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Modelling the role of oil in the Italian energy security

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ABSTRACT

It has become clear that the present energy paradigm is not sustainable anymore and it is necessary to find new ways to comply with global energy demand avoiding GHGs emissions (leading to global warming and consequently climate change phenomena) and air pollutant emissions (causing negative impacts on human health). Therefore, in the last years several international agreements were signed in order to counteract the climate change effects and to promote more sustainable energy policies supporting the so-called "energy transition". The aim is to move from traditional energy systems based on fossil fuels to an energy mix based on renewables.

Despite this need for de-carbonization, developing countries still push demand of fossil resources. Developed countries like Italy, on the contrary, promote sustainability-oriented policies. Indeed, renewable resources experienced a constant increase in their penetration during last 10 years and are expected to become the key commodities in the energy mix in the long term. Nevertheless, in the short mid-term, even in these countries fossil fuels still play a relevant role. In particular, oil still maintains a crucial role in transport sector.

As well, Italian energy system is still dependent on fossil fuels: oil and natural gas accounted respectively for 34,0% and 34,5% of total primary energy supply in 2018. Furthermore, due to the unavailability of internal oil reserves, Italy is a net importer from oil producing countries such as Iraq, Azerbaijan, Russia and Saudi Arabia. Thus, Italy is strongly subjected to geopolitical dynamics involving these countries and is more vulnerable to oil supply disruption. The relevance of energy security requires the availability of science-based models and tools for supporting the policy-decision making, in order to assess the impacts of possible contingencies and the mid-/long-terms effects of alternative mitigation strategies.

The aim of this thesis is to develop and implement a new model for quantification of the total energy risk related to Italian oil suppliers. For this purpose, an overall analysis of the oil trade is performed through the collection and processing of data from different open-source and purchased databases. Then all oil suppliers were identified and oil flows from the oil fields to the national entry points were tracked. Once known Italian entry points, the oil pathways were traced backwards through a georeferred mapping of both captive and open-sea corridors (including refineries, ports, pipelines and maritime routes). Moreover, further analysis was focused both on technical characteristics of oil pipelines, transport infrastructures and geopolitical risk of crossed countries. This multi-layer approach to risk analysis allows to provide a complete vision of the interconnections between national security and the geopolitical stability of supply countries. Furthermore, ad hoc metrics and integrated indicators were defined in order to provide an overall measure of energy risk of oil supply.

Finally, several scenarios were built and analysed with the aim of comparing the impact of possible adverse events (e.g., unavailability of a given infrastructure, emergence of geopolitical tensions or commercial disputes) on national energy security in terms of supply risk.

Summary

1 Introduction

This thesis is the result of the collaboration with Anolli Davide, student of the Polytechnic of Torino enrolled in the master course of Energetic and nuclear engineering. The combination between the Environmental and the Energy field allowed to perform a more thorough investigation of Italian energy security level and to develop a more comprehensive methodology for modelling energy risk related to Italian oil supply. Moreover, different backgrounds and personal skills enhanced development of a unique overall product. In particular, the collaboration supported the initial phase of data collection for Italian oil market characterisation and afterward on the theoretical development of the risk model. Davide managed the energy fluxes characterization and the processing of the model data. On the other hand, through my experience with GIS software, I dealt with georeferencing and characterization of all global infrastructure involved in Italian oil trade (not only Italian ports and refineries but also foreign ones). After that, I traced backwards open sea routes and captive corridors travelled by crude and petroleum products. Hence, I associated to each corridor and infrastructure corresponding information required to perform risk model. I selected the major corridor and grouped together routes with similar pathway whereas Davide performed energy flux sorting. Once succeeded to risk model development, we considered different scenarios and, consequently, different results. Finally, it should be point out that the general framework of the two thesis is different according to our personal master course. Davide has focused the attention on the role of oil in the energy sector, whereas I have analysed the oil trade from the point of view of the energy transition.

1.1 Oil role in the energy transition

Global environmental issues such as atmospheric pollution, biodiversity loss, depletion of natural resources and environmental degradation are caused by anthropic activities. It is proved by scientific evidences that global warming and atmospheric pollution are two serious problems related to the combustion of fossil fuels. Nevertheless, global energy and transport sector, still today, rely on fossil fuels even though it has become clear that actual energy paradigm is not sustainable anymore. In particular, energy sector is the main anthropogenic factor of climate change accounting for 62% of total CO_2 [1] emissions and it is the leading cause of global air pollution.

The Intergovernmental Panel on Climate Change (IPPC), which is intergovernmental body created by the United Nations (UN) in 1988 [2] for assessing implications and potential future risks related to climate change, has warned that, at the present rate of greenhouse gas emissions (GHG), it is expected an increase of global average temperature by more than three degrees Celsius this century [2]. Actually, the world is already experiencing the impacts of climate change, from sea-level rise to melting glaciers and extreme weather phenomena. Sustainability is an important part of counteracting these global threats. Hence, the UN is supporting a number of initiatives to improve "decarbonization" process and increase use of renewable sources.

Since traditional energy system relies mainly on fossil fuels, energy transition has become a global and priority need. To reach this goal, technological development and strategic policy action play a crucial role, but yet they are not enough. Actually, the main governments agree to cooperate in order to promote sustainable development policies and to support the energy transition from fossil sources to renewable source. On the other hand, there are many developing countries, which rely on the cheapest sources of energy to sustain their growth, mostly in the form of coal, oil and natural gas. Thus, a drastic reduction of fossil fuels consumption cannot be handled since it threatens to cause further conflicts, inequality and disparities especially to the least developed countries. In addition to this, world primary energy demand is still continuously increasing due to the improvement of lifestyles and population growth. However, in the last years, several international treaties were signed in order to fight the climate change and to promote sustainable development and energy policies which encourage replacing of fossil sources with renewable ones. Nevertheless, the effort of developed countries to support penetration of renewables in residential, industrial and mobility sectors seems to be still not enough to counterbalance the share of fossil sources in the global energy mix. Indeed, according to International Energy Information Administration (EIA), coal, oil and natural gas accounted in 2019 respectively for 13,98%, 33,86% and 38,74% of global primary energy consumption (Figure 1) [3]. Meanwhile, however, renewables are spreading and in 2019 accounted for +50,6% compared to 2009 [4]. Thus, two main trends can be observed: in one hand, increasing of sustainable energy production supported by developed countries, on the other, growth of overall primary energy demand from developing countries which maintains the oil's share supremacy, followed by natural gas.

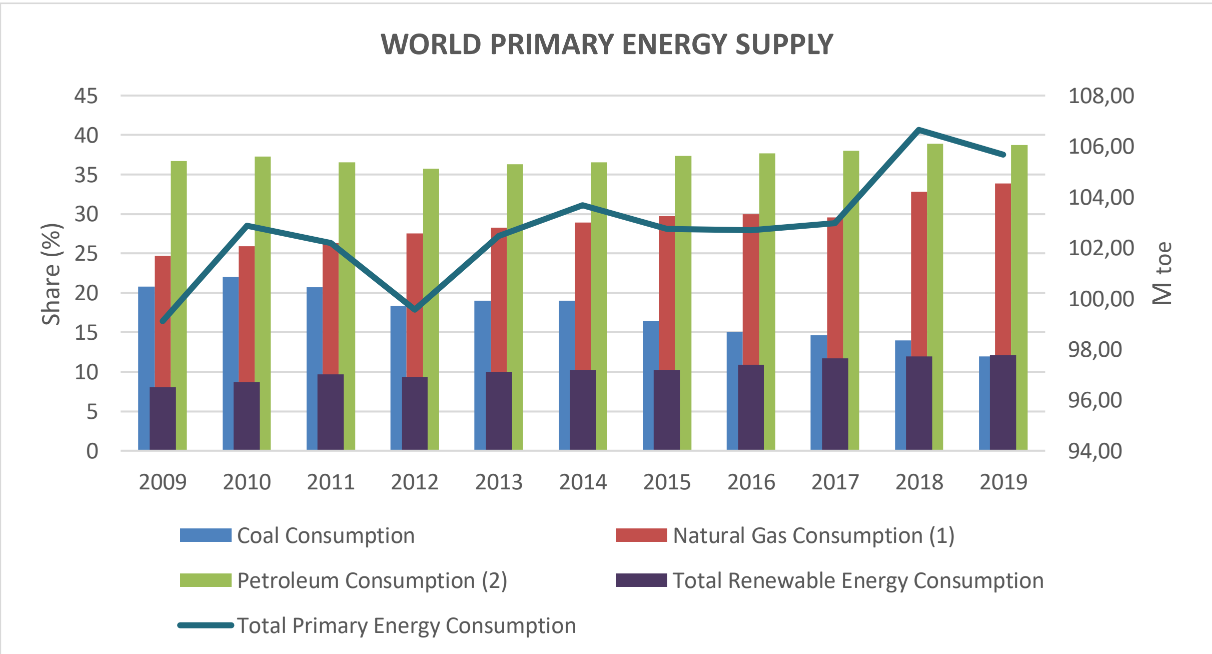


Figure 1:Primary Energy Consumption by Source (Source: Elaboration based on [4])

