracy and armed robbery index of the coastal countries. In order to express both the aspect in a unique value, the maritime WGI index $\varphi'_k$ is developed.

$$\varphi'_k = \frac{\varphi_k + \eta_k}{7}$$

Differently from the ZEE, the international waters are not under the jurisdiction of any state but are regulated by the international law. Since in literature does not exist a specific index the arithmetic average of the WGI world index is used.

$$\bar{\varphi}' = \frac{\sum \varphi'_k}{K} = 44.7$$

Where;

- $K$ total amount of coastal countries;
- $\varphi_k$ geopolitical risk of the k country;

The probabilities of cross different ZEE along the corridor are independent from each other because all the countries have to be successfully crossed in order to reach the final destination. Therefore, it is necessary to multiplied each maritime geopolitical risk. Actually the “spatial dimension” must be taken into account: each corridor can be divided in branches of different length according to the ZEE or country crossed. A weighting index $\gamma_k$is introduced so that the contribution to the overall risk of the single branch would be proportional to his length.

$$\gamma_k = \frac{l_i}{L_{tot}}$$

Where:

- $l_i$ length of a branch
- $L_{tot}$ is the total length of the maritime route

The final formulation is:

$$\xi_{rotta} = 100 * [1 - \prod \left(1 - \frac{\gamma_k * \varphi'_k}{100}\right)]$$

Where:

- $(1 - \frac{\varphi_k'}{100})$ is the probability of success of crossing country k
- $\prod_{k_i \in K_i}(1 - \frac{\varphi_k'}{100})$ is the probability (of independent event) of success of crossing all the country k involved along the corridor route
- $1 - \prod_{k_i \in K_i}(1 - \frac{\varphi_k'}{100})$ is the probability of failure for the entire corridor, and it is expressed as the complement of the probability of success

The international water is considered as a country with its corrected WGI index.

The radial graph shows the difference between the normal WGI index and the maritime WGI index. In general, the $\varphi'_k$ is lower respect $\varphi_k$ except for few cases such as Singapore, Malesia, and Nigeria that are strongly affected by the presence of the piracy and armed robbery phenomena.

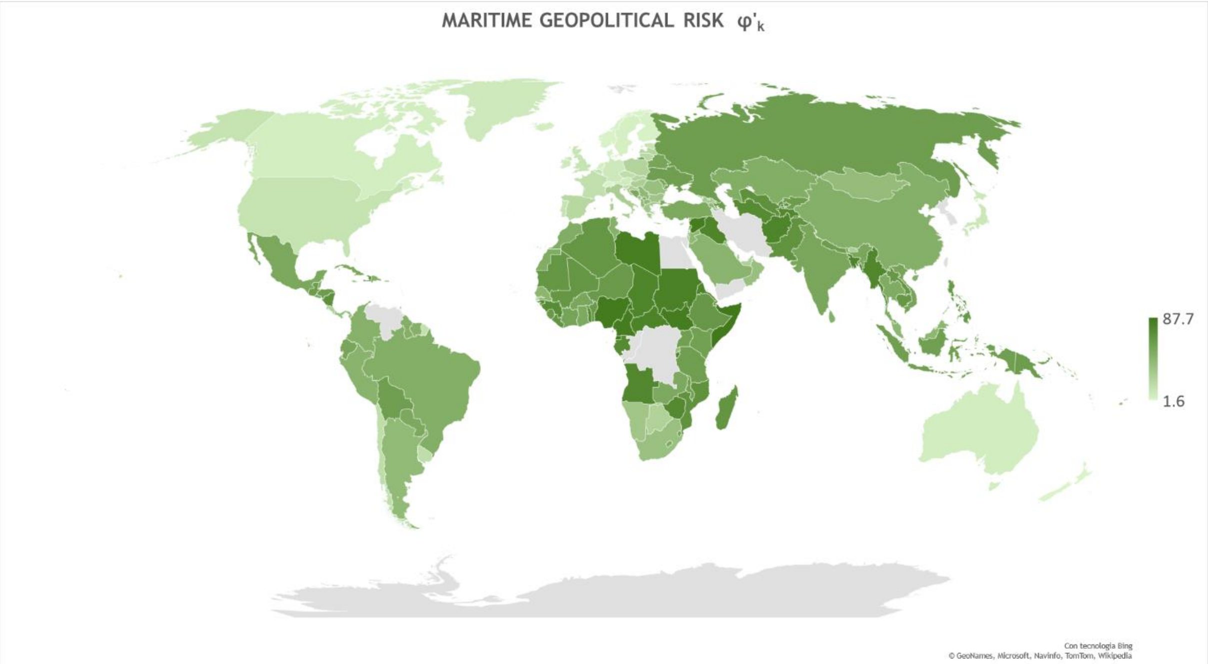


*Figure 34 - Maritime geopolitical risk $\varphi'_k$, GIS elaboration*

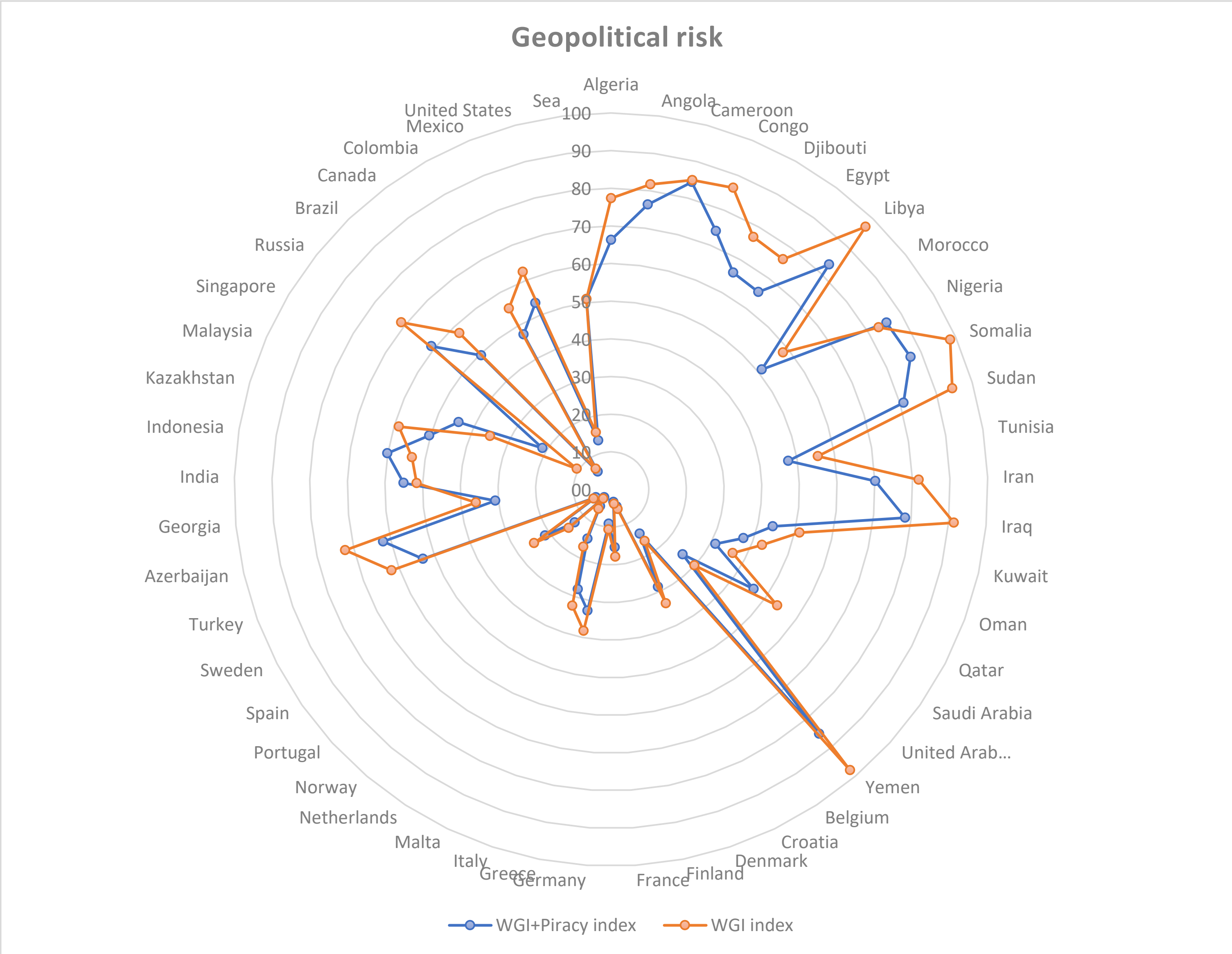


*Figure 35 - Comparison between geopolitical and maritime Geopolitical risk (Source: Elaboration based on: [29] and [31])*

The chokepoint parameter is separately handled respect to the countries' ZEE even if it has the same logical role according to the fault tree. Indeed, from a theoretical point of view, the strait is a "punctual element" on the corridor and a different chokepoint probability of failure assessment is required. The probability of chokepoint failure is defined with the following equation:

$$\xi_{cp} = L_{cp} * \dot{\alpha}$$

Where:

- $\xi_{cp}$ is the probability of chokepoint failure;
- $L_{cp}$ is the likelihood of failure;
- $\dot{\alpha}$ is the vulnerability index;

The likelihood of chokepoint failure is supposed to be very low due to:

- Low number of past critical events;
- International chokepoints agreement;
- International task force guarding the straits;

A bibliographical research, resumed in the following table, highlight the main critical event which have involved a partial or total failure of the straits in the last century. A partial failure means a reduction of the total amount of trade or the strait closure for a specific country.

*Table 7 - Historical chokepoints disruptions (Source: Elaboration on [35] and [36])*

| ***Historical chokepoints disruption*** | | | |
|---|---|---|---|
| *Chokepoints* | *Failure* | *Type of Failure* | *Failure duration* |
| Hormuz | Tank war | Partial | 8 years |
| | Iran-USA economic conflit | Partial | 4 years |
| Bab el-Mandeb | [-] | Never | [-] |
| Suez | Israeli-Egyptian war 1957 | Total | 3 months |
| | Six-Days War 1967 | Total | 8 years |
| Turkish | I world war | Partial | 4 years |
| Malacca | [-] | Never | [-] |
| Gibraltar | I/II world wars | Partial | 9 years |

The low frequency of these disruption event confirm that a chokepoint is a HILP. Therefore, instead of the historical likelihood, is taken into account the maritime geopolitical risk of the sovereign countries provided by the maritime geopolitical index $\varphi'$. In case of more than one sovereign state the average value is considered.

$$L_{cp} = \bar{\varphi}'_k$$

*Table 8 - Chokepoints likelihood of disruption (Source: Elaboration based on [29] )*

| ***Likelihood*** | | | |
|---|---|---|---|
| *Chokepoints* | *Sovereing country* | $\varphi'_k$ | $\bar{\varphi}'_k$ |
| Hurmuz strait | Iran | 70.2 | 53.8 |
| | Oman | 37.4 | |
| Bab el-Mandeb strait | Djibouti | 66.1 | 75.6 |
| | Yemen | 85.2 | |
| Suez canal | Egypt | 65.4 | 65.4 |
| Turkish straits | Turkey | 53.2 | 53.2 |
| Malacca strait | Malaysia | 44.2 | 41.9 |
| | Singapore | 21.3 | |
| | Indonesia | 60.2 | |
| Gibraltar strait | Spain | 21.4 | 28.4 |
| | Morocco | 51.2 | |
| | England | 12.7 | |

Nevertheless, the maritime WGI index does not take into account the conformation of the chokepoint that plays an import role in safety assessment. For this purpose, each value is multiplied by the vulnerability index.

$$\alpha_{cp} = \frac{\text{length}_{\text{cp}}}{\text{width}_{\text{cp}}}$$

The vulnerability index expresses the strait's intrinsic tendency to be less or more susceptible to an eventually closure. Higher is the length and lower is the width, more critical is the strait. Indeed, a very narrow strait is easily controlled by the sovereign countries that at every time can block it by sinking some oil tankers or by deploying a small number of combat ships. The index is normalized respect to the highest and lowest value in order to obtain a coefficient ranging between 0 and 1.

$$\alpha\dot{\_cp} = \frac{\ln\left(\alpha_{cp}+1\right) - \ln\left(\alpha_{cp_{\min}}+1\right)}{\ln\left(\alpha_{cp\_}+1\right)}$$

Table 9 - Chokepoint probability of failure

| ***Probability of failure*** | | | | | |
|---|---|---|---|---|---|
| *Strait* | *Length [km]* | *Navigable width [km]* | $\dot{\alpha_{cp}}$ | *L* | $\xi_{choke} = L * \alpha\dot{\_cp}$ |
| *Hormuz* | 60 | 3 | 0.28 | 53.8 | 14.9 |
| *Bab el mandeb* | 130 | 28 | 0.03 | 75.6 | 2.4 |
| *Suez Canal* | 190 | 0.3 | 0.91 | 65.4 | 59.7 |
| *Turkish strait* | 70 | 0.7 | 0.57 | 53.2 | 30.3 |
| *Malacca* | 800 | 50 | 0.24 | 41.9 | 10.0 |
| *Gibraltar* | 60 | 14 | 0.02 | 28.4 | 0.6 |
| *Panama* | 81.1 | 0.08 | 1.00 | [-] | [-] |
| *Dover* | 560 | 34 | 0.24 | [-] | [-] |
| *Danish strait: big belt* | 60 | 16 | 0.00 | [-] | [-] |
| *Danish strait: small belt* | 50 | 0.8 | 0.48 | [-] | [-] |

The most critical chokepoint is the Suez Canal because it is totally controlled by the Egypt that has a high maritime geopolitical risk and moreover, it is characterized by a critical conformation that render the strait susceptible to suddenly closure (v. Table 7). On the other hand, Gibraltar probability of failure is almost zero: the likelihood of disruption is low because of the geopolitical stability of Spain and the geographical shape do not allow to a total blocked.

Therefore, the final formulation of the maritime probability of failure is obtained:

$$\xi_{OpenSea} = 1 - [(1 - \xi_{choke}) * (1 - \xi_{rotta})]$$

$$\xi_{OpenSea} = 1 - (1 - L_{cp} * \dot{\alpha}) * (1 - 100 * [1 - \prod\left(1 - \frac{\gamma_k * \varphi'_k}{100}\right))$$

Where:

- $1 - \xi_{choke}$ is the probability of success in crossing the chokepoint;
- $1 - \xi_{rotta}$ is the probability of success in travel the maritime route;

## 3.3. Captive corridors

Currently, Italy has only one pipeline that cross the national border and allow to trade crude oil with the others countries. It is an important European project called *Trans Alpinen Leigtung (TAL)* that links the terminal of Trieste with eight foreign refineries in Germany, Austria and Czech Republic [19]. Since it is an exports channel for the crude oil, it is neglected in this discussion because, from the Italian point of view, the TAL does not represent an external risk. Nevertheless, the failure of a foreign pipeline could have strong impact on the global oil affecting also the Italian energy security. The characterization of the main foreign pipelines that are involved in the oil trade toward Italy is performed through a bibliographical survey and the purchasing of Energy Web Atlas (EWA) products. EWA provides a fully integrated global intelligence platform for liquids and gas pipelines, LNG, gas processing, refining and petrochemical projects. The analyse of the database have underlined that almost all the exporting port are supplied by pipeline systems. Indeed, they represent the cheaper oil means of transport on-shore because allow to handle millions of oil tonnes every year. It will be impossible to reach the same result with wheeled transport.