(1)(Excluding Supplemental Gaseous Fuels)
(2) (Excluding Biofuels)

In addition, fossil fuels often rise issues in terms of geopolitical stability since they are the most valuable commodities but they are not distributed evenly in the world. Therefore, "*In a fossil-fuel world, control over oil and gas reserves is an essential component of national power*" [5], the majority of crude extraction relies on few countries which are continuously subjected to political instability and threats of attack. Indeed, since fossil fuels constitute the major source of income for governments that control their production and distribution, many conflicts and tensions are attributable to the fighting for control over gas and oil reserves. Especially as regards crude oil reserves, Middle East owns more than 54% of total crude reserves (Figure 2), followed by Latin America which accounts for almost 22% [6] whereas most countries are forced to import crude in order to satisfy oil demand and this fact deeply affects oil market dynamics.

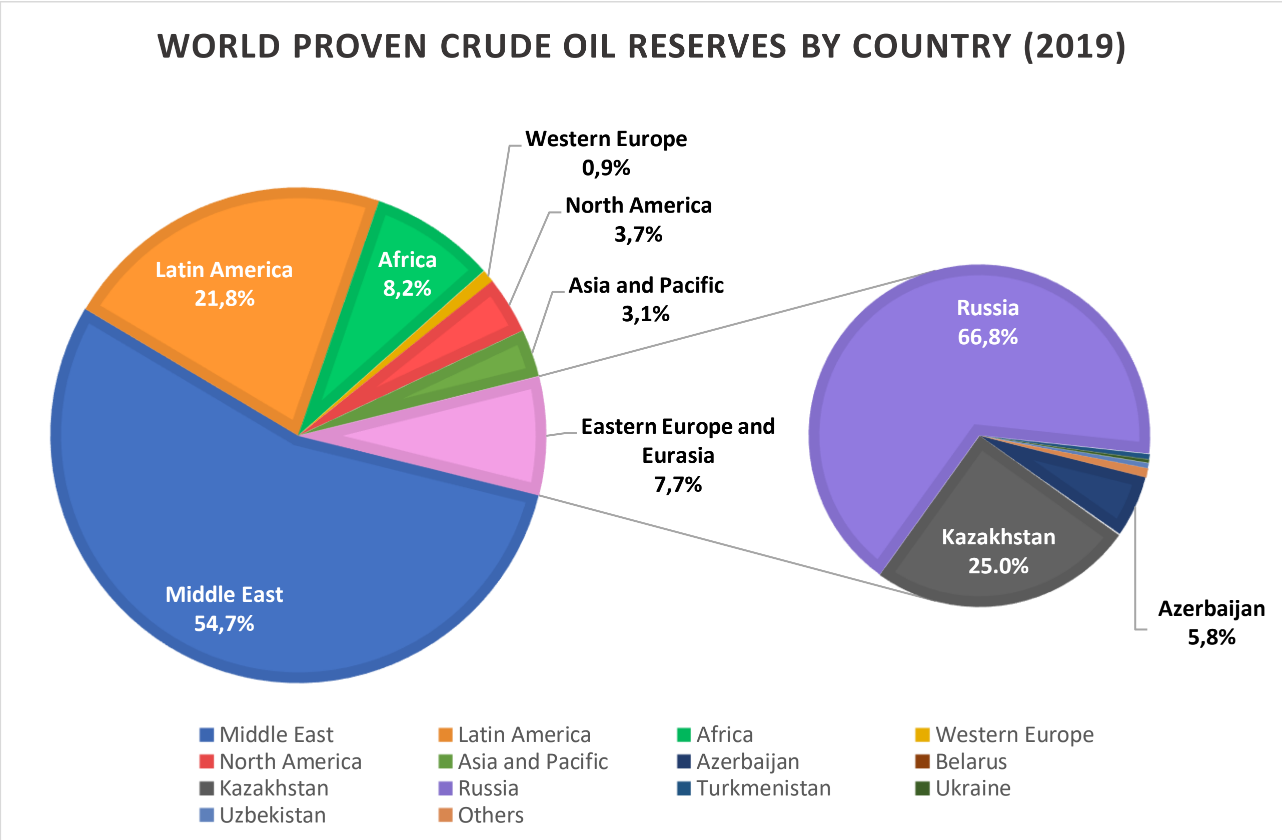


Figure 2:World proven crude oil reserves by country (Source: Elaboration based on [6])

However, contrary to renewables, oil is an exhaustible resource, hence it must be taken into account not only the total amount of proven reserves but also the rate of crude extraction. Indeed, the ratio between total reserves (R) and annual extraction (P) represents a representative indicator of the remaining reserves expressed in terms of years. By comparing the shares of proven crude reserves with the R/P ratios [7], it is clear that even if Middle East accounts for the major part of total crude reserve, due to its high rate of extraction, Mideast oil is expected to be depleted before than South and Central America (Figure 3).

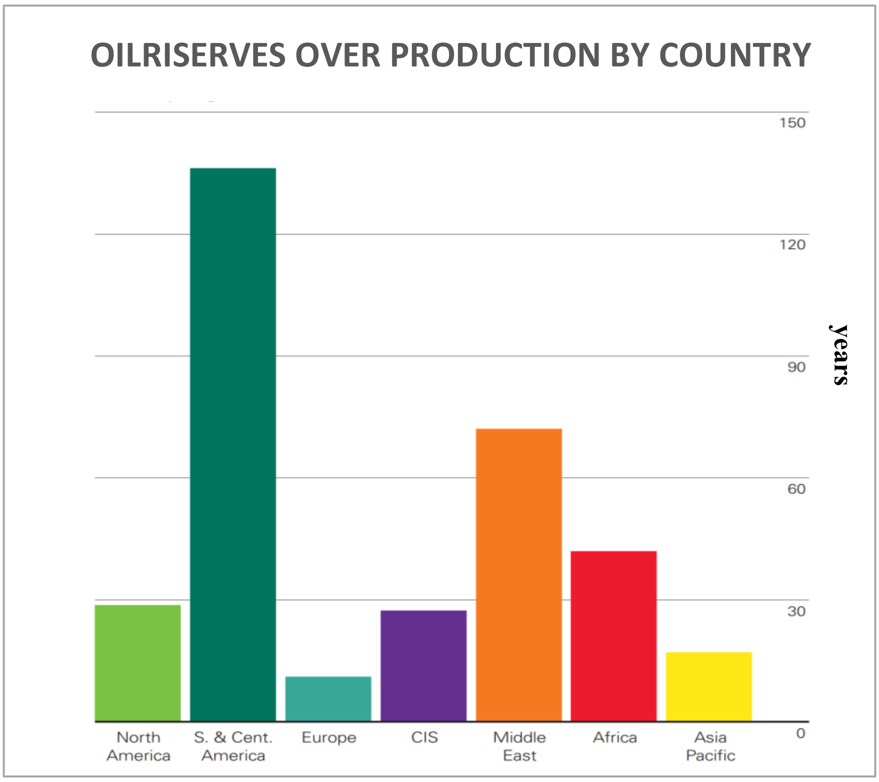


Figure 3: Reserves over production by country (Source: Elaboration based on [7])

Although depletion of oil source is an actual and critical issue, world oil demand followed the same growth trend experienced by global primary energy consumption as outlined by the Figure 4. Moreover, according to EIA's energetic statistics, oil will still account for 25% of total primary energy demand in 2050 [3].

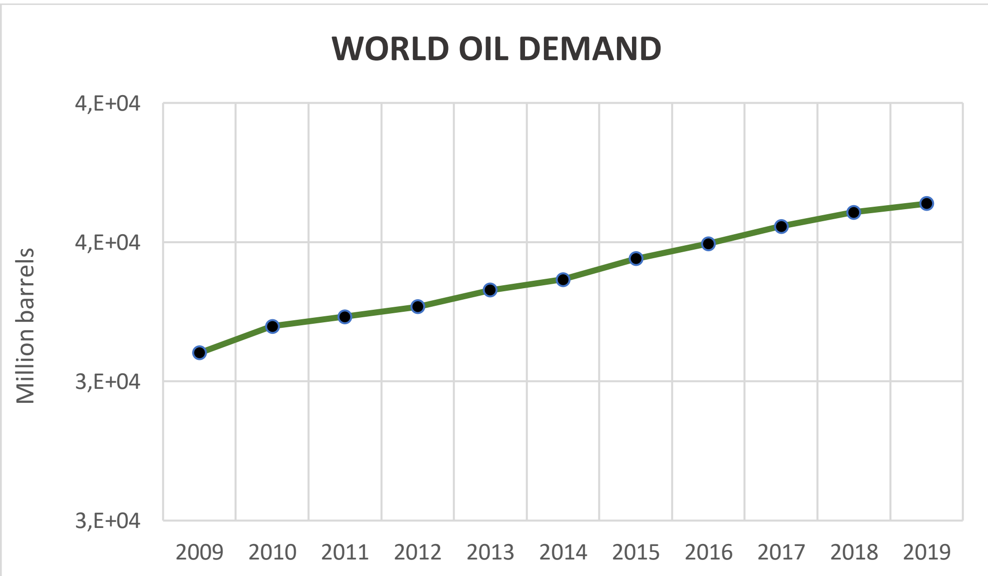


Figure 4: World Oil demand (Source: Elaboration based on [6])

Due to the rise of oil demand, oil production is increasing as well. In 2019 the top oil producers (United States, Saudi Arabia, Russia, China, Iraq and United Arab Emirates) accounted for 61 % [8] of overall crude oil and petroleum products production which amounted to 100.63 million barrels per day. According to OPEC's Annual Statistical Bulletin [6], these countries have also the highest rate of crude oil extraction as showed in Figure 5.

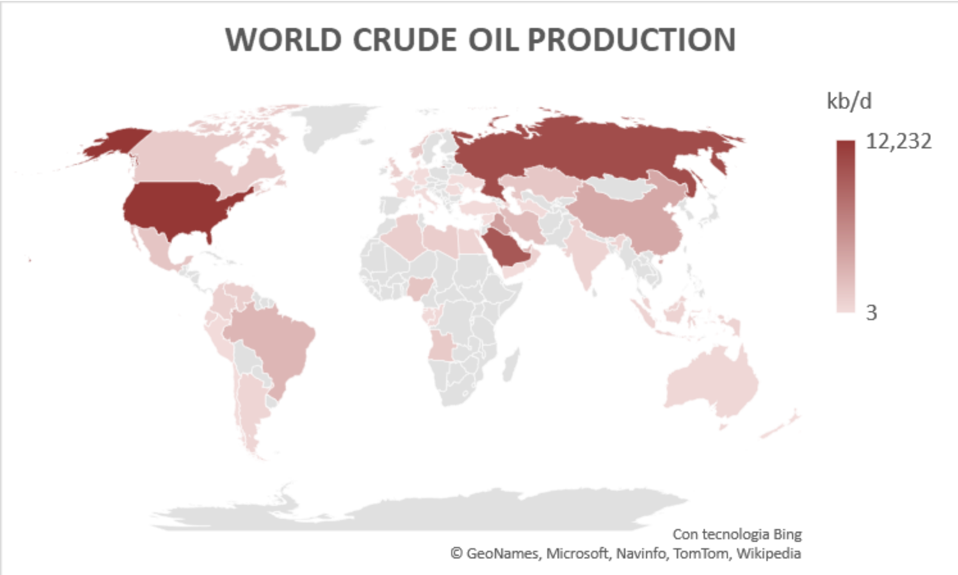


Figure 5: World crude oil production (Source: Elaboration based on [6])

Due to the strong demand for oil, even if inconsistent with the principle of energy transition, many countries are still investing in the development of traditional technologies of crude extraction. As a consequence, rather than decreasing, proven reserves are increasing over time as shown in Figure 6 [6].

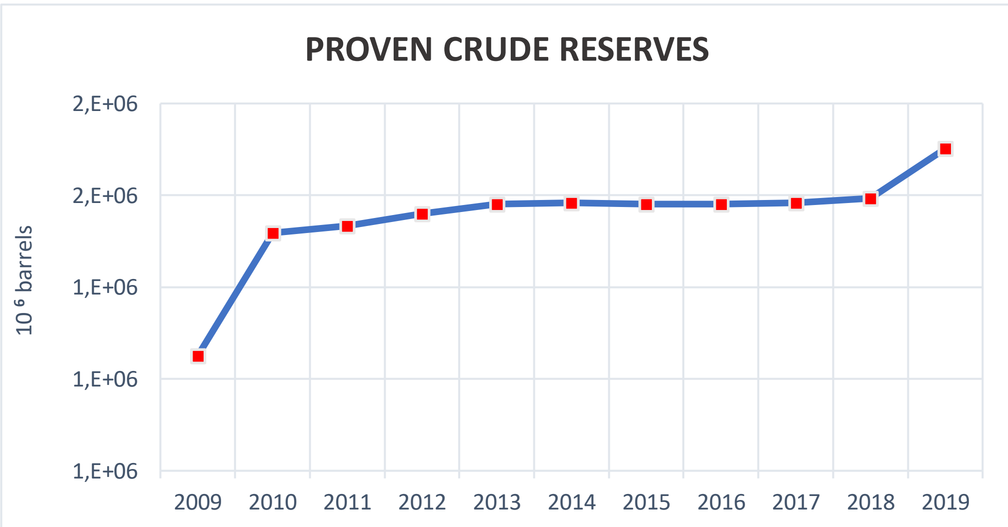


Figure 6: Proven crude global reserves (Source: Elaboration based on [6]

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

Energy reliability plays a crucial role in national security. However, since energy systems are complex and dynamic, an effective political decision making in energy sector must be supported by valid science-based tools able to assess potential risks and to support governments in the planning of strategical and corrective measures. In particular, risk analysis approach provides scientific evidence in order to evaluate the current situation and to estimate the impact of different decisions and alternative scenarios. Risk analysis is intended to be a multi-layer approach able to obtain a complete vision of the interconnection and interactions between socio-economic, geopolitical and environmental issues.

In particular, Italian energy security is really vulnerable to oil supply disruption due both to the unavailability of internal reserves and the large oil consumption. Thus, the aim of this thesis is to develop a science-based approach able to develop a model which produces an overall risk indicator. This index, expressed in joules, represents the expected energy loss related to a certain supply corridor. Since, this dissertation aims to develop a science-based methodology which is easily comprehensible for policy decision makers, maps and explanatory graphs play a central role in the developed risk model.

On one hand, numeric data were used to evaluate the current and historical statistics on global and national oil production, consumption, import and export. On the other, by using GIS software, more focused analyses were performed by collecting geographic and spatial information about oil infrastructure (e.g., the length of pipeline and of the maritime routes, the position of refineries, foreign ports, Italian ports etc.) and oil fields.