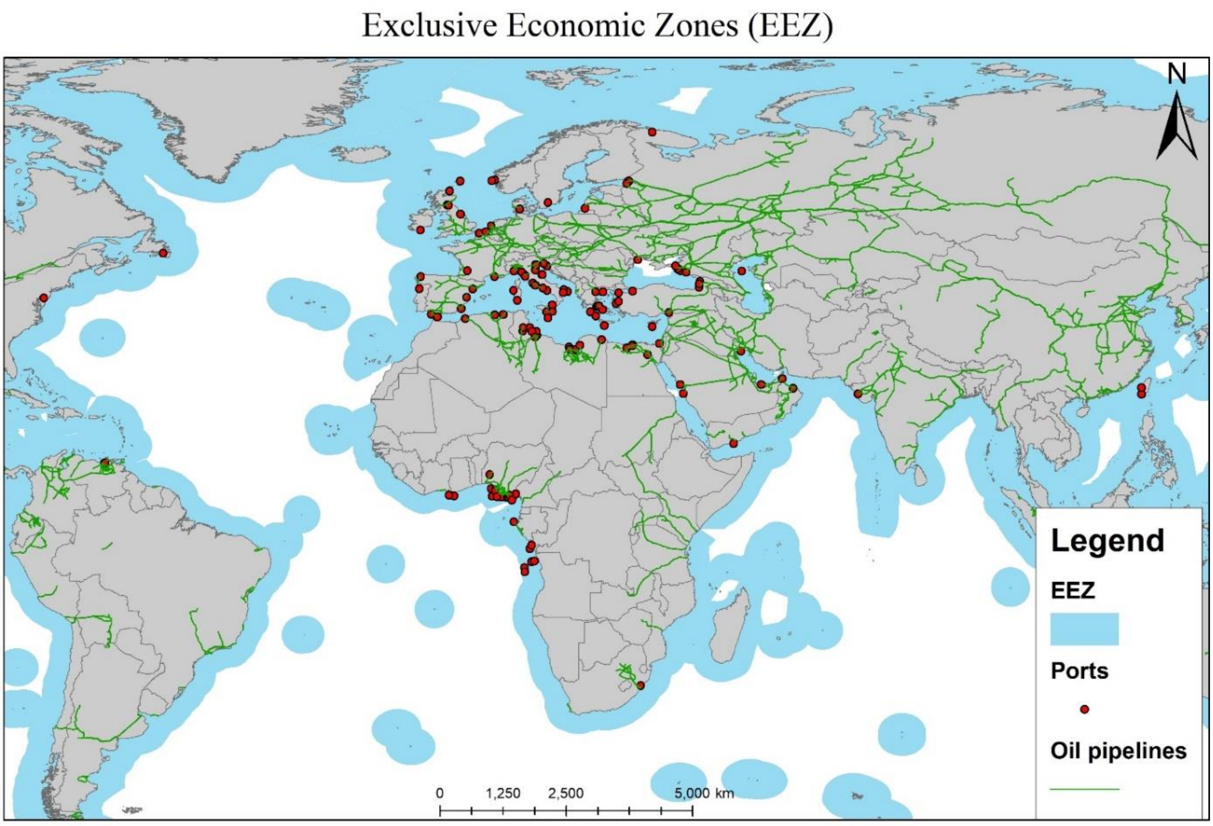


*Figure 36 - Captive corridor (Source: Elaboration through GIS based on [7] and [21] )*

### *3.3.1. Captive threats*

As for the maritime route, also the probability of failure of the captive corridor depends on the geopolitical stability of the crossed country expressed by the WGI index. The geopolitical index is used without the correction of the parameter piracy and armed robbery that is meaningless on-shore. In particular the attention is focused on the “international” pipelines that have to cross at least one national border because different values of geopolitical risk index have to be used. For the internal pipeline is sufficient to know the length because the WGI index is the same for all the route. The Table 10 resume the data obtained from the EWA shapefiles.

*Table 10 - Characterisation of the main captive corridors (Source: Elaboration based on [21])*

| ***Main captive corridors*** | | | | | |
|---|---|---|---|---|---|
| *Pipelines [EWA]* | *Commodity* | *Start Point* | *End point* | *Total Length [km]* | *Capacity [ton/y]* |
| Baku-Tiblisi-Ceyhan pipeline (BTC) | Crude oil | Sangachal (Azerbaijan) | Ceyhan (Turkey) | 2204 | 49.3 |
| Iraq-Turkey pipeline | Crude oil | Kirkuk (Iraq) | | 1225 | 78.9 |
| Caspian pipeline consorzium (CPC) | Crude oil | Astrakhan (Kazakhstan) | Novorossiysk (Russia) | 2149 | 34.5 |
| Northen Early Oil (NEO) | Crude oil | Sangachal (Azerbaijan) | | 1805 | 5.0 |
| YUG | Product | Russian internal pipeline | | 1020 | 4.0 |
| JSC | Crude oil | Russian internal pipeline | | 223 | 3.0 |
| SUMED | Crude oil | Ain Sukhna (Egypt) | Sidi Kerir (Egypt) | 368 | 123.3 |
| CORC | Crude oil | Suez (Egypt) | | 550 | 7.8 |
| Uzen-Atyrau-Samara (UAS) | Crude oil | Uzen (Kazakstan) | Ust-Luga (Russia) | 4575 | 24.7 |
| Western route export pipeline (WREP) | Crude oil | Sangachal (Azerbaijan) | Supsa Marine Terminal (Georgia) | 995 | 7.2 |
| Baltic pipeline system 1 (BPS_1) | Crude oil | Russian internal pipeline | | 3794 | 76.5 |
| Baltic pipeline system 2 (BPS_2) | Crude oil | | | 3794 | 50 |
| Egypt | Crude oil | Egyptian internal pipeline | | 830 | [-] |
| Iraq | Crude oil | Iraqi internal pipepline | | 1421 | [-] |
| Libya | Crude oil | Libyan internal pipeline | | 780 | [-] |

The main captive corridors are concentrated is the Caspian area providing a total oil flow capacity of 124 million tons per year. Indeed, Kazakhstan and Azerbaijan have great availability of crude oil reserves but they do not have access to the Mediterranean Sea. The CPC pipeline consortium and the UAS transfer the Kazaki crude oil extracted in the Caspian Sea to the Russian ports, while the NEO, WREP and TBC deliver the Azeri crude oil respectively to Russia and Georgia and Turkey. The Iraqui-Turkey pipeline delivers the Iraqui crude oil, extracted from the Kirkuk oil field, to the Turkish port of Ceyhan. The pipeline has been designed with the aim to reduce the Iraqi exporting dependency from the ABOT terminal that represents the only outlet by sea. Others important infrastructures are the Egyptian SUMED and CORC pipelines that support the operation of the Suez Canal. Indeed, the bigger oil tankers have a draft incompatible with the depth of the canal therefore, before the transit, they dock to the terminal of Ain Sukhna and partially discharge the commodity transported in order to reduce the draft. After having pass the canal they recover the load in the Sidi Kerir port where the Sumed and CORC pipelines end.

### *3.3.2. Quantification of captive probability of failure*

The captive corridor probability of failure depends on the successfully crossing the national border. As for the maritime route, the probability of cross the countries are independent from each other. The mathematical formulation derives from the fault tree that takes into account all the relevant parameters identified in 3.3.1.

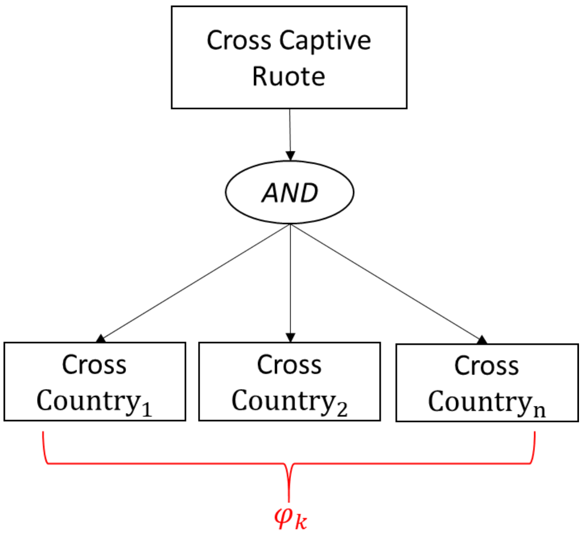


*Figure 37 - Fault tree of captive corridors probability of failure*

$$\xi_{\text{Captive}} = 100 * [1 - \prod \left(1 - \frac{\gamma_k * \varphi_k}{100}\right)]$$

Where $\gamma_k$ takes into account the "spatial dimension" by giving a weight to the branches of the captive corridor depending on their length.

$$\gamma_k = \frac{l_i}{L_{tot}}$$

In the end, the overall probability of failure associated to each corridor is calculated with the following empirical function developed according to the overall fault tree (Figure 24):

$$\xi_i = 1 - [(1 - \xi_{OpenSea}) * (1 - \xi_{Captive})]$$

On the contrary, the probability of success is:

$$\omega_i = (1 - \xi_{OpenSea}) * (1 - \xi_{Captive})$$

Where:

- $1 - \xi_{OpenSea}$ is the probability of success in crossing the open sea route;
- $1 - \xi_{Captive}$ is the probability of success in crossing the captive corridor;

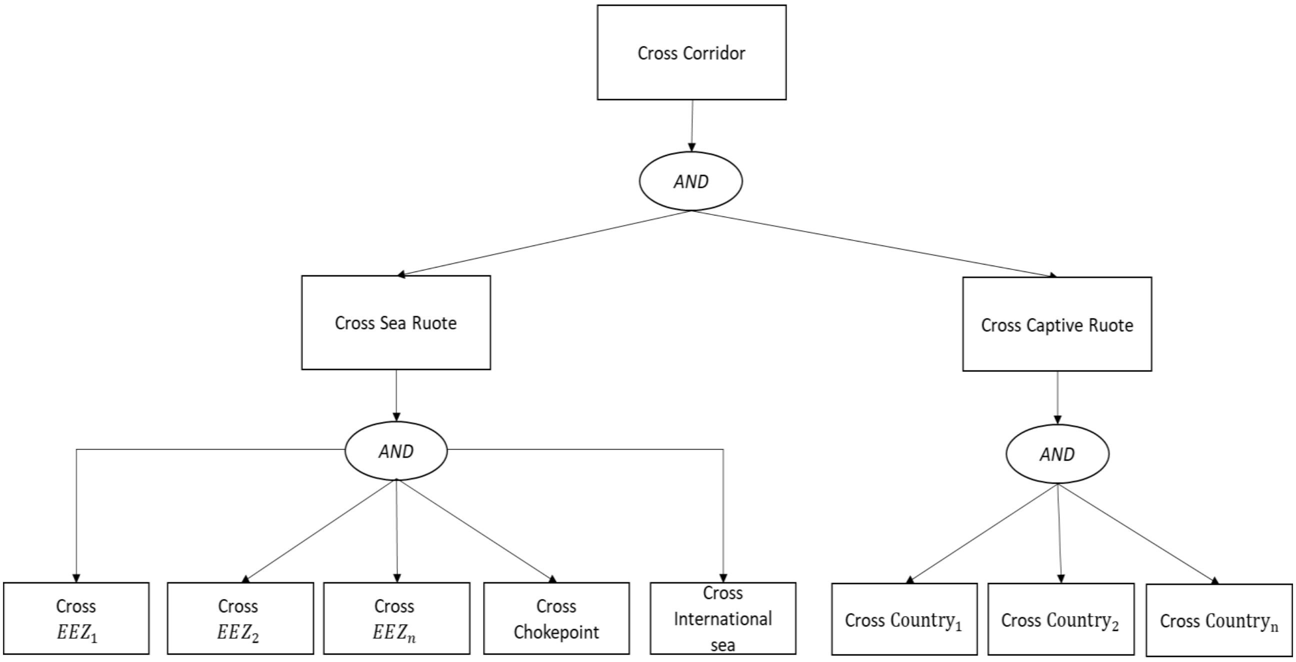


*Figure 38 - Fault tree, probability of failure assessment*

## 3.4. Overall risk assessment

Finally, the corridor risk can be obtained multiplying the probability of failure with the consequences of the failure that is the amount of energy characterizing each corridor [25].

$$R^c{}_i = \xi * E^c{}_i$$

Where:

- $E_i$ is the energy transported through the corridor $i$;

The overall formula, contains all the parameter described, is the following:

$$R^c{}_i = 1 - [(1 - \xi_{OpenSea}) * (1 - \xi_{Captive})] * E^c{}_i$$

$$R^c{}_i = [1 - (1 - (1 - L_{cp} * \dot{\alpha}) * (1 - 100 * [1 - \prod\left(1 - \frac{\gamma_k * \varphi'_k}{100}\right)]) * (1 - 100 * \left[1 - \prod\left(1 - \frac{\gamma_k * \varphi_k}{100}\right)\right])] * E^c{}_i$$

The calculation of the corridor probability of failure is implemented through an excel spreadsheet. The Figure 40 resumes the supply chain of the oil that reach the national border, reporting for each step the data providers take into account.

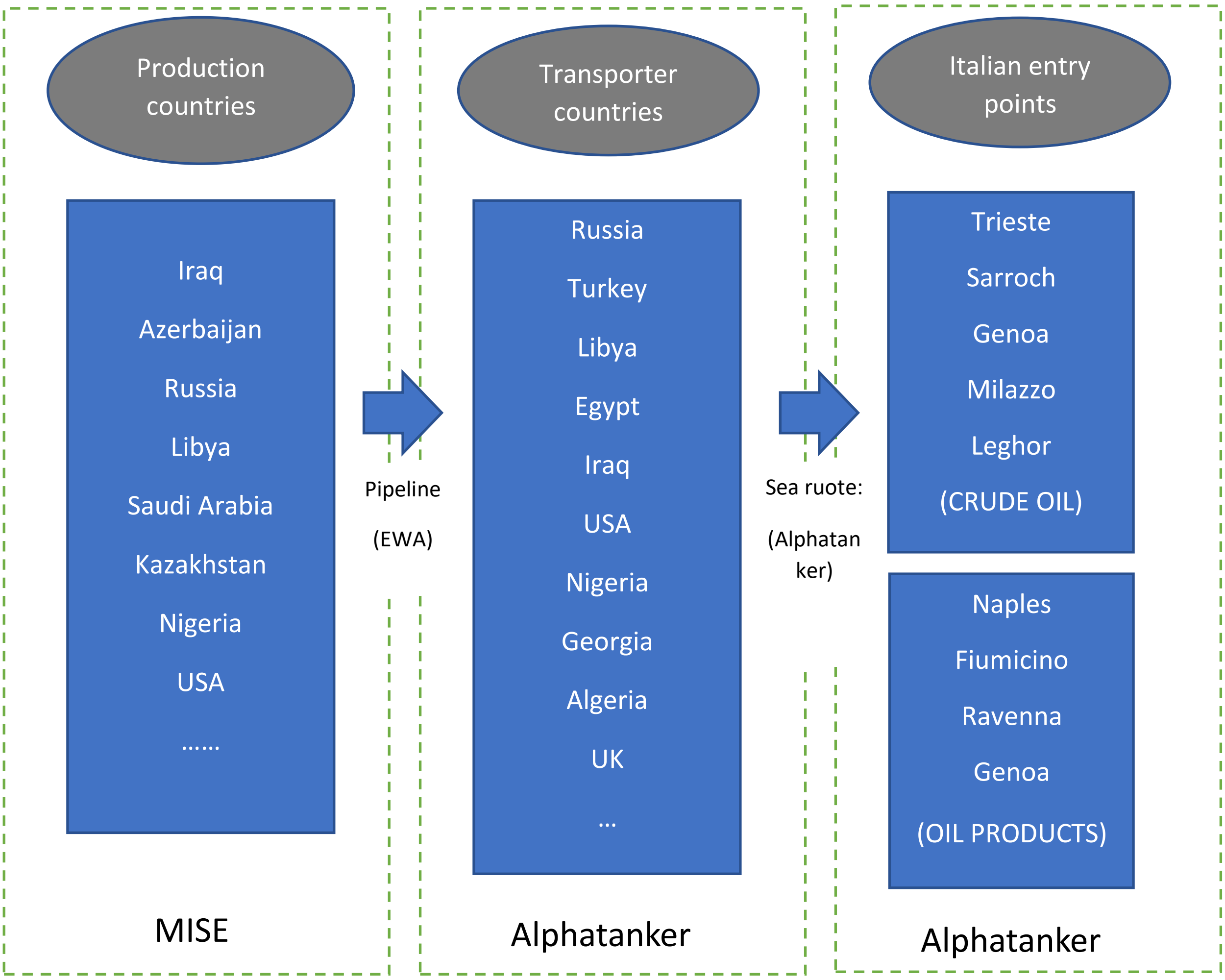


*Figure 40 – Oil supply chain*

Even if the mathematical formula is obtained, it is not possible to directly apply it in the model previously described. Indeed, there are several "practical" problems that have to be discussed and solved with simplifying assumptions.

### *3.4.1. Energy flux diversification*

The evaluation of the corridor energy is not trivial because the amount of commodity transport by the sea route can have different origins and consequently different probability of failure. This happen for the major port that usually are linked through "international pipelines" with the production countries that do not have direct access to the sea. Therefore, the energy of the maritime corridor has to be split in as many components as are the country of origin.

The main turkey exporting port is an explanatory example. Ceyhan exports crude oil that derives from Azeri and Iraqi's production fields through the Baku-Tbilisi-Ceyhan pipeline and the Iraq-Turkey-Pipeline. Therefore, the total amount of crude oil transported by the oil tanker have to be split in two components.