Intrinsically, a multi-disciplinary approach is required in order to develop a model which succeeds in taking into account economical and socio-political interdependencies among supplier countries, complexity of energy systems and energy market and physical characteristics of oil infrastructures. To conclude, this thesis tries to combine technical skills in different fields such as Energy, Geomatics, Economics, Policy making, in order to obtain a complete and integrated model through which is possible not only to evaluate the current level of security of a country but also to predict the potential energy risk related to different political choices or accidental events related to oil supply.

1.3 Outline of the thesis

Chapter 1 is focused on a general overview of global issues due to the fossil fuels consumption and the necessity of a new energetic paradigm based on renewable resources and supported by the energy transition. Afterwards, the aim of the thesis is explained followed by the presentation of the implemented science-based model for quantitative assessment of Italian energy security related to crude and petroleum products supply.
In Chapter 2, after a brief description of the main data sources consulted and their specific contribution to energy risk assessment, the results of analyses are reported and commented in order to provide a comprehensive view of Italian energy context mainly focused on its oil dependency on foreign countries.. A particular attention is paid to the evaluation of the oil suppliers diversification index (Shannon index) that is a crucial parameter for the national energy security.

Chapter 3, firstly, introduces the fundamental approach for risk assessment and, in particular, for quantitative evaluation of energy risk related to oil supply from other countries. The external risk concept is explained and its application on the Italian energy security assessment.

Afterwards, the preliminary step of georeferencing and the output maps are illustrated, followed by a description of parameters which affect the probability of failure of a maritime and captive corridor. The logical relations between these parameters are summarized through the so-called Fault Tree whereas the mathematical relations are explained step by step to the final formulation of overall external risk. The critical issues encountered along the model construction are outlined and then grouping routes and energy diversification processes are presented as valid solution to overcome them. Finally, the developed risk model is applied to the reference scenario (2019) and the results are commented.

In chapter 4, five different realistic scenarios are assumed with the aim to evaluate the impact on Italian energy security of possible hazardous events. All the alternative scenarios are compared with the reference scenario. If scenario supposes a loss of energy, feasible mitigative measures are proposed and their corresponding impact on the overall external energy risk.

The chapter 5 contains the conclusion of the thesis underlying the strength but also the weakness of the model. Finally, suggestions are proposed in order to improve the model by taking into account also the economical aspect and enhancement of results visualization.

2 Italian energy context

Nowadays Italian primary energy consumption is still driven by oil and natural gas [9]. The remaining shares are coal, net import of electricity and renewable sources. Nevertheless, Italian production of oil and natural gas is not enough to meet the national demand. As a consequence, Italy is a net importer of both crude and natural gas and this aspect affects strongly its energy security level.

2.1 Characterization of oil supply

Oil trade characterization process turned out to be not easy to perform neither feasible to succeed solely through open-source data. Firstly, because nations are usually reluctant to share information about the internal infrastructure, hence, purchased dataset are necessary to compensate the lack of information. Moreover, oil supply is a very complex system which involves several means of transport (oil tankers, pipelines, tank trucks and trains) and pathways (open sea and captive routes). In addition to this, it is influenced by many unpredictable variables which make the system even more dynamic. For instance, maritime routes may vary according to external events both natural or anthropic which may affect safety navigation and consequently Italian energy security since oil demand depends mainly on crude supply which is usually transported by oil tankers. Nevertheless, despite of pipelines, the “good side” of sea corridor is that in case of disruption it is easier to avoid the loss of energy by modifying route path or, eventually, by changing supplier port.

In other words, in order to perform a thorough investigation of Italian oil corridors, purchasing of further dataset and cross-analyses of a large number of data were required in order to enhance characterization of the oil supply. Although, datasets collection and sorting data were solely the starting steps: a further data validation process must be performed in order to justify some contradictions and differences between data providers.

2.1.1 Validation of data providers

Ministero dello Sviluppo Economico" (MiSE) and "Unione Petrolifera" (UP) are open-source providers which give information about Italian energy context such as oil demand, consumption, import and export. Despite they deal with the same data, several mismatches are present, especially in the amount of imported commodity from a specific country. This is justified by the fact that MiSE and UP belong to different type of institution. MiSE is the government department to which all the entities involved in oil trade must periodically send their data through the compilation of a specific format. On the other hand, UP is a trade-union association that does not include all entities involved in oil system and, moreover, it does not have the authority to claim the information from UP's associate members. Nevertheless, UP publishes an annual oil report which furnishes a detailed overview of Italian situation resulting from analyses performed by high level expert. MiSE and UP data, however, are not enough to perform a complete risk assessment because they do not provide details about crossed countries neither length of branches into national or international waters. Therefore, MiSE and UP are used only to perform analysis of overall Italian energy context.

The missing data are compensated by two further purchased datasets: Alphatanker which provides details about oil maritime routes and Energy Web Atlas (EWA) which gives information about oil pipelines. More specifically, Alphatanker is a dataset that contains all the commercial oil maritime routes with a very high level of spatial and temporal granularity which allows to perform a very detailed investigation. Indeed, it is possible to track specific oil tanker's route, also in real-time, and to obtain information such as load and discharge ports, vessel DWT, amount of commodity transported, sea duration and so on. But since the aim of this dissertation is to achieve an overview of oil supply, bottom-up approach was applied to aggregate the single vessel' details and to obtain a comprehensive and reliable assessment of maritime oil trade towards Italy. Hence, firstly routes with load port and discharge port in common were grouped together in order to form a single sea corridor, then sea corridors starting from the same load country were grouped together. However, since vessels and sea routes grouping required aggregation of a large number of data, this process has been automatized by a MATLAB code in Appendix E. Afterwards, aggregated values obtained by Alphatanker data processing are compared with aggregated value provided by Mise. The graph illustrated in Figure 7 outlines that discrepancies between two data providers are absolutely not negligible.

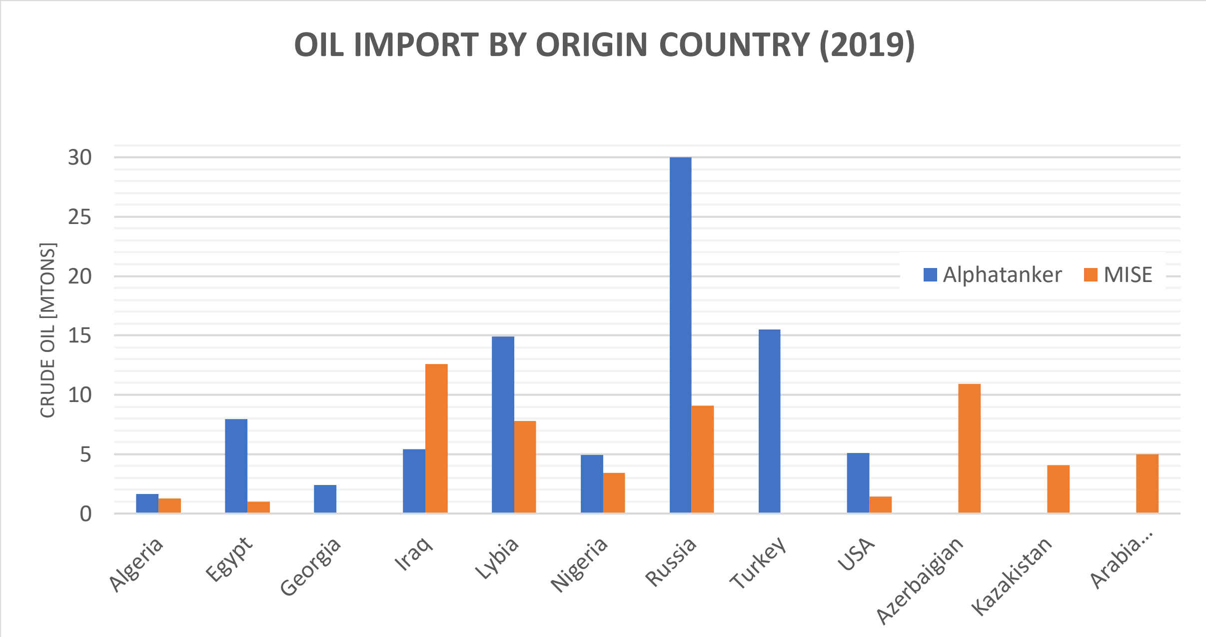


Figure 7: Oil import according to MiSE and Alphatanker (Source: Elaboration base on [10] and [11])

The huge difference between these data providers can be justified by two considerations:

- Alphatanker: reports the amount of commodities delivered to Italian ports by sea, even if only in transit
- MiSE: reports the amount of commodities imported by Italy independently of the type of transport route

Consequently, Alphatanker takes into account also those commodities that transit through Italy and then are exported (therefore not considered by the MiSE). Furthermore, the discrepancies are enhanced 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 exportation.

As a consequence, characterization of the oil pipelines becomes a fundamental step to understand the connection between exporting countries and producing countries. For example, Azerbaijan and Kazakhstan do not have direct access to the Mediterranean Sea, thus their exports succeed thanks to Russian, Georgian and Turkish ports which are linked to oil field by pipelines and deliver Azeri and Kazak crude oil to importer countries, like Italy. To perform this kind of characterization further details about pipelines are required. After several researches, EWA resulted to be the more complete data provider to comply with this need.

Moreover, nomenclatures adopted by Alphatanker and MiSE for classifying oil products are totally different. A bibliographical research pointed out the lack of a unique and international classification system with a specific code and therefore, each institution has developed a personal oil products categorisation. However, with reference to the IPCC's "Guideline for national greenhouse gas inventory" [2] and to the "Questionario sul petrolio" [12] , an association between Alphatanker and MISE has been performed by referring to available data about each category such as distillation temperature, viscosity and field of use.

Table 1: Classification of oil products (Source: Elaboration based on [10] and [12]

Alphatanker terminology	***MiSE code***	***MiSE terminology***
Ultra low sulphur 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 Overview of Italian energy consumption

The historical data of Italian total primary energy supply (TPES), highlights that energy mix always relied on fossil fuels (Figure 8). In 2018, oil accounted for 34.0%, natural gas for 34.5% of and solid fuels for 5.4% [13]. Actually Italy, according to the UN's goal of decarbonization, strives to enhance penetration of renewables in the energy mix, on the other, replacing fossil resources with renewable ones will be a gradual process that requires step-by-step approach.

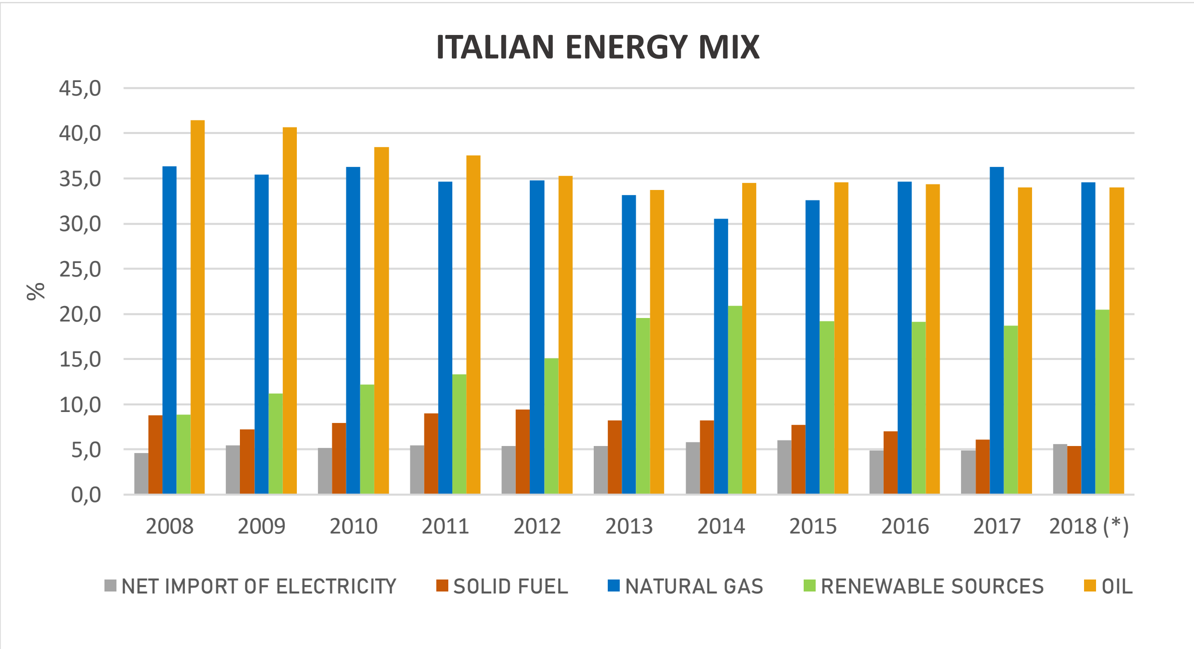


Figure 8: Italian total primary energy supply (Source: Elaboration based on [13])

As shown in the Figure 9, fossil fuels consumption is reduced in the last 10 years: in particular oil decreased from 80 million of toe in 2008 to less than 60 million of toe in 2018. Renewable resources, though, have increased their share in Italy's energy consumption from less than 9% in 2008 to over 20% in 2018 (Figure 8) [13].

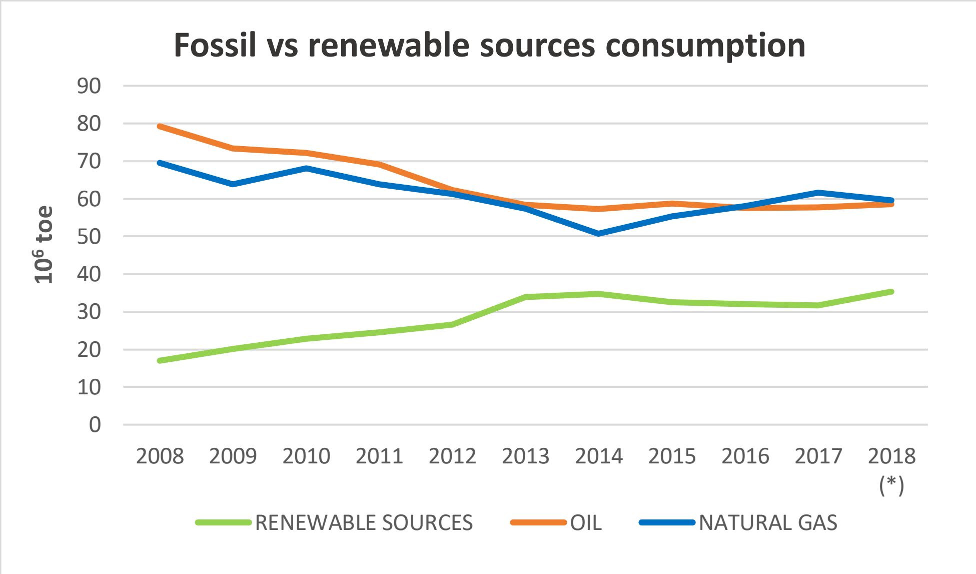


Figure 9: Trends of fossil fuels and renewables consumption (Source: Elaboration based on [13])

Even though the green line shows the increasing trend in renewables, actually fossil fuels still maintains a central role in the Italian energy mix. Indeed, Bilancio Energetico Nazionale (BEN) [9] outlines that transport and industry sectors till depend mainly on oil and natural gas, as well as civil use (Figure 10). In particular, as shown in Table 2, the highest contribution is due to transport (69.7%) rather than industry (5.4%) or civil use (5.2%). Hence, a total electrification of vehicles would lead to a drastic reduction of oil consumption and consequently cut of GHG emissions.