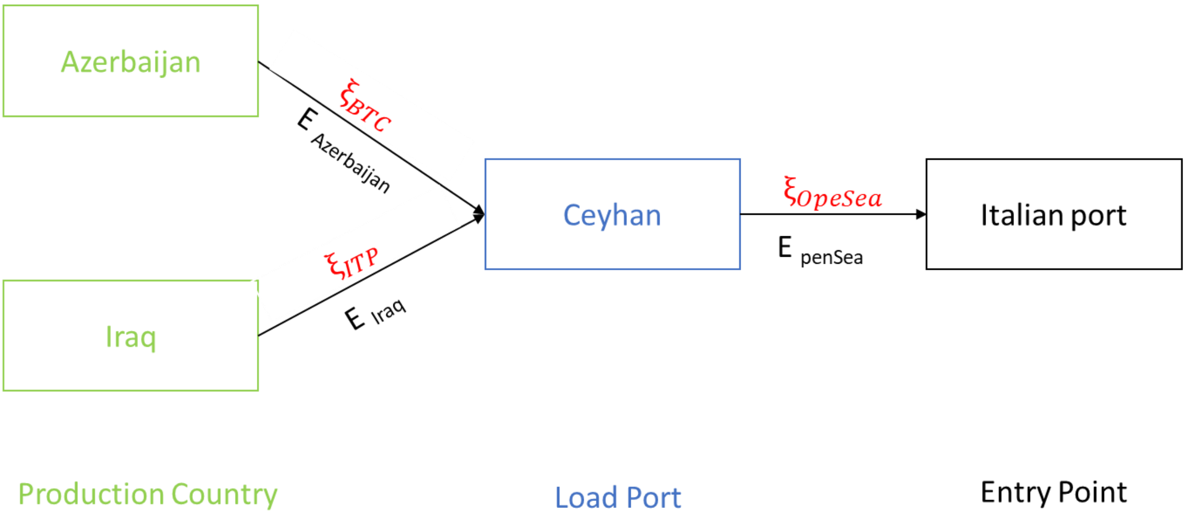


*Figure 41 - Energy diversification conceptual map*

The main corridor Ceyhan-Italy have to be split in two sub-components:

- Iraq-Ceyhan-Italy: $\text{Risk}_{\text{Azerbaijan}} = [1 - (1 - \bar{\xi}_{BTC}) * (1 - \xi_{\text{OpenSea}})] * E_{Azerbaijan}$ ;
- Azerbaijan-Ceyhan-Italy: $Risk_{Iraq} = [1 - (1 - \xi_{ITP}) * (1 - \xi_{\text{OpenSea}})] * E_{Iraq}$ ;

Where the sum of the energy coming from Azerbaijan and Iraq is equal to the energy transported in the sea corridor Ceyhan-Italy.

Nevertheless, the EWA data about the pipelines are not complete: the information about the effective used capacity is not available and the minor crude oil and almost all the product pipelines miss. Therefore, the energy splitting process is carried out with several assumptions. Regarding the crude oil captive corridors:

- All the crude oil reaches the load port through pipelines systems. The eventually wheel transport is assumed to be negligible.
- If there are no "international pipelines" all the commodity is assumed to belong to the load port's country
- In absence of any crude oil pipeline feeding a load port, a captive length section is obtaining depending on the country size. $\overline{Length} = (Area_{country})^{\frac{1}{2}}$
- The energy diversification is performed depending on of the nominal capacity of the pipeline that reach a specific load port. $Share_{pipeline} = \frac{Cp_i}{\sum Cp_i}$

- The investigation of the oil origins ends after the captive corridor which delivers the exporting port. Further travel beyond the captive corridors is not taken into account due to the lack of information. In other words, the origin of the crude oil that flow inside the Sumed or the BTC pipeline is neglected even if it probably derives from Saudi Arabia and Kazakhstan.

*Table 11 - Supplier diversification process (Source: Elaboration based on [7] and [21] )*

| ***Supplier diversification*** | | | | | | |
|---|---|---|---|---|---|---|
| *Load port* | *Total export [ton]* | *Pipelines [EWA]* | *Capacity[ton/y]* | *Share [%]* | *Supply diversification [ton]* | *Country of origins* |
| *Ceyhan - Turkey* | 18,855,927 | BTC | 49 | 0.38 | 7,252,280 | Azerbaijan |
| | | Iraq-Turkey pipeline | 79 | 0.62 | 11,603,647 | Iraq |
| *CPC terminal-Russia* | 14,223,666 | CPC | 35 | 1.00 | 14,223,666 | Kazakhstan |
| *Novorrossiysk - Russia* | 3,763,253 | NEO | 5 | 0.63 | 2,352,033 | Russia |
| | | JSC | 3 | 0.38 | 1,411,220 | Azerbaijan |
| *Primorsk - Russia* | 4,786,280 | BPS_1 | 77 | 1.00 | 4,786,280 | Russia |
| *Ust-Luga - Russia* | 3,428,269 | BPS_2 | 50 | 0.67 | 2,295,771 | Russia |
| | | UAS | 25 | 0.33 | 1,132,498 | Kazakhstan |
| *Supsa Marine Terminal - Georgia* | 2,405,907 | WREP | 49 | 1.00 | 2,405,907 | Azerbaijan |

The crude oil exported by the ports connected with "international" pipelines is assigned to the origins production countries according to the share of pipeline capacity. The assumption used is strong and not representative of the real oil flow, nevertheless it is possible to explain, at least in a qualitative way, the mismatching between MiSE and Alphatanker data (Figure 4). Russia, Turkey and Georgia present higher value of exportation according to Alphatanker because deliver the commodity on behalf of Kazakhstan, Azerbaijan and Iraq through the CPC, WREP, NEO and Iraq-Turkey pipelines. The Egyptian port of Sidi Kerir, through the SUMED and CORC pipelines, carries the crude oil coming from the maritime sea route of Saudi Arabia and Iraq, explaining the exporting surplus of Egypt according to Alphatanker.

The product captive corridors are neglected in the analysis because the EWA dataset provides only few pipeline systems without specifying the type of product transported. There are not sufficient data to obtain reliable results therefore the risk calculation takes into account only the maritime corridors. Summarizing, the limits of the captive corridor's analysis derive from a lack of information and not from conceptual issue. Therefore, the achievement of more detailed data allows to obtain more reliable results with the same model.

### *3.4.2. Corridors grouping*

Finally, through the energy sorting process, the maritime and captive characterization of the digitalized corridors is achieved. Nevertheless, as Table 6 shown, the total amount of commodity considered with the digitalized maritime corridor is not sufficient: 55.3% for the crude oil and 46.7% for the oil products. Therefore, it is necessary to reduce the level of detail in the corridor characterization, by performing a route grouping process, in order to consider a larger share of the oil market. The first step is to calculate the weighted average probability of failure of the digitalized corridor starting from the same country.

$$\overline{\xi_{corridor}} = \frac{(\xi_{corridor_1} * Energy_1 + \xi_{corridor_2} * Energy_2 + \xi_{corridor_n} * Energy_n)}{\sum Energy_i}$$

Afterwards, the less relevant corridor (that are not digitalized) are grouped with the main ones assuming that the route starting from the same country have similar pathway and therefore similar probability of failure. In conclusion the described procedure brings a simplification in the model and therefore an associated error. Nevertheless, the inaccuracy introduced by the route grouping is certainly lower respect to not consider a large share of the market. Table 12 shows a section of the grouping process underling the calculation of the average corridor probability of failure and the grouping of the minor corridor.

*Table 12 - Corridor grouping process (Source: Elaboration based on [7] )*

| ***Grouping routes process*** | | | | | |
|---|---|---|---|---|---|
| *Country* | *Corridor name* | *Corridor energy [TEP]* | *Corridor failure* | *Average failure [$\overline{\xi}$]* | *Final energy considered [TEP]* |
| *Turkey* | Ceyhan-Augusta via BTC | 1,751,816 | 0.418 | 0.403 | 18,943,660 |
| | Ceyhan-Augusta via ITP | 2,802,905 | 0.427 | | |
| | Ceyhan-Genova via BTC | 2,460,642 | 0.407 | | |
| | Ceyhan-Genova via ITP | 3,937,026 | 0.413 | | |
| | Ceyhan - Trieste via BTC | 2,456,347 | 0.382 | | |
| | Ceyhan - Trieste via ITP | 3,930,156 | 0.381 | | |
| *Libya* | Zueitina-Sarroch | 1,210,331 | 0.603 | 0.541 | 14,933,449 |
| | Es Sider - Trieste | 5,562,303 | 0.527 | | |
| *Total* | | 24,111,526 | | | 33,877,109 |

The process allows to consistently increase the analysed percentage of the crude oil and oil product market.

*Table 13 - Final market share considered*

| ***Grouping process resume*** | | | | | |
|---|---|---|---|---|---|
| *Crude Oil* | | | *Oil Products* | | |
| *Digitalized intake* | 54,032,629 | 55% | *Digitalized intake* | 3,806,707 | 47% |
| *Grouping intake* | 80,700,394 | 82% | *Grouping intake* | 5,303,560 | 65% |
| *Total Intake* | 98,413,190 | Share | *Total Intake* | 8,149,760 | Share |

# 4. Scenario analysis

The mathematical model for quantitative energy security assessment developed in chapter 3 is able to characterized each corridor in term of energy, probability of failure and therefore in term of energy at risk. It not performs a forecasting analysis taking into account possible hazardous events that can compromise the security of the Italian energy corridor. Nevertheless, these events can occur and strongly affect the Italian energy security thus a sensitivity analysis, based on the definition of several incidental scenario, is performed.

## 4.1. Scenarios setting

Countless factors can affect the current geopolitical situation. The political instability, the economic situation and cultural factors can lead to a dangerous series of events including war, terrorist attacks, embargos and sudden closure of trade relations between countries. All of them are unpredictable and moreover a geopolitical event in a certain country can also affects others countries in the same geographical area. The proposed methodology can certainly not take into account the complexity of the world nevertheless it is flexible enough to developed several realistic scenarios. Indeed, is possible to modify the model input parameters taking into account different type of failures and the increasing of geopolitical tension. The scenarios are classified in two main categories: *actual* scenario and *potential* scenario. A *potential* scenario is a series of events of which only the potential risk of their occurrence is considered. For example, the worsening of the diplomatic tension between Russia and the European Union could lead to an increasing of the probability of failure of the corridor starting from Russia. Therefore, the *potential* scenario in allows only to act the geopolitical risk index without providing any response to eventually occurrence of accidents. The corridor's energy flow remains constant. On the other hand, an *actual* scenario is a series of events that have happened at the present moment, such as a chokepoint or a corridor disruption, and that require mitigation measures. The mitigations measure are specific countermeasures planned in order to recover the loss of energy due to the adverse event. Particularly attention is paid to the feasibility of the mitigation action that have to be consistent with the oil market previously described.

## 4.2. Disruption assessment

The failure of a corridor implies the loss of the whole amount of energy transported from a specific load port to the Italian entry point. In order to simulate the loss of energy is sufficient to set the failure probability of the corridor to $\xi = 100\%$. The loss of energy is counterbalanced by the increasing of oil import from others foreign ports. The energy redistribution process is not randomly:

- The chosen ports to recover the energy loss are not influenced by the failure;
- The increasing of the import from a load port cannot exceed the 50% given that the adverse event is not predictable and the mitigation measure have to be planned in a very short time;

- The crude oil transported through the lost corridor have to be substitute with a similar type of crude oil. Therefore, not all the port can be used for the redistribution;
- The redistribution ports selected are as near as possible to Italy because the priority is to cover the loss of energy in the minimum amount of time;

The failure of a chokepoint does not necessary involve the completely loss of energy transported by the corridor crossing it. Indeed, in some case alternative pathways are available and therefore, part of the energy flow can be saved. As well as for the corridor failure, the mitigation actions consist in the redistribution of the loss energy through others ports. The impact index is used to expressed the percentage of commodity that could not reach the destination in case of chokepoint disruption. A detailed analysis is carried out for each chokepoint in order to assess the presence of alternative pathways. Two possibilities exist:

- Alternative pipelines;
- Alternative sea-routes;

The availability of the alternative pipelines depends on their unused capacity reported in the "World Oil Transit Chokepoints" published by IEA in 2016 [37]. In case of a chokepoint disruption an eventually available pipeline is able to carry part of the commodity which would be lost. The available capacity is defined as the ratio between the unused capacity of the alternative pipelines over the total trade flow through the chokepoints.

$$C_p = \frac{Unused\ capacity}{Total\ trade\ flow} * 100\ [\%]$$

Instead, the availability of the alternative sea routes is related with the delay that the different routes cause on the ships' travel. The delay is estimated by calculating the average additional distance, using the opensource platform Marine Traffic, and dividing it by the average velocity of the oil tanker that is set at 13 kn (24km/h). The average additional distance is obtained by considering different shipping route through the strait. For each chokepoint the two possibilities are analysed.

*Table 14 - Alternative routes assessment: Available capacity (Source: [37]); Delay (Source: Elaboration based on [38] )*

| ***Alternative routes*** | | | |
|---|---|---|---|
| *Chokepoints* | *Alternative pipeline* | *Available capacity [%]* | *Delay [Days]* |
| Hormuz strait | Petroline, ADCOP | 21.1 | [-] |
| Bab el-Mandeb strait | [-] | [-] | 23.5 |
| Suez canal | Sumed | 19.0 | 23.5 |
| Turkish straits | [-] | [-] | [-] |
| Malacca straits | [-] | [-] | 2.9 |
| Gibraltar straits | [-] | [-] | 31.1 |

Although, in order to compare the available capacity with the delay it is necessary to convert the days into a dimensionless parameter ranging between 0 and 1. The following normalization is used:

$$D = \frac{60 - \boldsymbol{x}}{60}$$

$$X \begin{cases} X & \text{se } X<60 \\ 60 & \text{se } X>60 \end{cases}$$

Where:

- $\boldsymbol{x}$ is the delay expressed in day;
- 60 is a reference value which takes into account the UE legislation related to the oil stock;

Italy, as a member of the European union, need to maintain some oil stocks in order to guarantee a certain level of supply security. The UE legislation (Direttiva UE 2009/119/CE art. 3) state that "an oil stock level equal to the maximum between 90 days of net import or 60 days of internal average consumption " [39]. The oil stocks are managed by the "Organismo Centrale di Stoccaggio Italiano" (OCSIT).

Finally, the value of the impact can be obtained from the following empirical equation:

$$I_{cp} = 1 - C_p - [D * (1 - C_p)]$$

Where:

- $C_p$ is the available capacity of the pipeline;
- D is the non-dimensional parameter expressing the delay;

As shown in the Figure 42, the impact is mitigated by the available capacity of the pipeline: the higher is the capacity the lower is the impact. On the other hand, the higher is the delay the higher is the impact.

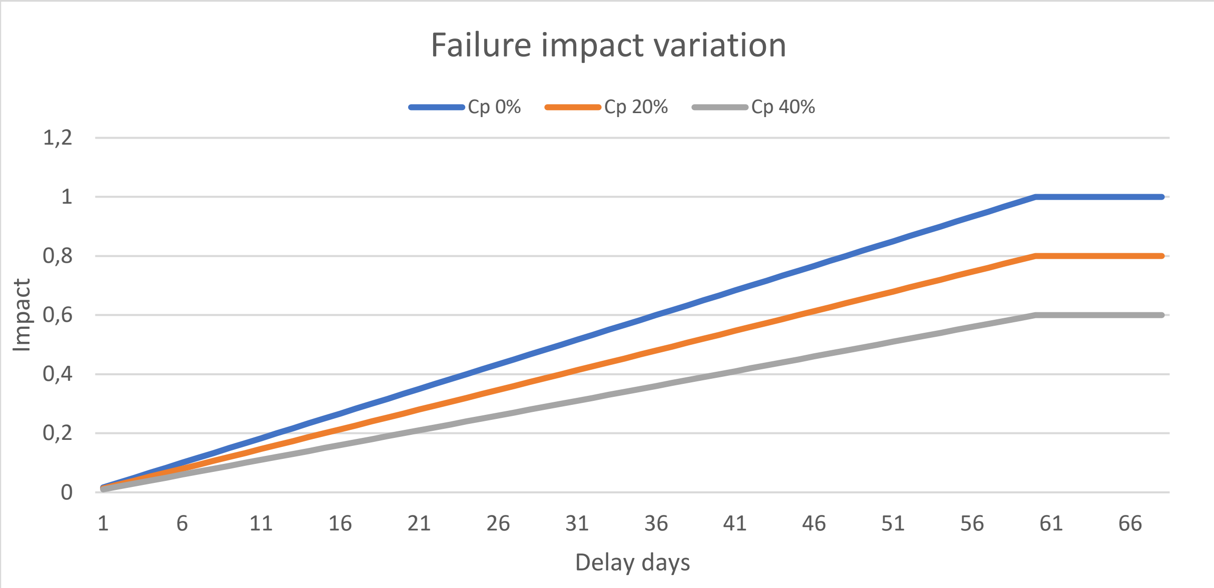


*Figure 42 - Chokepoints failure impact variation in function of available capacity and delay days*

*Table 15 - Chokepoints failure impact assessment*

| Failure impact | | | | |
|---|---|---|---|---|
| **Chokepoints** | **$C_p$ [%]** | **Delay [day]** | **Failure Impact [$I_{cp}$]** | **Average stock [days]** |
| *Hormuz strait* | 21.1 | N/A | 78.9 | 60 |
| *Bab el-Mandeb strait* | 0 | 23.5 | 39.2 | |
| *Suez Canal* | 19.0 | 23.5 | 31.8 | |
| *Turkish straits* | 0 | N/A | 100.0 | |
| *Malacca strait* | 0 | 2.9 | 4.8 | |
| *Gibraltar strait* | 0 | 31.1 | 51.8 | |

The results show that the most critical chokepoint are the Turkish straits due to the fact that they do not have alternative pipeline neither alternative sea routes. On the contrary Malacca has the lowest impact because in case of disruption only few days of delay are required to bypass the strait. The product between the impact index and the amount of commodity passing through the strait correspond to the energy loss that have to be re-collocated via others ports.

## 4.3. Reference case

The base scenario (REF) simulates the geopolitical situation and oil market for the year 2019, without takes into account any type of potential risk or disruptions. The results of the crude oil and oil products market are presented separately. In the graphs each corridor is characterized by a triplet of values that reveal at a glance the security of the Italian import market. The *energy* [TEP] is the total amount of commodity transported during the 2019 from the specific load country (Alphatanker data) instead the *final risk* is the amount of energy exposed to the risk of failure. The mismatching between the actual energy imported and the energy at risk is due to the failure probability of the considered corridor. The name of the corridor is referred to the load exporting country but in case of crude oil the calculation of the failure probability takes also into account also the captive corridor that precede the maritime one. Instead the probability of failure of the product maritime corridors is obtained neglecting the presence of captive corridor because of the EWA lack of information.

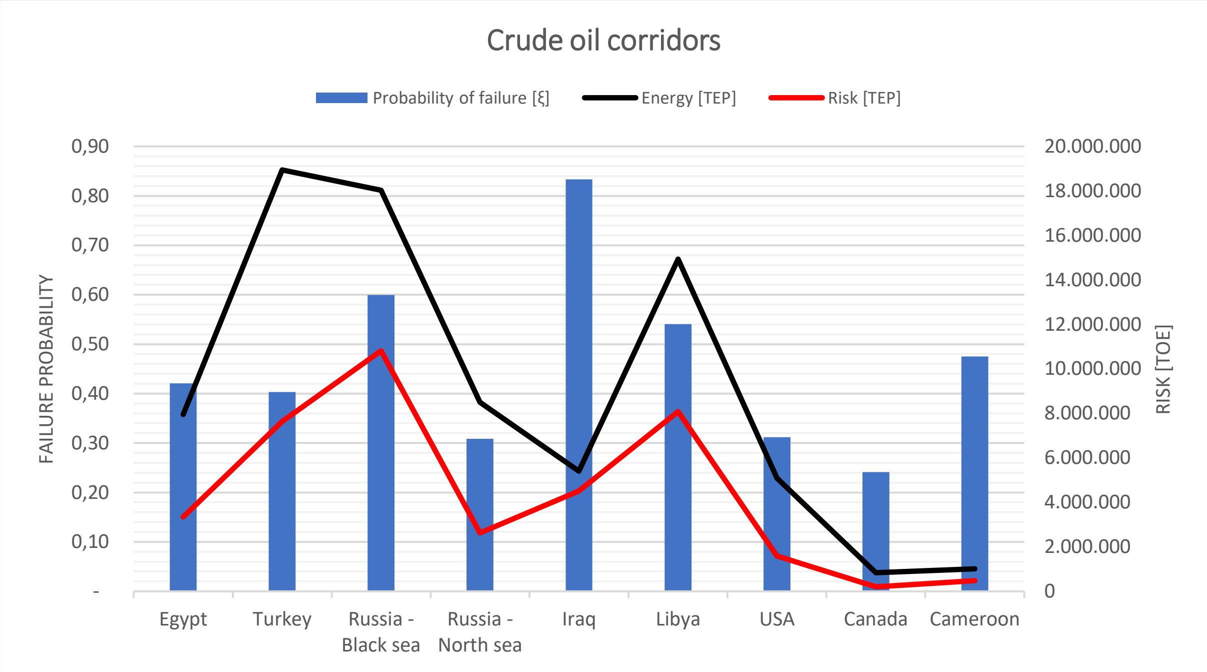


*Figure 43 - Crude oil reference case analysis*

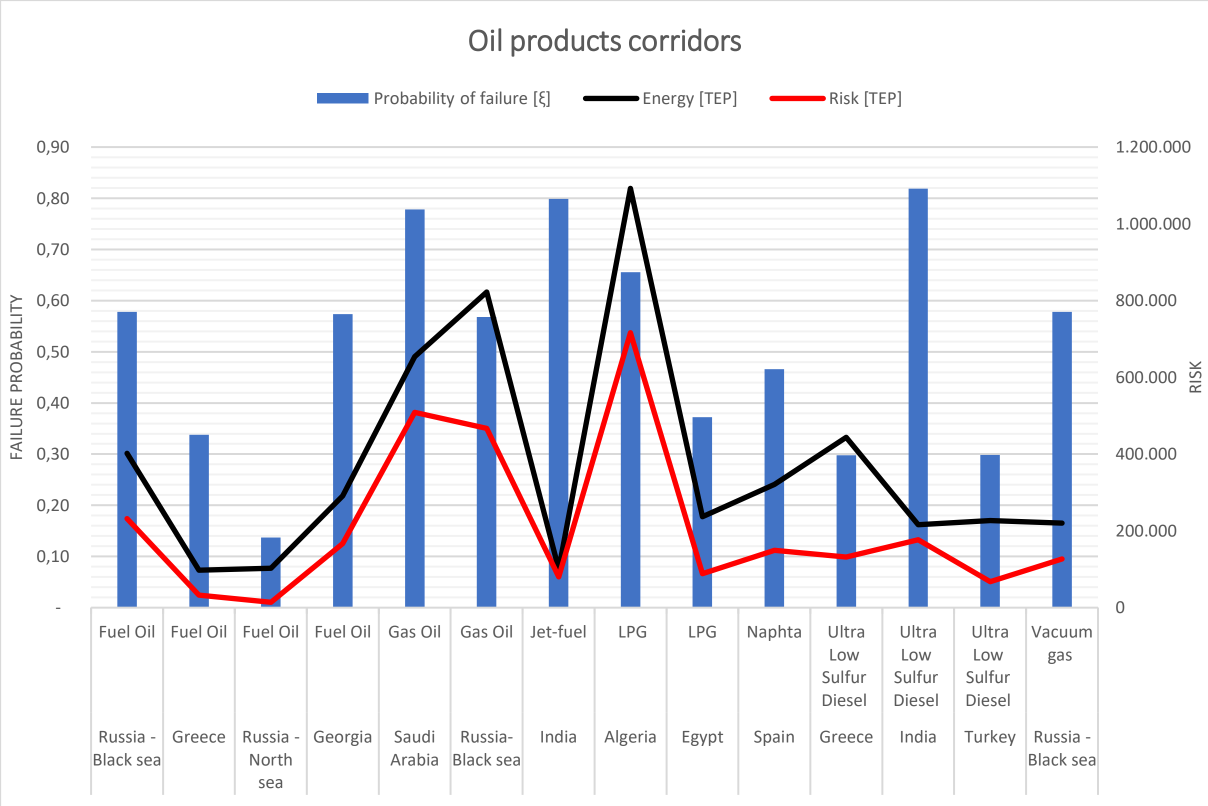


*Figure 44 - Oil products reference case analysis*

It is logical to expect that the energy imported through the corridors should depend on the probability of failure: higher is the probability lower should be the commodity transported. Instead the situation in some cases is the opposite: USA and Canada have a low failure probability but they are characterized by a low level of export whereas the Italian import from Libya, Russia and Turkey is much bigger. It is clear that in the supplier choice decision process a relevant role is covered also by the economical aspect that is affected by the spatial dimension of the exporting countries and the price of the commodities. The middle east and the Caspian countries, thanks to their proximity and the relatively low price are more competitive respect to safer regions. In conclusion, the base scenario analysis show that the energy at risk is the 49% and the 56% of the total amount of crude oil and oil products considered. In order to improve the national energy security, the amount of commodity imported from the more safety corridor have to be increased at the expense of the critical ones.

*Table 16 - Reference case resume*

| ***Resume*** | | | |
|---|---|---|---|
| *Commodity* | *Actual energy [TEP]* | *Risk [TEP]* | *Average failure probability [ξ]* |
| Crude oil | 80,594,653 | 39,374,128 | 0.49 |
| Oil products | 5,374,521 | 3,013,275 | 0.56 |

## 4.4. Scenarios analysis

Five possible adverse scenarios are implemented firstly, to test the reliability of the risk model and secondly, to assess the Italian energy security. *Scenario 1* and *Scenario 2* are *potential* scenarios in which only the potential risk of their occurrence is considered whereas *Scenario 3 Scenario 4* and *Scenario 5* are *actual* scenario that require mitigation measure in order to recover the loss of energy.

*Scenario 1* (SC1) simulates the deterioration of the European-Russian diplomatic relation due to the political situation in Belarus. The tension causes an increasing of the Russia geopolitical risk index of 30%.

S*cenario 2* (SC2) simulates a political destabilization of the northern Africa area due to the civil war in Libya, the conflict of interest between Italy and Egypt and the increasing of terroristic attacks. The geopolitical risk of Morocco, Algeria, Libya, Tunisia and Egypt increase of 20%.

*Scenario 3* (SC3) simulates the failure of the maritime corridor from the terminal of ABOT in Iraq caused by terroristic attacks against the pipelines which feed the port. The failure of the corridor implies a loss of 5.4 million tons of sour crude oil that is recovered by increasing the import from the port of Es Sider, Ceyhan and Ust-Luga.

*Scenario 4* (SC4) simulates the disruption of the Turkish straits resulting from the plummet of the diplomatic relation between European Union and Turkey:

- the worsening of migratory phenomena through the Greece-Turkey border;
- the turkey military support to the leader of the national government accord (Fayez al-Serraj);
- the turkey opposition to Assad and the destabilization of the middle east;

The failure of the Turkish strait brings a loss of 18.8 million tons of crude oil that Italy have to quickly restore by increasing the import from the port of: Ceyhan, Es Sider, Sidi Kerir, Ust-Luga, Primorsk, Az Zawiyha, Zueitina.

*Scenario 5* (SC5) simulates the reduction of the Libyan oil field extraction rate due to the worsening of the civil war. The rebel of the "Libyan National Army" occupy the majors oil fields situated in the southern part of the country in order to threaten the official government of Haftar by reducing the productivity. An overall 50% of the Libyan total export is lost. The loss of energy is restored through an import increase from the ports of: Ceyhan, CPC terminal, Sidi Kerir.

*Table 17 - Scenarios characterization*

| ***Scenarios characterization*** | | | | |
|---|---|---|---|---|
| Code | Name | Type | Definition | Mitigation measures |
| SC1 | Increase Russian risk | Single-increasing geopolitical risk (*Potential scenario*) | The geopolitical risk of Russia increases by 30%, conflict between UE and Federal Russia | [-] |

| | | | | |
|---|---|---|---|---|
| SC2 | Increase north Africa risk | Multi-increasing geopolitical risks (*Potential scenario*) | The geopolitical risk of: Libya, Egypt, Algeria, Tunisia, Morocco increases by 20% | [-] |
| SC3 | ABOT failure | Corridor failure (*Actual scenario*) | Total loss of oil from ABOT | Redistribution from: Es Sider (+20%); Ust-Luga (+20%); Ceyhan (+20%); |
| SC4 | Turkish straits failure | Chokepoint failure (*Actual scenario*) | Bosforo and Dardanelli straits closed | Redistribution: Ceyhan +50%; Primorsk; Es sider (+40%); Sidi Kerir (+40%); Zueitina (+40%); Ust-Luga (+30%); Primorsk (+30%); Az Zawiyah (+30%); |
| SC5 | Libya oil field partial disruption | Oil field disruption (*Actual scenario*) | The extraction rate of the Libyan oil field is reduced of 50% | Redistribution: Ceyhan (+10%); CPC terminal (+25%); Sidi Kerir (+35%); |

Hereafter, the numerical results of each scenarios are presented together with some graphical representations. The name of the corridor is referred to the load exporting country but the calculation of the failure probability takes also into account also the captive corridor that precede the maritime one. The impact of the scenarios on the oil product trade have been disregarded since they represent only the 10% of the overall trade and for the captive corridors lack of information. In the graph type *a* are represented the probability of failure of each corridor (blue histogram) and the energy at risk (green line). In case of *actual scenario*, that required mitigation measures, only the final energy at risk is reported through the green line. The triangular red label reports the variation of the risk respect the base scenario.

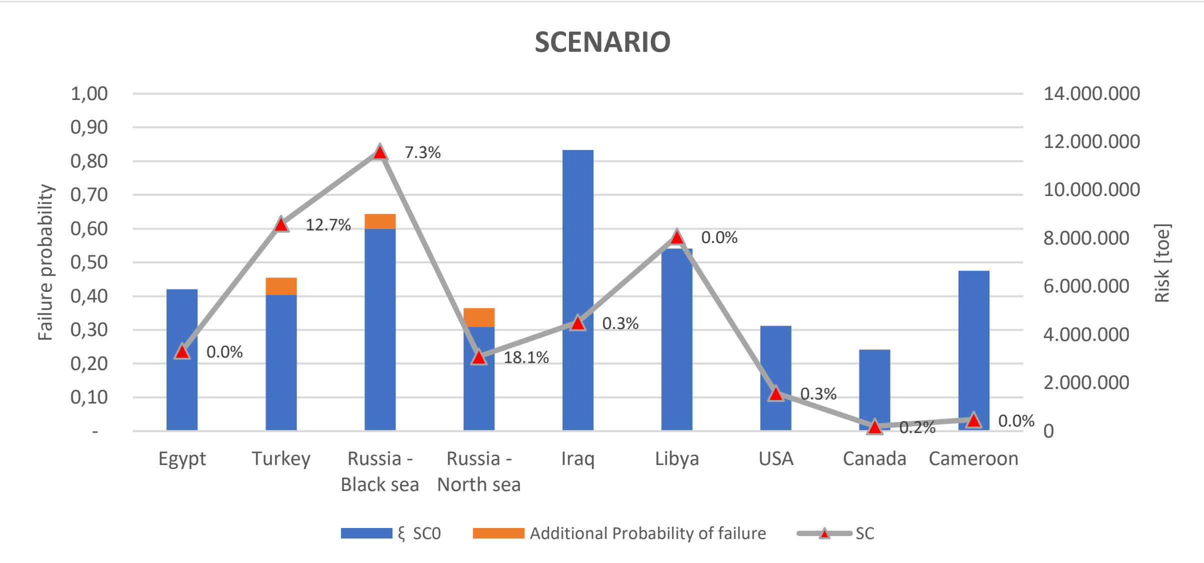


*Figure 45 - Graph type a*

The graph type b is focused on the energy at risk making a comparison between the reference case, the scenario and the eventually effects of the mitigation measures. Both Figure 45 and Figure 46 are examples, the data reported shall not be taken as reference.

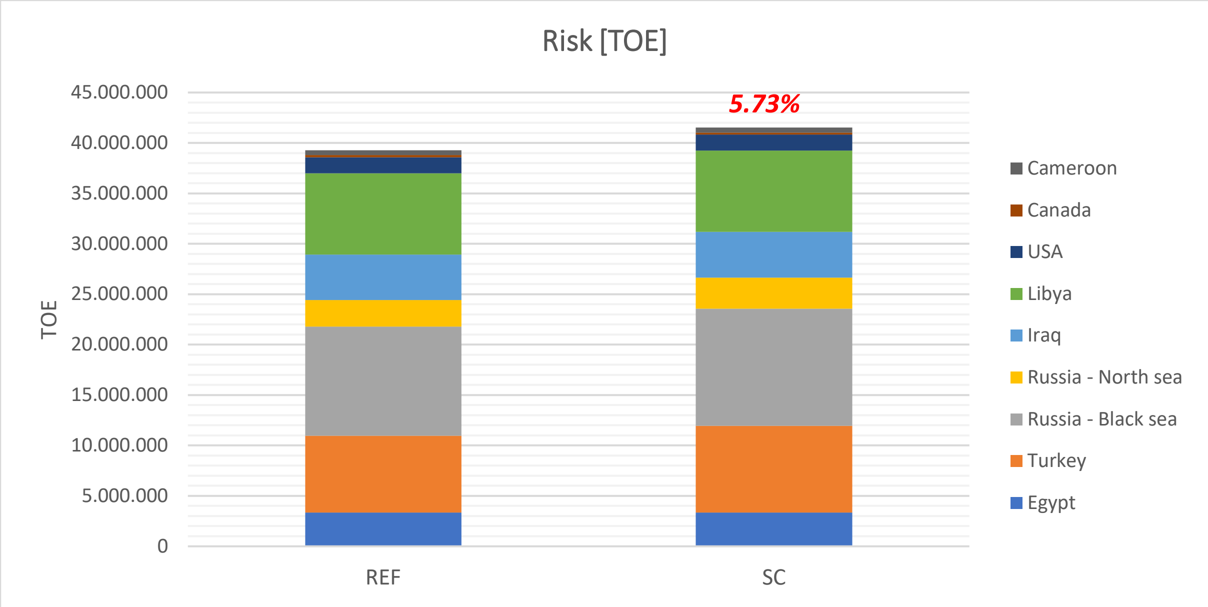


*Figure 46 - Graph type b*

*SC1 – Increasing of Russian geopolitical risk*

The consequences of SC1 mainly affect the routes which start from Russia, causing an increase of the commodity at risk of +2.6%.