Table 2: Total oil Italian consumption (Source: Elaboration based on [8])

OIL	Mtoe	%
industry	2,88	5,42
transport	37,06	69,69
civil use	2,78	5,23
agriculture	2,29	4,31
non-energy use	5,02	9,44
bunker	3,15	5,92

On the contrary, natural gas owes his consumption to civil use (mainly for heating) and industry which accounted respectively for 62.4% and for 33.4% (Figure 12). Finally, as regards renewable resources (Figure 11), consumption is mainly due to comply with civil use needs (84.2%)

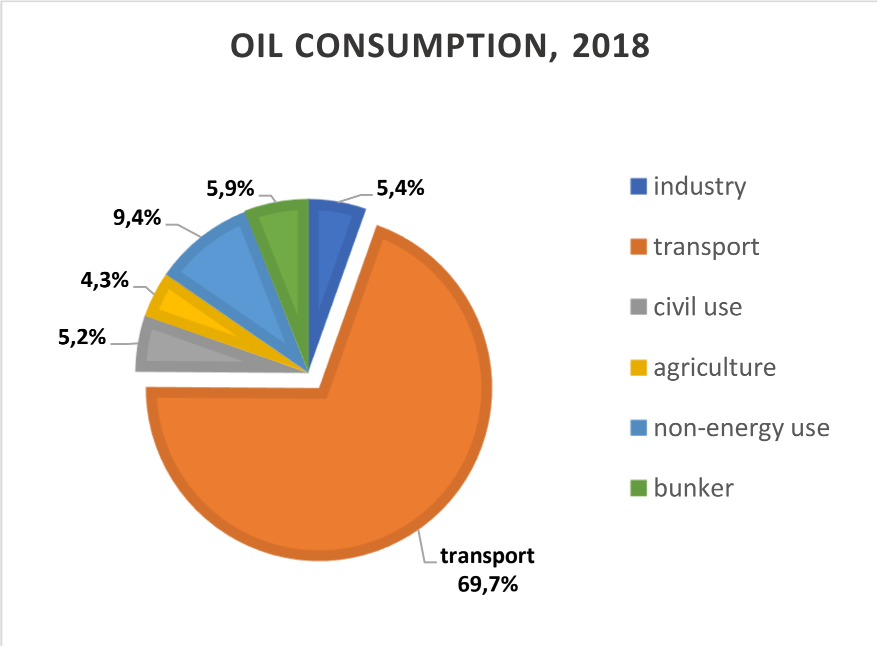


Figure 10: Total oil Italian consumption (Source: Elaboration based on [9])

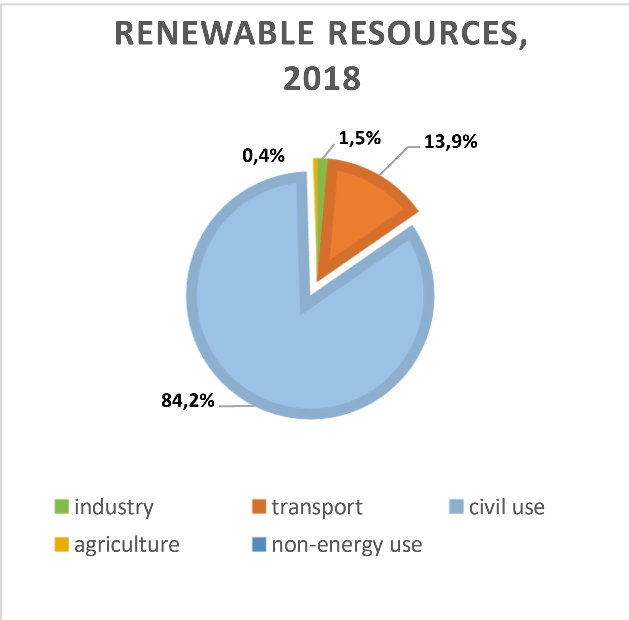


Figure 11: Total renewables Italian consumption (Source: Elaboration based on [8])

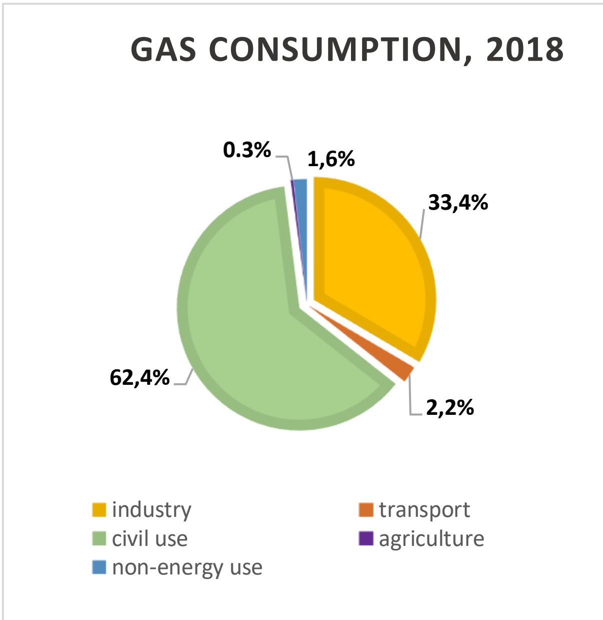


Figure 12: Total natural gas Italian consumption (Source: Elaboration based on [8])

2.3 Domestic crude production and proven reserves

Generally, an oil reserve is classified according to the technical and commercial certainty of extraction using existing technology. This degree of certainty 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 [14], [15], [16]:

1. Proved reserves

2. Probable reserves
3. Possible reserves

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% [17].
According to MiSE, in 2018, Italian oil proved reserves are located for the most part in Basilicata (Table 3) [18].

Table 3: Total Italian oil reserves (Source: Elaboration based on [18]

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	100,00%

In addition, Italian oil extraction platforms are mostly located onshore (89,5%) rather than offshore (Figure 13).

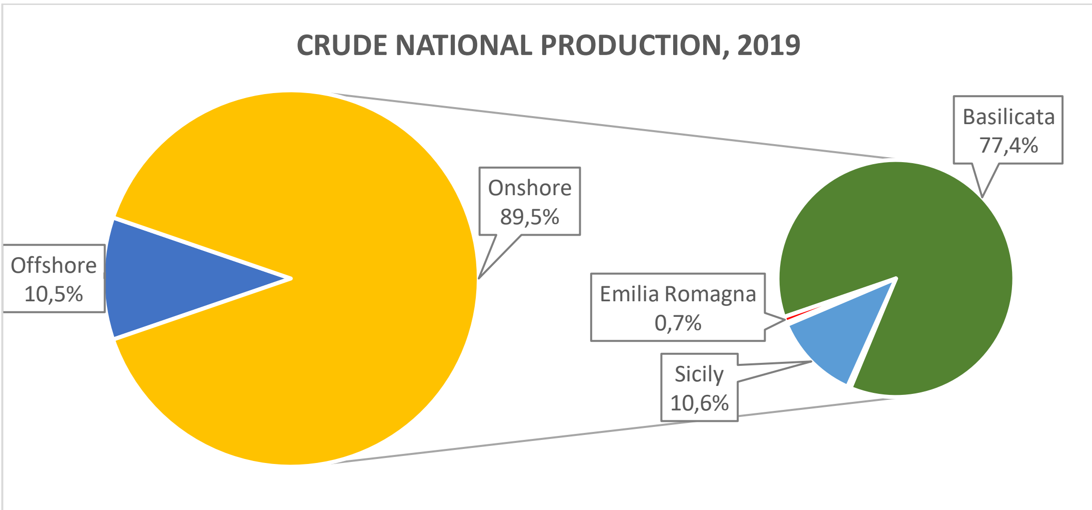


Figure 13: Offshore and onshore shares of oil production (Source: Elaboration based on [18])

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 [18]. Otherwise, further onshore crude production installations are located in Sicily, Emilia Romagna, Piedmont and Molise. Offshore extraction instead, which always played a less relevant in national crude production, further decreased in recent years and 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. Subsequently, the domestic output of crude oil dropped again, reaching an all-time low of 3.75 million tons in 2016. After the minimum peak, the production slightly increased until 2018 before experiencing another decrease in 2019 (Figure 14).