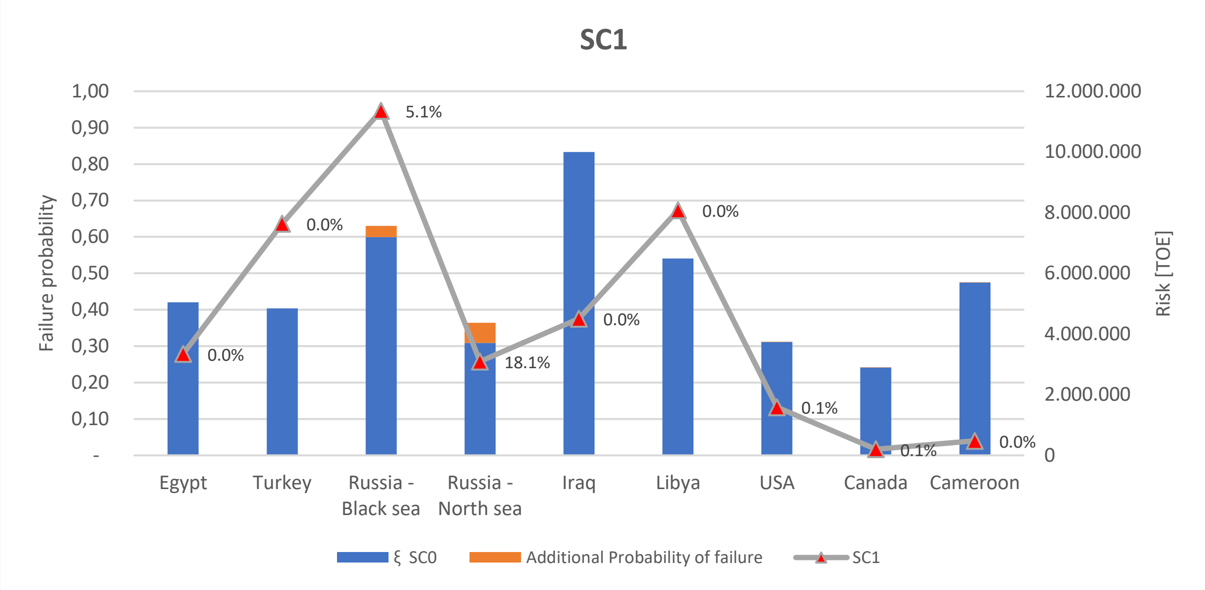


*Figure 47 - Scenario 1: Russian geopolitical risk increasing*

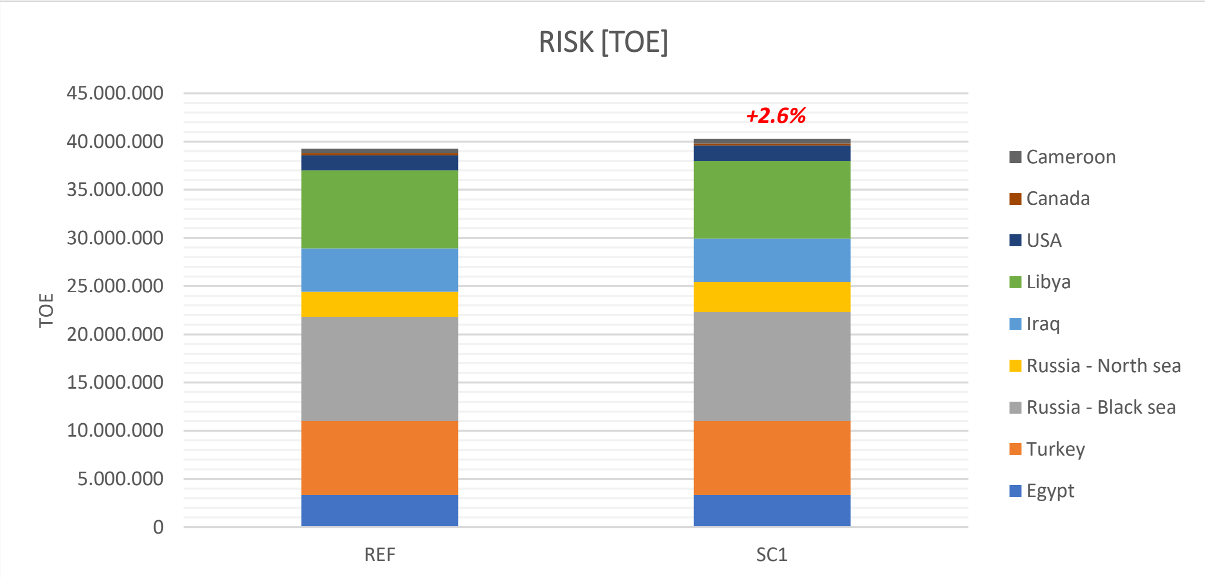


*Figure 48 – Scenario 1: Energy at risk*

The high increasing of the *Russia – North Sea* corridor probability of failure is due to the presence of almost 4000 km of captive corridors that deliver the Russian crude oil to the port of Primorsk and Ust-Luga. Therefore, even if only the 2% of the maritime route cross Russian EEZ, the overall corridor is strongly affected by the Russia geopolitical risk.

*SC2 - Northern Africa tension increasing*

The overall increase of the energy at risk is equal to +2.37%. The impact of the additional tension in northern Africa also affects also the route passing through the Gibraltar straits and the Suez Canal.

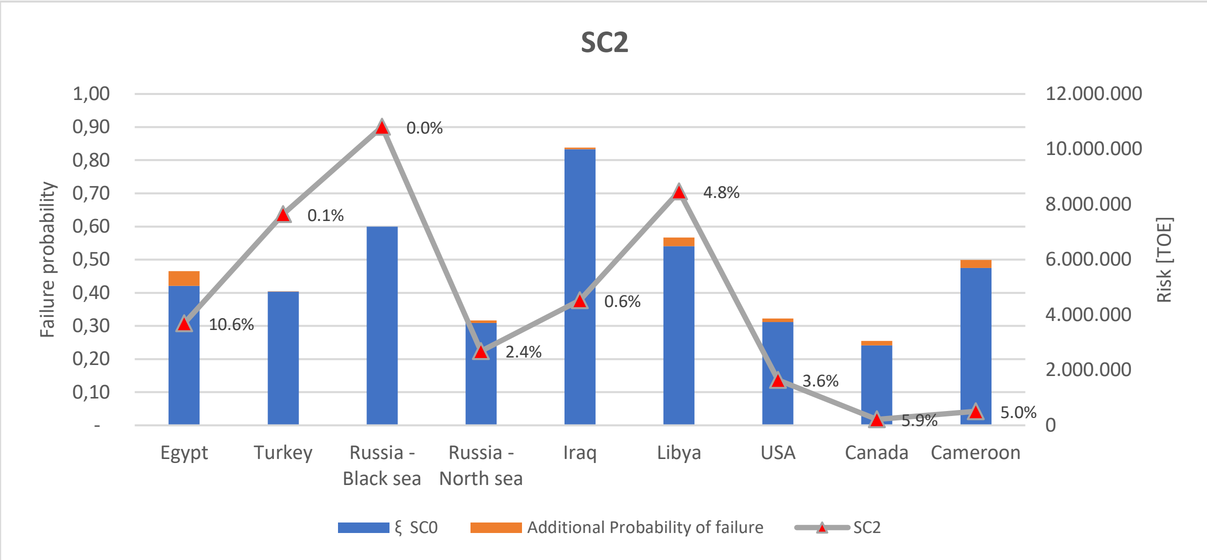


*Figure 49 - Scenario 2: Northern Arica geopolitical risk increasing*

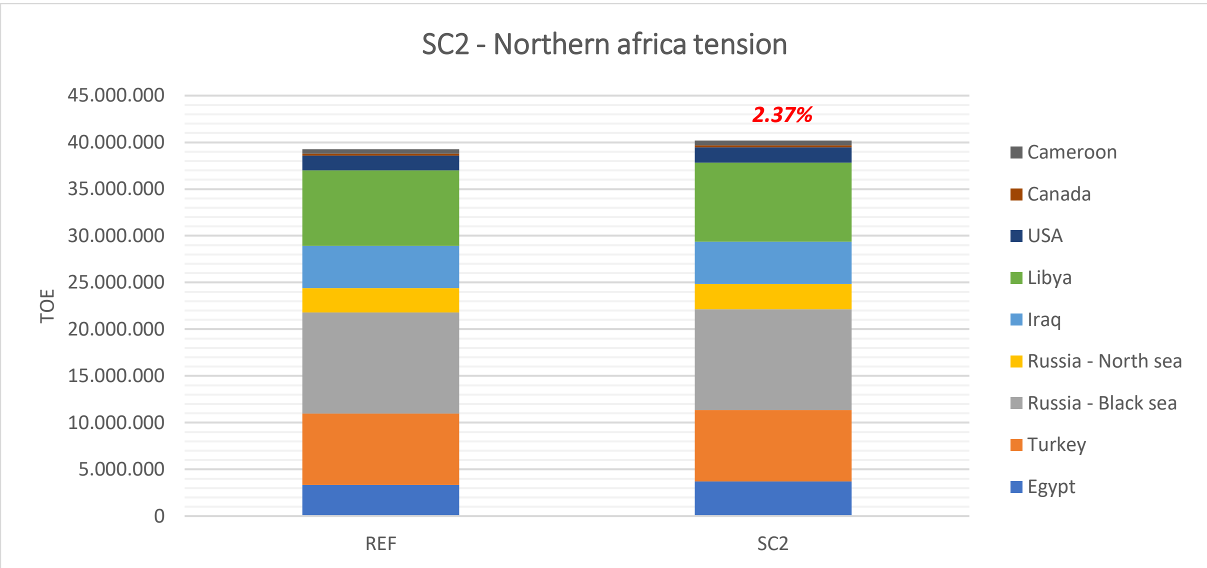


*Figure 50 - Scenario 2: Energy at risk*

The increase of the energy at risk is much evident for the *Egypt* corridor because of the non-negligible percentage of the captive corridor (26%) respect its total length. For the other corridors the increasing of the risk is more contained and distributed.

*SC3 – ABOT terminal failure*

The failure of the ABOT export corridor suddenly cause a loss of 5.4 million of crude oil tonnes. The Iraqi probability of failure is set equal to 100% whereas the overall Italian risk increases only of 2.3% because the Iraq is already characterized by a high-risk value. Several mitigation measures have to be implemented in order to recover the needed supply taking into account the typology of crude oil lost: the redistribution have to guarantee similar characteristics. Replacement of the loss energy with the increasing of the import from Es Sider (+25%), Arzew (+15%), Ust-Luga (+20%), Corpus Christi (+20%), Ceyhan (+30%). The overall risk decreases of 5.8% because the Iraq-Italy corridor, that have a high probability of failure, is substituted with safer ones and the energy loss is totally recovered.

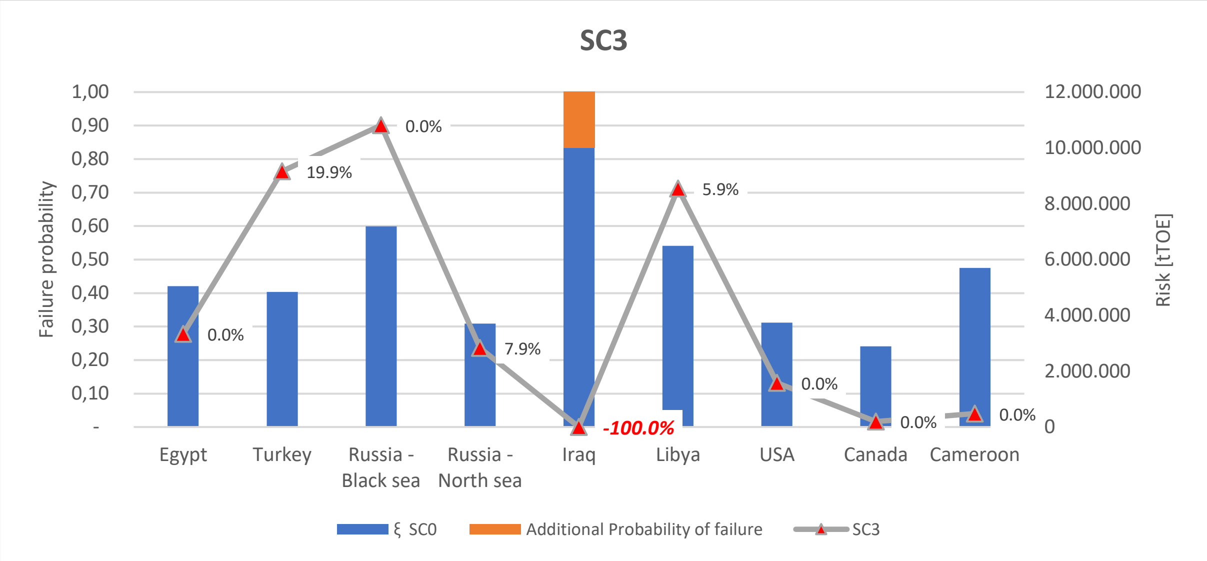


*Figure 51 - Scenario 3: ABOT terminal total failure of export*

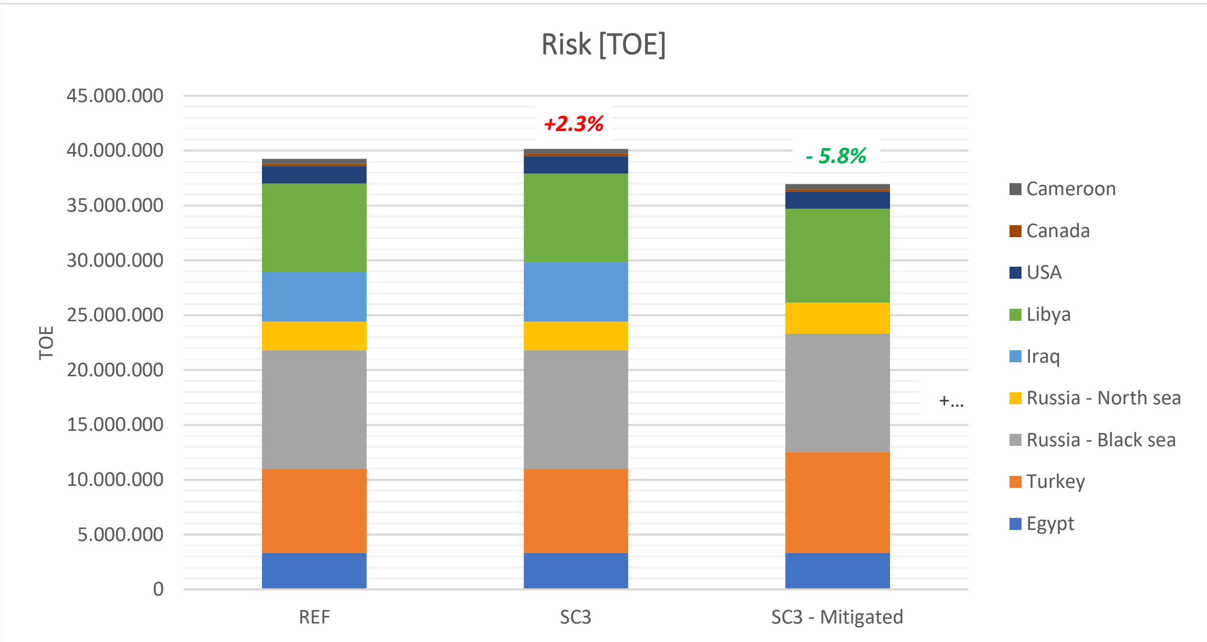


*Figure 52 - Scenario 3: Energy at risk*

*SC4 – Turkish strait disruption*

The Turkish strait failure involves the suddenly disruption of 18 million of tonnes on import: no alternative routes or pipelines are available. The *Russian – Black Sea* probability of failure is set equal to 100% since the oil tanker is supposed to cannot reach the Italian port. The increasing of the overall risk is of 18.39%. The redistribution process is very complex and require great efforts: Ceyhan +50%; Ust-Luga, Sidi Kerir; Zueitina and Primorsk +30%; Es Sider and Az Zawiyha +40%. As a result of the mitigation measures, the *Russian – Black Sea* become zero because all the impot is suspended instead the *Egypt, Turkey, Russia-North Sea and Libya* corridors' risk increase because of the import rise (due to the redistribution process) and not because of the rise in their probability of failure. The final risk decreases of 8.6%.

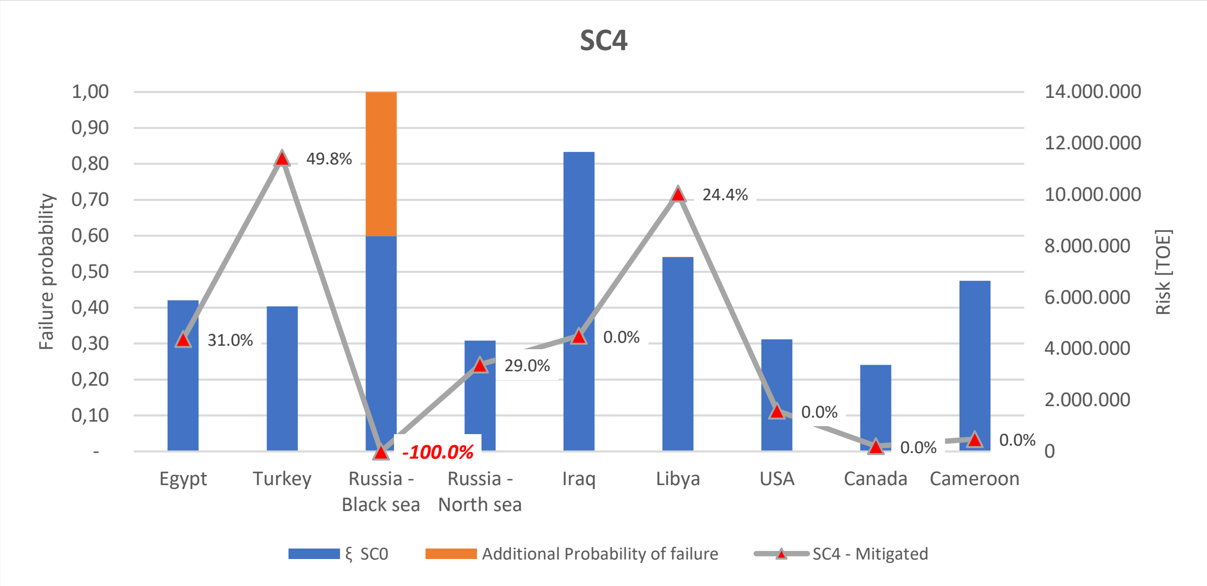


*Figure 53 - Scenario 4: Turkish stratis failure*

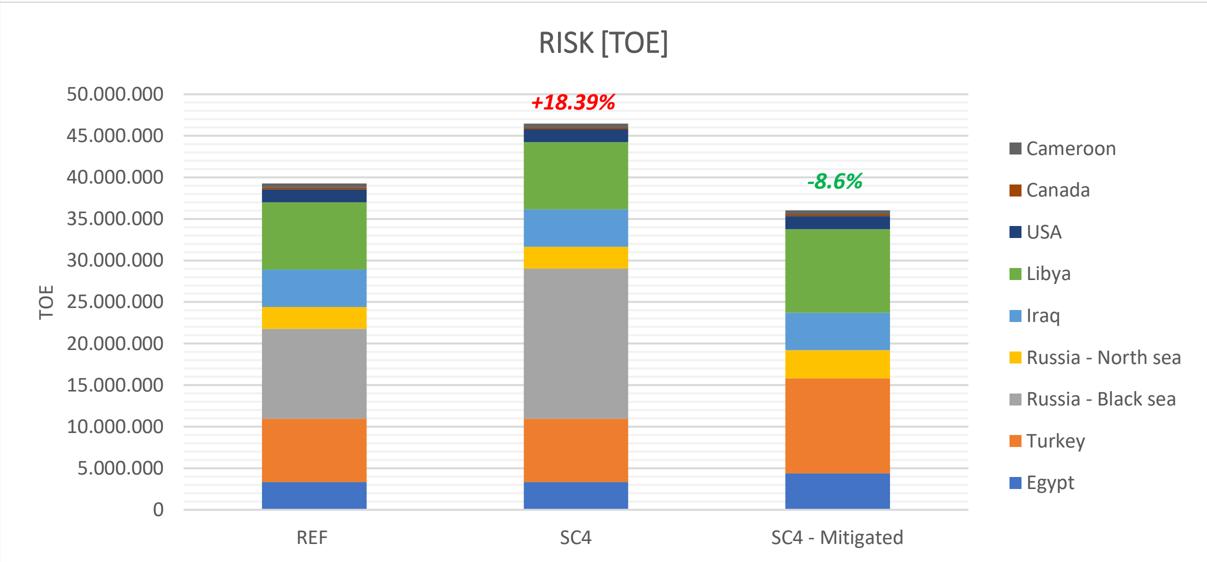


*Figure 54 - Scenario 4: Energy at risk*

*SC5 – Partial Libyan oil field disruption*

The reduction of the Libyan oil field extraction rate caused the loss of 7.4 million of tons exported from the coastal ports. The increasing of the overall risk is of 8.74%. The redistribution process involves the ports of Sidi Kerir +35%, Ceyhan + 10% and the CPC terminal +25%. The final risk decrease respect to the reference case of 0.59% because the redistribution process gives more weight to safer corridor such as the Turkish and the Egyptian ones.

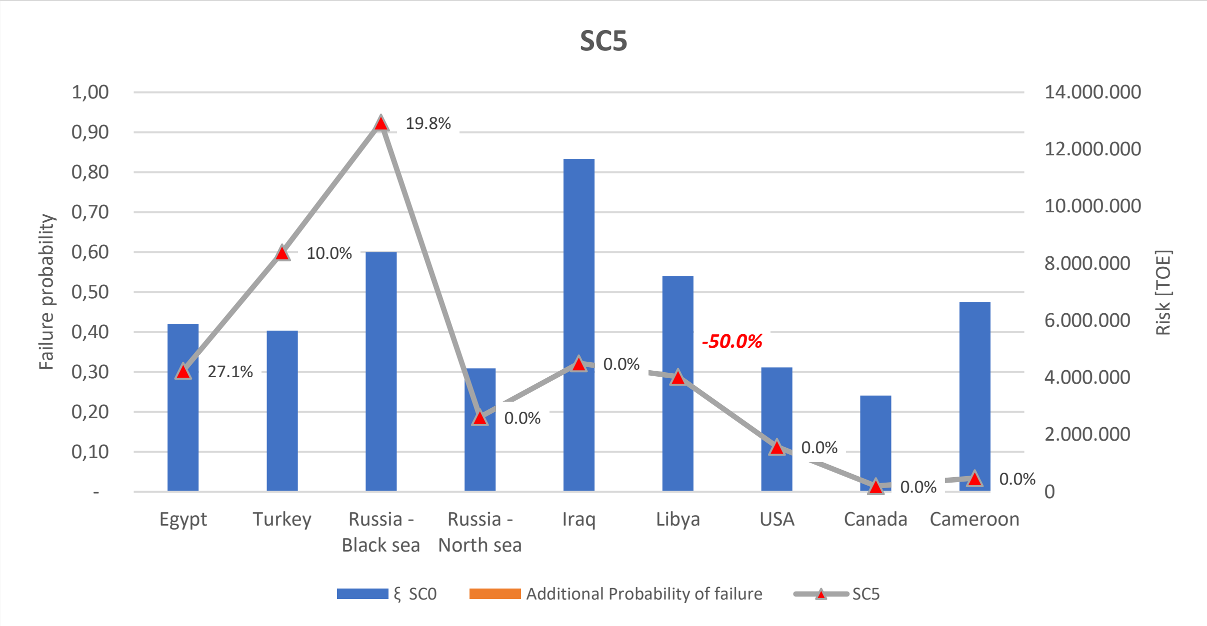


*Figure 55 - Scenario 5: Partial failure of Libyan oil field*

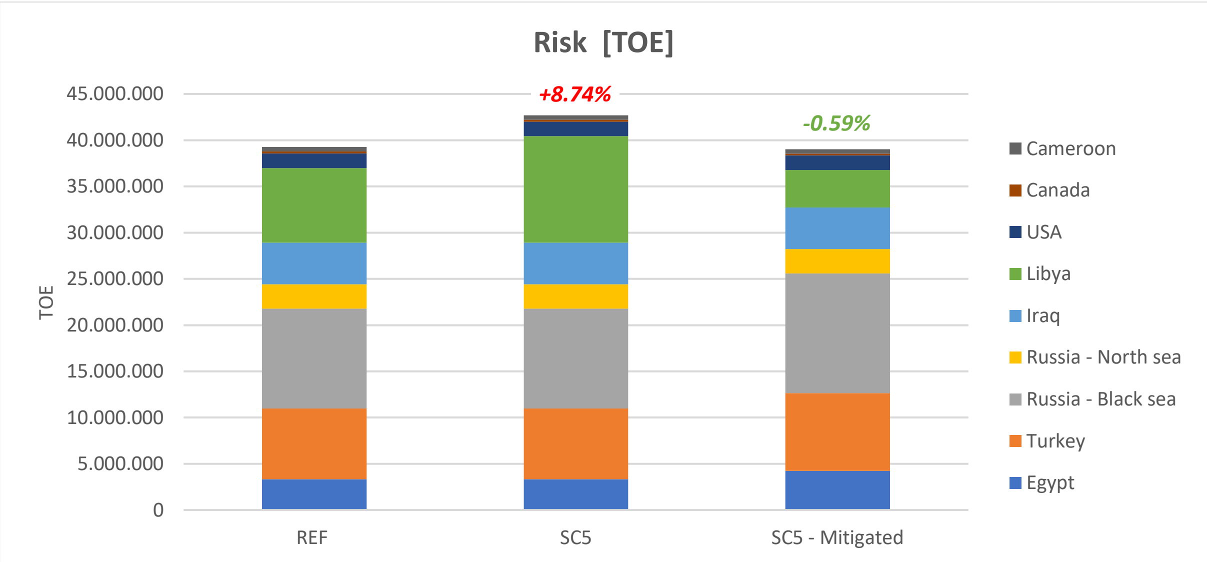


*Figure 56 - Scenario 5: Energy at risk*

The comparison among the risk in the different scenarios is reported in Figure 57 and Table 18. In case of an *actual scenario*, it is represented the energy at risk both before and after the application of the mitigation measures.

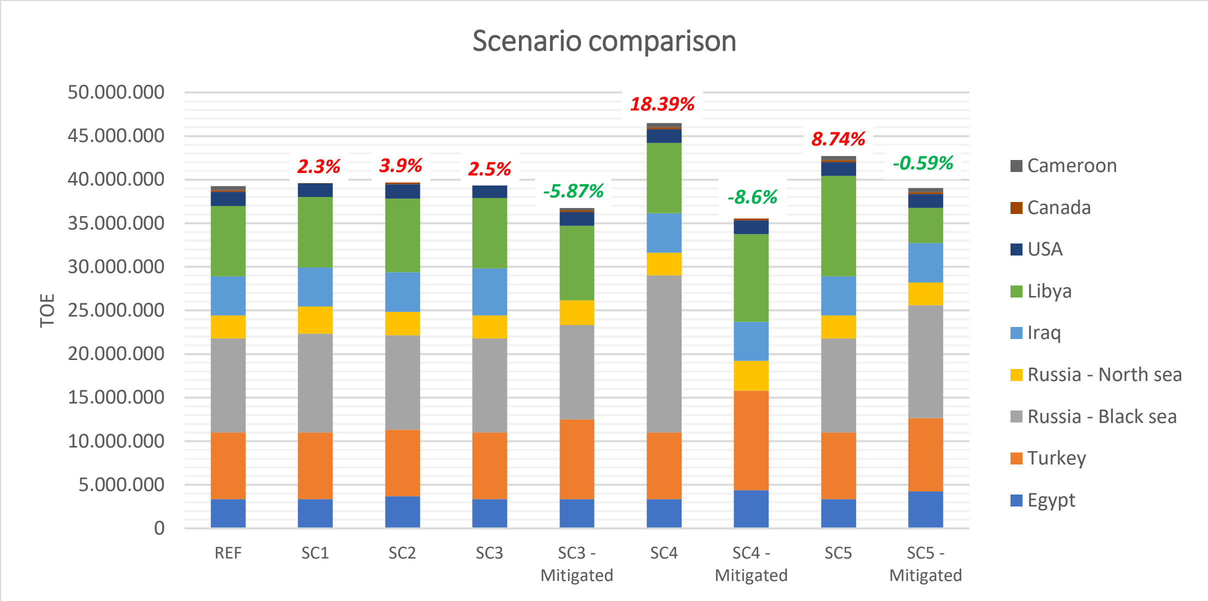


*Figure 57 - Scenario comparison: Energy at risk*

*Table 18 - Scenario resume*

| ***Scenario resume*** | | | |
|---|---|---|---|
| *Scenario* | *Description* | *Increase of risk [%]* | *Mitigation actions [%]* |
| Scen1 | Russian tension | 2.3 | [-] |
| Scen2 | Africa tension | 3.9 | [-] |
| Scen3 | ABOT failure | 2.5 | -5.8 |
| Scen4 | Turkish straits failure | 18.39 | -8.6 |
| Scen5 | Libyan oil field disruption | 8.74 | -0.59 |

For all the *actual scenarios*, the mitigation measures improve the reference scenario by decreasing the amount of energy at risk. This happen because the redistribution process interests maritime corridor characterized by a lower probability of failure respect to the disrupted one. The lack of an optimization algorithm that calculate the best possible solution in term of both energy and economics aspect makes the results changing depending on the arbitrary choices of the researcher.

# 5. Conclusions and future work

The developed methodology is a first attempt to create an interactive tool that can supports the decision makers in assessing and ranking the criticalities of an energy system. The model is particularly useful for all the countries that are characterized by a high level of import dependency and thus by low level of energy supply security. Italy belongs to this category since the 92% of the overall oil consumption is imported. Therefore, assure the security of the oil supply became a priority for the Italian government. Five main points are requested to assess and improve the national security:

1. A detailed snapshot of the actual Italian oil trade able to characterized the oil infrastructure, the oil flow, the geopolitical situation of the country crossed by each corridor and the supplier country;
2. Assessment of the actual level of the Italian energy security by providing energy risk index for each corridor;
3. Forecast the impact on the Italian oil import of future contingencies such as the failure of a maritime routes or the disruption of a chokepoint;
4. Suggest possible counterbalance to the contingences in order to contain the loss of energy flow;
5. Assess the mid-long-term effect of alternative energy strategies implemented by the government;

The methodology developed is able to handle and process the Italian oil market data and to fulfil the second and third requirement.
The analysis about the market distribution, performed though the Shannon index calculation, underlines the presence of a "*chokepoint effect*" in the oil supply chain between the production country and the exporting country. Indeed, can happen that a single port export crude oil that belong to other countries without access to the sea and thus different captive energy flux converge to the same point. Therefore, the apparent high diversification index calculated with the MiSE data (75%) does not respect the reality that is better represented by sea-route of Alphatanker (50%). In general, the mainly criticality of the oil trade depends on the oil pipelines pathway that links the oil field with the exporting port that, differently from the open sea corridors, are unchangeable in a short time scale. This reduce the degree of choice that the single governments have between exporting port giving priority to the one connected with the main pipeline system.
The risk indexes obtained provide a completely overview about the energy security of the main Italian oil corridors and the model is able to assess the impact of events and the consequence of the mitigation measures.
Instead it cannot automatically suggest counterbalance measures through an optimisation algorithm and moreover cannot assess the mid-long-term effect of energy strategies implemented by the government. An additional limit of the methodology is the lack of information regarding the captive corridors that makes impossible to go back in the oil supply

chain with a high level of precision. The assumptions used in order to overcome the lack of information, such as the flux sorting and the route grouping process, bring with them a degree of error that is complex to assess. Nevertheless, the simplicity and the easy handling of model allow to rapidly modify the input data, in case of more information become available, and to obtain new results.

In future it could be interested to improve the model by introducing an optimisation algorithm able to suggest the best solution in case of corridor disruption and to create a direct interface with Alphatanker so that the input data can be monthly updated. Moreover, the economics aspects should be introduced in order to assess the impacts of hazardous events on the Italian economy and society making the model able to manage not only the energy security sphere.