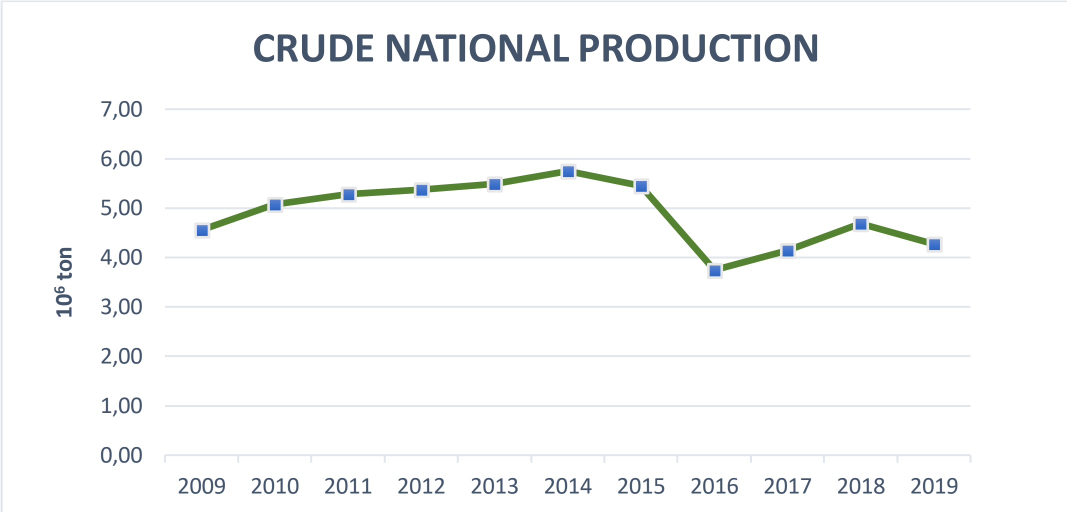


Figure 14: Crude national production (Source: Elaboration based on [19])

2.4 Oil import and export

Since MiSE is the public institution which is responsible for periodically updating Bollettino Petrolifero to provide latest information about oil statistics, it is used as reference dataset to perform a focus on current Italian oil exports and imports. Also UP is used as further data source for Italian oil supply characterization.
As regards crude, by comparing with annual requirement of 57.8 Mtoe recorded in 2019, national production accounted for 7.4% [11]. Furthermore, since net imports of crude satisfied over 90% of the demand [19], Italy is considered as a net importer of oil. The Italian dependence on external oil suppliers is due to the low availability of oil reserves and consequently to the low domestic production of crude. However, thanks to decrease of semi-finished and petroleum products imports, in 2019 Italian overall oil imports decreased of 1.1% compared to 2018 [19]. The decrease affected mainly imports from the Middle East (-26%) and America (-9.7%).

According to UP, oil import appears to be well distributed in 2019: Middle East accounted for almost 28% of total, Africa and Asia respectively for 27% and 24%, European for 17% and America only for 4% (Table 4). Nevertheless, total crude imported in 2019 amounts to 63.14 Mtoe, slightly increased by 1.8% compared to 2018.

Table 4: Ranking of top oil supplier (Source: Elaboration based on [19])

2019	**[M toe]**	**[%]**
1° MIDDLE EAST	17,57	27,8
2° AFRICA	17,09	27,1
3° ASIA	15,03	23,8
4° EUROPE	10,79	17,1
5° AMERICA	2,66	4,2
TOTAL	63,14	

Anyway, these shares varied over the years: in Figure 15, it can be observed two particular trends (blue and orange lines) which represents the evolution of African and Middle Eastern crude import by 2015 to 2019.

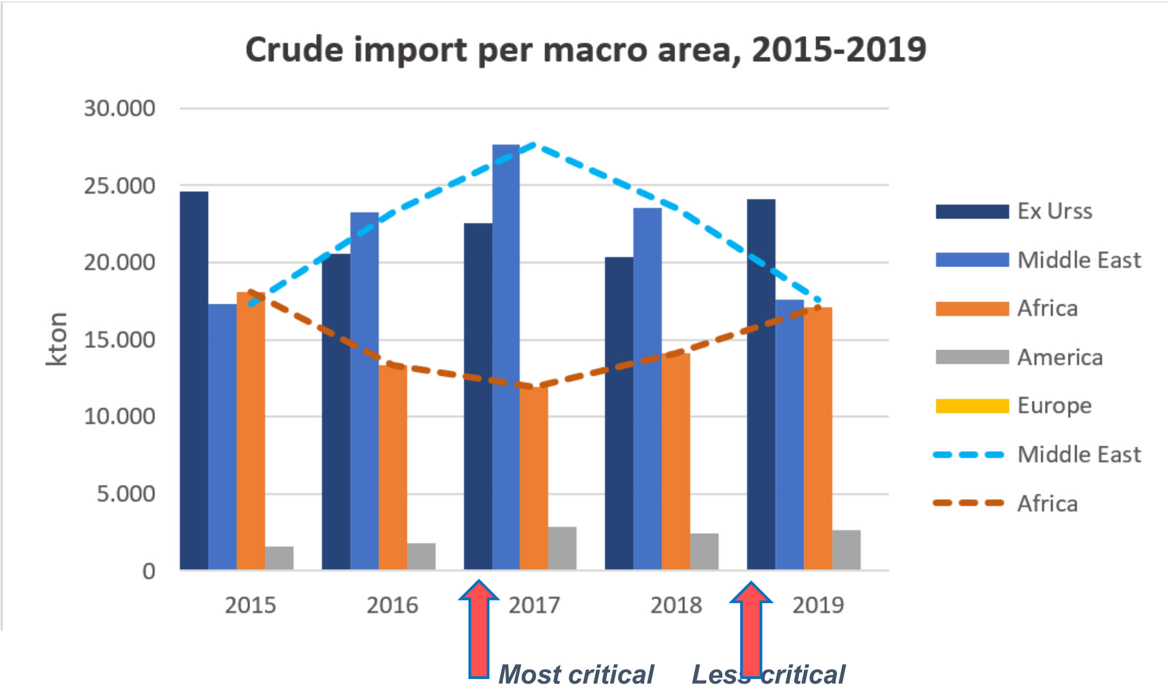


Figure 15: Shares of oil supply by country of origin (Source: Elaboration based on [19])

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 (Figure 16) [19].

	2017	2019	Var 2019/2017
Middle East	27626,9	17589,3	▼ -36%
Africa	11935,1	17090,2	▲ 43%

Figure 16: Trends of Middle East and Africa oil export to Italy (Source: Elaboration based on [19])

In fact, thanks to these shifts, a better balance has been achieved between the three main areas of crude supply [19]:

1. 38% from the ex URSS;
2. 28% from the Middle East;
3. 27% from Africa.

Due to the strong dependence on foreign countries, Italy needs a good level of differentiation of oil suppliers in order to minimize risks for national energy system. Although, in 2019 ex URSS still had greater influence than Africa and Middle East (Figure 15)

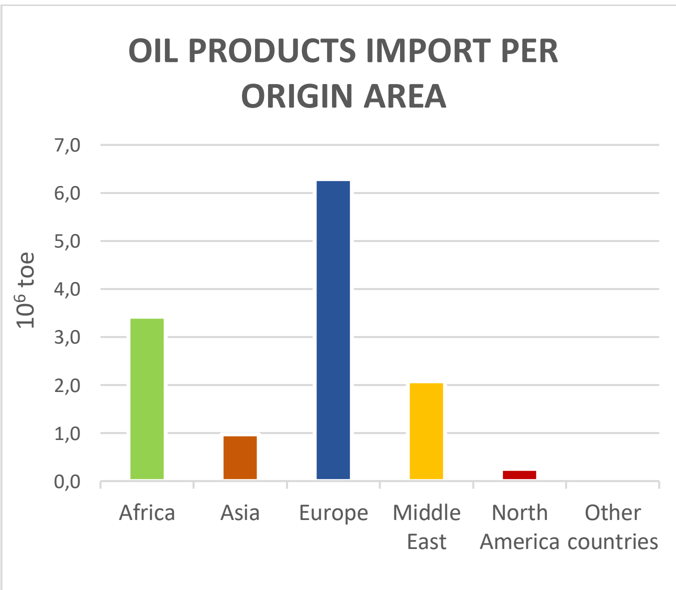
Moreover, by focusing on suppliers countries (Appendix B), in 2019 Iraq overtook Azerbaijan with 12.6 Mtoe (+36.8% than 2018), whereas Azerbaijan accounted for 10.9 Mtoe, Russia for 9.1 Mtoe, Libya for 7.8 Mtoe, Saudi Arabia for 5.0 Mtoe and Kazakhstan for 4.1 Mtoe [19]. The final balance of 2019 shows 24 overall suppliers and 73 different types of crude oil, though the top three exporters (Iraq, Azerbaijan and Russia) supply 51.7% of the total crude demand. Furthermore, oil products experienced a fluctuating trend last years, whereas semi-finished products were characterized by a steady decrease [19].
Anyway, overall semi-finished and finished products import is very low with respect to crude (Table 5).