# APPENDIX A: GLOSSARY AND DEFINITIONS

*Table 19 - Symbology*

| Name | Symbol | Definition | Formula | Unit | Reference projects and source |
|---|---|---|---|---|---|
| Commodities | $\mathscr{C}$ | Set of energy commodities | $\mathscr{C} = \{\ldots,c_c,\ldots\}$ | - | Alphatanker, MISE |
| Corridors | $\mathscr{I}$ | Set of energy corridors | $\mathscr{I} = \{\ldots,i_i,\ldots\}$ | - | Alphatanker, PE, EWA |
| Countries | $\mathscr{K}$ | Set of countries:<br>• Supplier countries<br>• Countries crossed by corridors | $\mathscr{K} = \{\ldots,k_k,\ldots\}$ | - | Alphatanker, MISE |
| Ports | $\mathscr{P}$ | Set of ports:<br>• discharge port<br>• load port | $\mathscr{P} = \{\ldots p_p \ldots\}$ | - | Alphatanker |
| Voyages | $\mathscr{V}$ | Set of voyages | $\mathscr{V} = \{\ldots,v_v \ldots\}$ | - | Alphatanker |
| Maritime Routes | $\mathscr{M}$ | Set of maritime voyages | $\mathscr{M} = \{\ldots,m_m \ldots\}$ | | Alphatanker |
| Chokepoints | $\mathscr{C}_p$ | Set of chokepoints | $\mathscr{C}_p = \{\ldots,c_p \ldots\}$ | - | AD-DE |
| Pipelines | $\mathscr{P}_p$ | Set of pipelines | $\mathscr{P}_p = \{\ldots,p_p \ldots\}$ | | EWA |
| Refineries | $\mathscr{R}$ | Set of refineries | $\mathscr{R} = \{\ldots,r_r \ldots\}$ | | DA-ED, UP |
| Sea Duration | $\mathscr{D}_m{}^c$ | Average sea duration of maritime route m associated to a commodity m | - | day | Alphatanker |
| Corridor Length | $\mathscr{L}_i$ | Overall length of a single corridor | - | km | GIS, Alphatanker,EWA |
| Branch Length | $\ell_i$ | Length of a single branch | - | km | GIS, Alphatanker,EWA |
| Weighting factor | $\gamma_k$ | Weight of a single branch with respect to the overall corridor length | $\gamma_k = \frac{l_i}{L_{tot}}$ | - | GIS, Alphatanker,EWA |
| Dead-Weight Tonnage of a single voyage | $dwt_v$ | Measure of capacity of a single vessel | - | ton | Alphatanker |
| Total Dead-Weight Tonnage of maritime route | DWT | Total DWT associated to a corridor i | $\sum_{v=1}^{N} dwt_v$ | ton | AD-DE |
| Transported commodity by single voyage v | $t_v^c$ | Amount of commodity c transported by a single voyage along the maritime route m | - | Mton | Alphatanker |
| Transported commodity by route m | $T_m^c$ | Total amount of commodity c transported through the maritime route m | $T_m^c = \sum_{v=1}^{V} t_v^c$ | Mton | AD-DE |
| Transported commodity by corridor i | $T_i^c$ | Total amount of commodity c transported through the corridor i | $T_i^c = T_m^c$ | Mton | AD-DE |
| Average trip intake | $\bar{T}_m^c$ | Average amount of total commodity c transported by the maritime route m | $\bar{T}_m^c = \frac{T_m^c}{N}$ | Mton | AD-DE |
| Filling Ratio | $F^c_m$ | Average vessel's filling percentage of commodity c associated to the maritime route m | $F^c_m = \frac{T_m^c}{DWT} * 100$ | % | AD-DE |

| | | | | | |
|---|---|---|---|---|---|
| Low Heating Value | $LHV^c$ | Low heating value of commodity c | – | MJ/Kg | IPCC |
| Corridor Energy Flux | $E^c_i$ | Amount of transported commodity through a single corridor, in term of energy | $E_i = \frac{T_i^c * LHV^c}{3.6\ GJ}$ | MWh | AD-DE |
| Geopolitical Risk | $\varphi_k$ | Political risk index based on World Banks's Worldwide Governance Indicators (WGI) | $\varphi_k = \sum_{j=1}^{6} \frac{WGI_j}{6}$ | - | WGI |
| Piracy Index | $\eta_k$ | Piracy index provided by "One Earth Future" in the publication "The state of maritime piracy" | - | - | One Earth Future |
| Maritime Geopolitical Risk | $\varphi'_k$ | Combination of geopolitical risk and piracy index | $\varphi'_k = \frac{\varphi_k + \eta_k}{7}$ | - | DA-ED |
| International Maritime Geopolitical Risk | $\overline{\varphi'}$ | Arithmetic average of Maritime Geopolitical Risk of all coastal countries | $\bar{\varphi}' = \frac{\sum \varphi'_k}{K}$ | - | DA-ED |
| Probability of Failure of Maritime Route | $\xi_{route}$ | Probability of failure related to the shipping hazards without considering chokepoint crossing | $\xi_{route} = 100 * \left[1 - \prod\left(1 - \frac{\gamma_k * \varphi'_k}{100}\right)\right]$ | - | DA-ED, EC |
| Likelihood of chokepoint disruption | $L_{cp}$ | Arithmetic mean of Maritime Geopolitical Risk of chokepoint's supervisor countries | $L_{cp} = \bar{\varphi}'_k$ | - | DA-ED |
| Chokepoint Vulnerability Index | $\alpha_{cp}$ | Ratio between length and width of a specific chokepoint | $\alpha_{cp} = \frac{length_{cp}}{width_{cp}}$ | - | DA-ED |
| Normalized Chokepoint Vulnerability Index | $\dot{\alpha_{cp}}$ | Empirical normalization of chokepoint vulnerability index through logarithmic function | $\dot{\alpha_{cp}} = \frac{\ln(\alpha_{cp}+1) - \ln(\alpha_{cp_{\min}}+1)}{\ln(\alpha_{cp_{max}}+1)}$ | - | DA-ED |
| Probability of Chokepoint Failure | $\xi_{cp}$ | Combination of intrinsic chokepoint vulnerability and likelihood of chokepoint disruption | $\xi_{cp} = L_{cp} * \dot{\alpha}$ | - | DA-ED |
| Probability of Failure of Open Sea Corridor | $\xi_{OpenSea}$ | Probability of failure related to the shipping hazards considering also chokepoint crossing | $\xi_{OpenSea} = 1 - [(1 - \xi_{cp)} * (1 - \xi_{route})]$ | - | DA-ED |
| Probability of Failure of Captive Corridor | $\xi_{Captive}$ | Probability of disruption of pipelines passing through several countries | $\xi_{Captive} = 100 * \left[1 - \prod\left(1 - \frac{\gamma_k * \varphi_k}{100}\right)\right]$ | - | DA-ED, EC |
| Probability of Corridor Failure | $\xi_i$ | Empirical function calculated as the combination of probability of failure of both open sea and captive corridors | $\xi_i = 1 - [(1 - \xi_{OpenSea}) * (1 - \xi_{Captive})]$ | - | DA-ED |
| Probability of Corridor Success | $\omega_i$ | Probability of success related to a single corridor | $\omega_i = 1 - \xi_i$ | - | EC |
| Energy Risk Supply Of Corridor i | $R^c_i$ | Risk of failure of corridor i delivering commodity c, expressed in terms of energy loss | $R_i^c = \xi_i * E_i^c$ | TJ | EC |
| Specific Expected Supply of Commodity c | $\Omega^c_i$ | Expected supply of commodity c by single corridor i | $\Omega_i^c = \frac{\omega_i}{100} * E_i^c$ | TJ | EC |
| Total Expected Supply of Commodity c | $\Omega^c$ | Total expected supply of commodity c | $\Omega^c = \sum_{i=1}^{I} \frac{\omega_i}{100} * E_i^c$ | | EC |
| Total Supply of Commodity c | $S^c$ | Total supply of commodity c | $S^c = \sum_{i=1}^{I} S_i^c$<br>Where:<br>▪ $S^c_i$ : general amount of supplied commodity | | MISE, U.P., Alphatanker |

| | | | | | |
|---|---|---|---|---|---|
| National Energy Risk Supply | $R^c_{ext}$ | Overall risk of supply (external risk) in terms of energy loss for a given country. | $R_{ext} = \sum_{i=1}^{I} \frac{\xi_i}{100} * E^c{}_i$ | TJ | EC |
| National Energy Security | $R^c_n$ | Overall national energy security index obtained by the combination of both internal and external risk | $R^c{}_n = R^c{}_{int} * w_1 + R^c{}_{ext} * w_2$<br>Where:<br>$R^c{}_{int}$: overall internal risk related to:<br>▪ availability of national energy resources<br>▪ resilience to possible internal attacks against the infrastructures<br>$w_1$= Weight coefficient for the internal risk<br>$w_2$= Weight coefficient for the external risk | TJ | EC |
| Import commodity | $I^c_k$ | Amount of commodity c imported from country k | - | Mton | MISE, P.E. |
| Export commodity | $J^c_k$ | Amount of commodity c exported to country k | - | Mton | MISE, P.E. |
| Share of commodity | $h_i^c$ | Share of commodity c associated to a single corridor i | $h_i{}^c = S_i^c / S^c$ | - | EC |
| Diversification of primary energy demand | $H$ | Measure of the diversification of oil suppliers. Indicator obtained adapting Shannon diversity index. | $H = -\sum_i h_i^c * ln(h_i^c)$<br>$H = \frac{H}{\ln(Z)}$<br>Where<br>▪ Z is the number of primary suppliers. | - | DA-ED |

## APPENDIX B: CHARACTERIZATION OF CRUDES IMPORTED BY ITALY

*Table 20 and Table 21: Parameters of crude characterization (Source [16])*

| API | |
|---|---|
| >> 31.1 | very light |
| > 31.1 | light |
| 22.3-31.1 | medium |
| < 22.3 | heavy |

| % SULFUR | |
|---|---|
| << 0.5% | very sweet |
| < 0.5% | sweet |
| > 0.5% | sour |
| >> 0.5% | very sour |

*Table 22a, 22b, 22c, 22d and 22e: Crude characterization by country (Source: Elaboration based on [6])*

| MIDDLE EAST | Varieties of crude oil | | | ITALY, CRUDE IMPORT 2019 [ton] | % |
|---|---|---|---|---|---|
| ARABIA SAUDITA | API | > 31.1 | light | 4.973.824 | 28,3 |
| | % SULFUR | > 0.5% | sour | | |
| IRAQ [1] | API | > 31.1 | light | 2.251.552 | 12,8 |

| | | | | | |
|---|---|---|---|---|---|
| | % SULFUR | > 0.5% | sour | | |
| IRAQ [2] | API | 22.3-31.1 | medium | 10.348.722 | 58,9 |
| | % SULFUR | >> 0.5% | very sour | | |

| AFRICA | Varieties of crude oil | | | ITALY, CRUDE IMPORT 2019 [ton] | % |
|---|---|---|---|---|---|
| Algeria | API | > 31.1 | light | 1.292.571 | 7,6 |
| | % SULFUR | < 0.5% | sweet | | |
| Angola [1] | API | > 31.1 | light | 463.089 | 2,7 |
| | % SULFUR | < 0.5% | sweet | | |
| Angola [2] | API | 22.3-31.1 | medium | 780.026 | 4,6 |
| | % SULFUR | < 0.5% | sweet | | |
| Cameroon | API | 22.3-31.1 | medium | 949.377 | 5,6 |
| | % SULFUR | < 0.5% | sweet | | |
| Democratic Republic of Congo | API | > 31.1 | light | 123.112 | 0,7 |
| | % SULFUR | << 0.5% | very sweet | | |
| Egypt | API | > 31.1 | light | 989.451 | 5,8 |
| | % SULFUR | < 0.5% | sweet | | |
| Equatorial Guinea | API | 22.3-31.1 | medium | 84.307 | 0,5 |
| | % SULFUR | >> 0.5% | very sour | | |
| Gabon | API | 22.3-31.1 | medium | 388.157 | 2,3 |
| | % SULFUR | > 0.5% | sour | | |
| Ghana | API | > 31.1 | light | 390.998 | 2,3 |
| | % SULFUR | < 0.5% | sweet | | |
| Libya [1] | API | > 31.1 | light | 6.232.441 | 36,5 |
| | % SULFUR | < 0.5% | sweet | | |
| Libya [2] | API | 22.3-31.1 | medium | 1.552.570 | 9,1 |
| | % SULFUR | > 0.5% | sour | | |
| Nigeria [1] | API | > 31.1 | light | 3.074.537 | 18,0 |
| | % SULFUR | < 0.5% | sweet | | |
| Nigeria [2] | API | < 22.3 | heavy | 205.432 | 1,2 |
| | % SULFUR | < 0.5% | sweet | | |
| Nigeria [3] | API | 22.3-31.1 | medium | 132.910 | 0,8 |
| | % SULFUR | < 0.5% | sweet | | |
| Tunisia [1] | API | > 31.1 | light | 228.836 | 1,3 |
| | % SULFUR | < 0.5% | sweet | | |
| Tunisia [2] | API | 22.3-31.1 | medium | 201.738 | 1,2 |
| | % SULFUR | > 0.5% | sour | | |

| ASIA | Varieties of crude oil | | % |
|---|---|---|---|

| | | | | ITALY, CRUDE IMPORT 2019 [ton] | |
|---|---|---|---|---|---|
| AZERBAIGIAN | API | > 31.1 | light | 10.942.139 | 72,8 |
| | % SULFUR | < 0.5% | sweet | | |
| KAZAKISTAN | API | >> 31.1 | very light | 4.086.348 | 27,2 |
| | % SULFUR | < 0.5% | sweet | | |

| EUROPE | Varieties of crude oil | | | ITALY, CRUDE IMPORT 2019 [ton] | % |
|---|---|---|---|---|---|
| ALBANIA | API | < 22.3 | heavy | 59.683 | 0,6 |
| | % SULFUR | >> 0.5% | very sour | | |
| GRECIA | API | 22.3-31.1 | medium | 55.855 | 0,5 |
| | % SULFUR | >> 0.5% | very sour | | |
| NORVEGIA [1] | API | > 31.1 | light | 310.035 | 2,9 |
| | % SULFUR | < 0.5% | sweet | | |
| NORVEGIA [2] | API | 22.3-31.1 | medium | 604.443 | 5,6 |
| | % SULFUR | < 0.5% | sweet | | |
| REGNO UNITO [1] | API | > 31.1 | light | 303.977 | 2,8 |
| | % SULFUR | > 0.5% | sour | | |
| REGNO UNITO [2] | API | 22.3-31.1 | medium | 360.914 | 3,3 |
| | % SULFUR | < 0.5% | sweet | | |
| RUSSIA [1] | API | > 31.1 | light | 1.055.690 | 9,8 |
| | % SULFUR | > 0.5% | sour | | |
| RUSSIA [2] | API | 22.3-31.1 | medium | 8.040.011 | 74,5 |
| | % SULFUR | > 0.5% | sour | | |

| AMERICA | Varieties of crude oil | | | ITALY, CRUDE IMPORT 2019 [ton] | % |
|---|---|---|---|---|---|
| CANADA | API | > 31.1 | light | 701.786 | 26,4 |
| | % SULFUR | > 0.5% | sour | | |
| COLOMBIA | API | 22.3-31.1 | medium | 15.189 | 0,6 |
| | % SULFUR | < 0.5% | sweet | | |
| MESSICO | API | < 22.3 | heavy | 88.751 | 3,3 |
| | % SULFUR | >> 0.5% | very sour | | |
| USA [1] | API | > 31.1 | light | 1.027.049 | 38,7 |
| | % SULFUR | < 0.5% | sweet | | |
| USA [2] | API | 22.3-31.1 | medium | 387.273 | 14,6 |
| | % SULFUR | > 0.5% | sour | | |
| VENEZUELA | API | < 22.3 | heavy | 436.713 | 16,4 |
| | % SULFUR | >> 0.5% | very sour | | |

Table 23: Ranking of top crudes imported by Italy (Source: Elaboration based on [6])

| 2019 | | | |
|---|---|---|---|
| Crude name | Country | Mton | vs 2018 |
| AZERI LIGHT | Azerbaijan | 8,31 | ↑ 5,9% |
| URALS | Russia | 7,44 | ↑ 49,0% |
| BASRAH LIGHT | Iraq | 5,27 | ↑ 5,8% |
| ARABIAN LIGHT | Saudi Arabia | 4,97 | ↓ -37,7% |
| CPC BLEND | Kazakhstan | 4,09 | ↑ 29,3% |
| EBCO | Iraq | 2,76 | ↑ 12,8% |
| AZERI BLEND | Azerbaijan | 2,63 | ↓ -51,0% |
| KIRKUK | Iraq | 2,25 | ↑ 66,5% |
| CRUDE OIL BLEND | Iraq | 2,19 | ↑ 55,5% |
| ES SIDER | Libia | 1,88 | ↑ 18,8% |
| AMNA | Libia | 1,72 | ↑ 20,1% |
| SAHARAN BLEND | Algeria | 1,29 | ↓ -14,8% |
| BU ATTIFEL | Lybia | 1,23 | ↓ -18,3% |
| BOURI | Lybia | 1,14 | ↑ 42,6% |
| SIBERIAN LIGHT | Russia | 1,06 | ↓ -40,6% |

*Table 24: Ranking of Italan crude suppliers (Source: Elaboration based on [16])*

| **Imported crude per country, 2019 (UP)** | | |
|---|---|---|
| | [kton] | |
| Iraq | **12.615** | **20,0%** |
| Azerbaijan | **10.942** | **17,3%** |
| Russia | **9.095** | **14,4%** |
| Lybia | **7.785** | **12,3%** |
| Saudi Arabia | **4.974** | **7,9%** |
| Kazakhstan | **4.086** | **6,5%** |
| Nigeria | **3.413** | **5,4%** |
| USA | **1.414** | **2,2%** |
| Algeria | **1.372** | **2,2%** |
| Angola | **1.243** | **2,0%** |
| Egypt | 989 | 1,6% |
| Cameroon | 949 | 1,5% |
| Norway | 914 | 1,4% |
| Canada | 702 | 1,1% |
| United Kingdom | 665 | 1,1% |
| Venezuela | 437 | 0,7% |
| Ghana | 391 | 0,6% |
| Gabon | 388 | 0,6% |
| Tunisia | 351 | 0,6% |
| Congo | 123 | 0,2% |
| Mexico | 89 | 0,1% |
| Equatorial Guinea | 85 | 0,1% |
| Albania | 60 | 0,1% |
| Greece | 56 | 0,1% |
| Iran | - | 0,0% |
| Kuwait | - | 0,0% |
| Mauritania | - | 0,0% |

*Table 25: Discrepancies between MiSE and Alphatanker (Source: Elaboration based on [7] and [6])*

| Imported crude oil 2019 [ton] | Alphatanker 2019 [ton] | MISE, Bollettino Petrolifero 2019 [ton] | Δ (MISE-ALPHATANKER) [ton] |
|---|---|---|---|
| Algeria | 1.658.607 | 1.292.571 | - 366.036 |
| Angola | 1.070.214 | 1.243.115 | 172.901 |
| Cameroon | 1.007.316 | 949.377 | - 57.939 |
| Canada | 837.667 | 701.786 | - 135.881 |
| Congo | 121.213 | 123.112 | 1.899 |
| Croatia | 84.502 | N/A | |
| Cyprus | 186.467 | N/A | |
| Denmark | 179.408 | N/A | |
| Egypt | **7.945.832** | 989.451 | **- 6.956.381** |
| Equatorial Guinea | 276.129 | 84.307 | - 191.822 |
| Gabon | 300.481 | 388.157 | 87.676 |
| Georgia | **2.405.907** | N/A | **- 2.405.907** |
| Ghana | 534.362 | 390.998 | - 143.364 |
| Gibraltar | 69.281 | N/A | |
| Greece | 699.836 | 55.855 | - 643.981 |
| Iraq | **5.408.242** | 12.600.275 | **7.192.033** |
| Italy | 686.396 | N/A | |
| Lybia | **14.931.261** | 7.785.011 | **- 7.146.250** |
| Malta | 954.191 | N/A | |
| Mexico | 92.182 | 88.751 | - 3.431 |
| Netherland | 78.814 | N/A | |
| Nigeria | **4.951.331** | 3.412.880 | **- 1.538.452** |
| Norway | 690.252 | 914.478 | 224.226 |
| Oman | 149.285 | N/A | |
| Russia | **29.988.743** | 9.095.702 | **- 20.893.041** |
| Singapore | 167.828 | N/A | |
| South Africa | 95.400 | N/A | |
| Taiwan | 69.194 | N/A | |
| Tunisia | 338.797 | 430.575 | 91.778 |
| Turkey | **15.488.700** | N/A | |
| United Arab Emirates | 159.998 | N/A | |
| United kingdom | 1.091.409 | 664.891 | - 426.518 |
| USA | **5.090.445** | 1.414.323 | **- 3.676.122** |
| Venezuela | 366.997 | 436.713 | 69.716 |
| Yemen | 156.686 | N/A | |

## APPENDIX C: CHARACTERIZATION OF ITALIAN OIL INFRASTRUCTURE

*Table 26: Italian oil infrastructure: refineries (Source: Elaboration based on [16] and [6])*

| NAME | LOCATION | TYPE | STATE | AUTHORIZED CAPACITY [$10^6$ton/anno] |
|---|---|---|---|---|
| ISAB PRIOLO | Priolo Gargallo (SR) | Refinery | ACTIVE | 20,0 |
| SARAS SARROCH | Sarroch (CA) | Refinery | ACTIVE | 18,0 |
| SARPOM TRECATE (NO) | Trecate (NO) | Refinery | ACTIVE | 12,5 |
| AUGUSTA SONATRACH | Augusta (SR) | Refinery | ACTIVE | 9,6 |
| API FALCONARA M. (AN) | Falconara Marittima (AN) | Refinery | ACTIVE | 3,9 |
| IPLOM BUSALLA (GE) | Busalla (GE) | Refinery | ACTIVE | 1,9 |
| ALMA | Ravenna | Refinery | ACTIVE | 0,6 |
| ENI Div. R&M SANNAZZARO | Sannazzaro (PV) | Refinery | ACTIVE | 11,1 |
| ENI-KUPIT RAFFINERIA DI MILAZZO | Millazzo (ME) | Refinery | ACTIVE | 11 |
| ENI Div. R&M TARANTO | Taranto | Refinery | ACTIVE | 6,5 |
| ENI Div. R&M LIVORNO | Livorno | Refinery | ACTIVE | 5,2 |
| ENI RAFFINERIA DI GELA (CL) | Gela (CL) | Bio-Refinery | ACTIVE | 0,75 |
| ENI Div. R&M P. MARGHERA | Porto Marghera (VE) | Bio-Refinery | ACTIVE | 0,36 |
| TAMOIL CREMONA | Cremona | Logistic hub | INACTIVE | 2010 |
| IES MANTOVA | Mantua | Logistic hub | INACTIVE | 2015 |
| RAFFINERIA DI ROMA | Pantano (Roma) | Logistic hub | INACTIVE | 2012 |

*Table 27: Italian oil infrastructure: crude pipelines (Source: Elaboration based on [16])*

| Crude pipeline | km | Owner |
|---|---|---|
| La Spezia - Arcola (SP) | 10 | ARCOLA PETROLIFERA |
| Genova-Ferrera (PV) | 90 | ENI |
| Ferrera (PV) - G.S. Bernardo | 206 | ENI |
| Trecate (NO) - Ferrera (PV) | 43 | ENI |
| Viggiano (PZ) - Taranto | 137 | ENI |
| Ragusa - Augusta (SR) | 57 | ENI |
| Genova-Busalla (GE) | 24 | IPLOM |
| Priolo Gargallo (SR) | 9 | ISAB |
| Quiliano (SV) - Trecate (NO) | 145 | SARPOM |
| Trieste - Timau (UD) | 145 | SIOT |

*Table 28:Italian oil infrastructure: oil products pipelines (Source: Elaboration based on [16]]*

| Oil products pipeline | km | Owner |
|---|---|---|
| Arcola (SP) - La Spezia | 10 | ARCOLA PETROLIFERA |
| Ferrera - Carrosio (AL) - Arquata (AL) | 62 | ENI |
| Sannazzaro (PV) - Rho (MI) | 51 | ENI |
| Sannazzaro (PV) - Chivasso (TO) - Volpiano (TO) | 93 | ENI |
| Sannazzaro (PV) - Fiorenzuola (PC) | 94 | ENI |
| Livorno – Firenze | 89 | ENI |
| Gaeta (LT) - Pomezia (RM) | 112 | ENI |
| Ferrera (PV) - Cremona | 113 | ENI |
| Rho - Malpensa | 39 | ENI |
| Carrosio – Fegino | 32 | ENI |
| Ferrera - Pero -Rho | 58 | ENI |
| Trecate (NO) - Chivasso (TO) | 84 | ESSO |
| Trecate (NO) - Arluno (MI) | 16 | ESSO |
| Trecate (NO) - Turbigo (MI) | 13 | ESSO |
| P. Marghera (VE) - Mantova | 124 | IES |
| Busalla (GE) - Genova | 24 | IPLOM |
| Priolo Gargallo (SR) | 9 | ISAB |
| Napoli terminale marino - Napoli deposito | 4 | KPI |
| Trieste - Visco (UD) | 58 | KRI SpA |
| Fiumicino (RM) - Pantano di Grano (RM) | 15 | RAFFINERIA DI ROMA |
| Trecate (NO) - Quiliano (SV) | 156 | SARPOM |
| Quiliano (SV) - Savona (SV) | 6 | SARPOM |
| Quiliano (SV) - Vado Ligure (SV) | 5 | SARPOM |
| Trecate (NO) - Malpensa (VA) | 33 | SARPOM |
| Genova - Lacchiarella (MI) | 112 | SIGEMI |
| Lacchiarella (MI) - Tavazzano (MI) | 25 | SIGEMI |
| Arquata Scrivia (AL) - Genova | 37 | SIGEMI |
| Genova Multedo - Genova S. Quirico (GE) | 13 | SIGEMI |
| Cremona - Trecate (NO) | 115 | TAMOIL |

*Table 29 and Table 30:Italian oil infrastructure: crude and oil products ports (Source: Elaboration based on [7])*

| Port | Crude [toe] |
|---|---|
| Trieste | 39.845.031 |
| Sarroch | 12.315.700 |
| Genoa | 9.543.134 |
| Milazzo | 9.352.799 |
| Augusta | 8.605.654 |
| Santa Panagia Bay | 6.316.416 |
| Vado Ligure | 5.881.519 |
| Leghorn | 2.695.410 |
| Ancona | 2.113.506 |
| Taranto | 1.316.484 |
| Falconara | 427.537 |
| TOTAL | 98.413.190 |

| | Oil products [ton] |
|---|---|
| Naples | 1.699.136 |
| Marghera | 1.464.544 |
| Porto San Leonardo | 1.141.547 |
| Fiumicino | 952.247 |
| Ravenna | 929.268 |
| Genoa | 864.166 |
| Augusta | 858.926 |
| Sarroch | 640.559 |
| Trieste | 503.074 |
| Brindisi | 492.712 |
| Leghorn | 418.237 |
| Other ports | 1.050.494 |
| TOTAL | 11.014.910 |

*MATLAB code developed with the aim to manage and ordered the data download from Alphatanker*

```
clear all
clc

[file,path] = uigetfile('*.xlsx');
path=strcat(path,file);
[n t]=xlsread(path);

a=t;
b=t(1,:);
c=n;
a(1,:)=[];

while size(a,1)>0
    f_name=a(1,4);
    index_r=find(strcmp(a,f_name))'-3*size(a,1);
    del_ind=find(index_r<=0);
    if ~isempty(del_ind)
        for i=length(del_ind):-1:1
                index_r(del_ind(i))=[];
        end
    end
    index_c=[2,3,1,5,6,7,9,10,11,12,13];
    matr=[b(2), b(3), b(1), b(5), b(6),
b(7),b(9),b(10),b(11),b(12),b(13)];
    for i=length(index_r):-1:1
        for j=1:length(index_c)
            if index_c(j)<5
```

```
                matr(i+1,j)=a(index_r(i),index_c(j));
            elseif index_c(j)==5
                matr{i+1,j}=num2str(c(index_r(i),1));
            elseif index_c(j)==6
                matr{i+1,j}=num2str(c(index_r(i),2));
            elseif index_c(j)==7
                matr{i+1,j}=num2str(c(index_r(i),3));
            elseif index_c(j)==9
                matr{i+1,j}=num2str(c(index_r(i),5));
             elseif index_c(j)==10
                matr{i+1,j}=num2str(c(index_r(i),6));
             elseif index_c(j)==11
                matr{i+1,j}=num2str(c(index_r(i),7));
             elseif index_c(j)==12
                matr{i+1,j}=num2str(c(index_r(i),8));
             elseif index_c(j)==13
                matr{i+1,j}=num2str(c(index_r(i),9));
            end
        end
        c(index_r(i),:)=[];
        a(index_r(i),:)=[];
    end
    xlswrite(char(f_name),matr);
end
```

# Appendix D: Geopolitical and maritime security assessment

*Table 31: Historical events of ship loss (Source: [34])*

| ***Ship Loss*** | | |
|---|---|---|
| ***Area*** | ***Accidents [2009-2018]*** | ***Share [%]*** |
| *China, Indo China, Indonesia & Philippines* | 234 | 22.6 |
| *East Mediterranean & Black Sea* | 153 | 14.8 |
| *Japan, Korea and North China* | 117 | 11.3 |
| *British Isles, the North Sea, English Channel, Bay of Biscay* | 77 | 7.4 |
| *Arabian Gulf* | 58 | 5.6 |
| *West African coast* | 46 | 4.4 |
| *West Mediterranean* | 39 | 3.8 |
| *East african coast* | 32 | 3.1 |
| *Bay of Bengal* | 28 | 2.7 |
| *Russian artic and bering sea* | 26 | 2.5 |
| *Others* | 226 | 21.8 |
| *Total* | 1036 | |

*Table 32 - Maritime risk calculation according to (Source: Elaboration based on [29] and on [31] )*

| ***Country*** | ***WGI*** | ***Piracy risk*** | ***Maritime risk*** | ***Country*** | ***WGI*** | ***Piracy risk*** | ***Maritime risk*** |
|---|---|---|---|---|---|---|---|
| Afghanistan | 92 | - | 79 | Kazakhstan | 59 | - | 50 |
| Algeria | 77 | - | 66 | Kenya | 69 | 2 | 59 |
| Angola | 82 | 44 | 76 | Kuwait | 51 | - | 44 |
| Armenia | 54 | - | 46 | Liberia | 76 | 17 | 68 |
| Azerbaijan | 72 | - | 62 | Libya | 97 | - | 83 |
| Brazil | 58 | - | 50 | Lithuania | 23 | - | 20 |
| Cameroon | 85 | 81 | 84 | Malaysia | 35 | 99 | 44 |
| Canada | 7 | - | 6 | Malta | 17 | - | 14 |
| Chile | 20 | - | 17 | Morocco | 58 | 8 | 51 |
| China | 57 | - | 49 | Namibia | 39 | - | 34 |
| Congo | 86 | - | 74 | Netherlands | 6 | - | 5 |
| Costa Rica | 29 | - | 25 | Nigeria | 83 | 100 | 85 |
| Côte d'Ivoire | 67 | - | 57 | Norway | 3 | - | 3 |
| Croatia | 34 | - | 29 | Oman | 43 | 6 | 37 |
| Cuba | 63 | - | 54 | Portugal | 15 | - | 13 |
| Cyprus | 24 | - | 21 | Qatar | 36 | - | 31 |
| Denmark | 6 | - | 5 | Russia | 71 | - | 61 |
| Djibouti | 77 | 1 | 66 | Saudi Arabia | 54 | - | 46 |
| Egypt | 76 | - | 65 | Senegal | 51 | 9 | 45 |
| Eritrea | 93 | - | 79 | Sierra Leone | 72 | 19 | 64 |
| Estonia | 15 | - | 13 | Singapore | 11 | 85 | 21 |
| Ethiopia | 76 | - | 65 | Slovenia | 20 | - | 17 |
| Finland | 4 | - | 3 | Somalia | 98 | 18 | 87 |
| France | 18 | - | 15 | South Africa | 43 | - | 37 |
| Gambia | 64 | 7 | 56 | South Sudan | 99 | - | 85 |
| Georgia | 36 | - | 31 | Spain | 25 | - | 21 |
| Germany | 11 | - | 9 | Sri Lanka | 54 | 16 | 48 |
| Ghana | 47 | 89 | 53 | Sudan | 94 | - | 81 |
| Greece | 38 | - | 33 | Sweden | 5 | - | 5 |
| Guinea | 83 | 22 | 74 | Switzerland | 2 | - | 2 |
| Guyana | 57 | - | 49 | Thailand | 56 | 22 | 51 |
| India | 52 | 76 | 55 | Togo | 77 | 70 | 76 |
| Indonesia | 54 | 100 | 60 | Tunisia | 56 | - | 48 |
| Iran | 82 | 1 | 70 | Turkey | 62 | - | 53 |
| Iraq | 91 | - | 78 | United Arab Emirates | 30 | - | 26 |
| Ireland | 10 | - | 8 | United Kingdom | 15 | - | 13 |
| Israel | 30 | - | 26 | United States | 16 | - | 13 |
| Italy | 33 | - | 28 | Venezuela | 95 | - | 82 |
| Jamaica | 40 | - | 34 | Vietnam | 59 | 40 | 56 |
| Japan | 12 | - | 10 | Yemen | 98 | 9 | 85 |

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