Table 5: Total import by commodity (Source: Elaboration based on [19])

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

In addition, oil products imports appear more dependent on Europe rather than crude ones [19]: indeed Africa, Middle East and Asia have lower contribute to Italian supply (Figure 17). In 2019, petroleum products import was mainly composed by three commodities (Figure 18):

- gas oil (38.6%);
- petroleum (21.0%);
- LPG (18.0%).



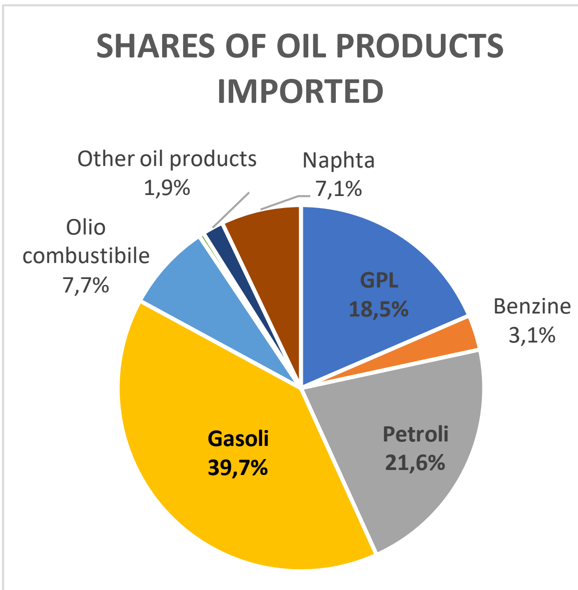
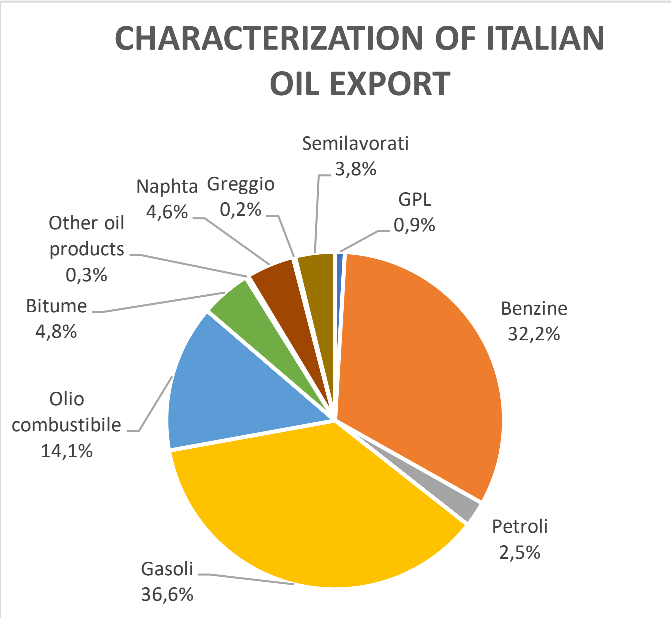


Figure 17 and Figure 18: Characterization of oil products imported by Italy(Source: Elaboration based on [19])

If on one hand, Italy is a net importer of crude due to the poor oil reserves; on the other, Italian refining activity produce several oil products which are partly exported and partly satisfy internal demand. Gasoline and gas oil are the most exported commodity, followed by fuel oil. The first importer of Italian oil products is Europe, which accounts for over 65% [19].



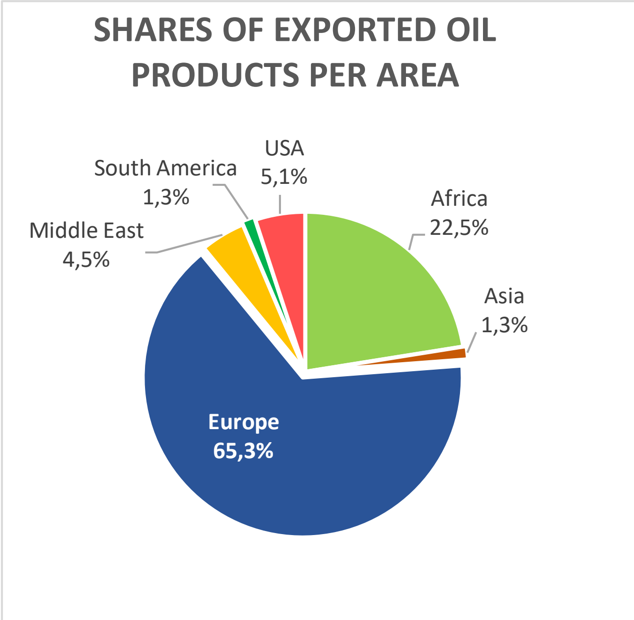


Figure 19 and Figure 20: Characterization of Italian oil exports (Source: Elaboration based on [19])

Moreover, by taking into account self-production, import and export, the so-called foreign dependence index D can be obtained [19]:

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

Where:

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

The historical trend of foreign dependence index confirms that Italy has always been strongly dependent on other country on oil supply. Even though in 2014 experienced a drastic reduction (Figure 21), Italian overall dependence still remains over 92%. This fact is mainly due to crude supply since national crude production is far less than total oil demand.

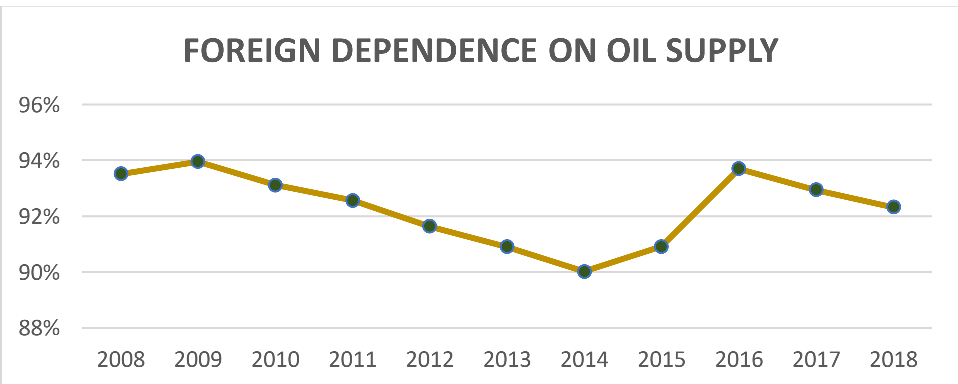


Figure 21: Trend of Italian oil foreign dependence (Source: Elaboration based on [19])

2.4.1 Shannon index

Especially for Italy, assessment of oil supply diversification is crucial. Actually, the concept of supply diversification includes three key elements [20]:

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. [21]

One of the most common diversity indicator is the Shannon index. Indeed, several Shannon indices are used but, according to the aim of this dissertation, only overall diversification indicator will be introduced for the characterization of the national energy security related to oil supply. Indeed, S_i assesses the diversification degree of oil suppliers, by taking into account both country of origin and the imported amount of a specific commodity.
In mathematical terms, S_i is defined as follows:

$$S_i = -\sum_j m_{ij} ln(m_{ij}) \quad [-]$$

Where:

- m_{ij} is the share of imports of commodity i from supplier j with respect of total import of commodity i
- S_i is overall diversification indicator 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. In this case, two level of detail are considered:
  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 grade of definition but it allows to compare Alphatanker and MiSE data. Actually, 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 the more balanced will be the supply of commodity i and, in case of failure of a corridor, the more easily will be to mitigate impact by increasing importation from other alternative corridors. In this way, however, commodities with greater number of suppliers turn out to be better distributed despite of 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 normalization, three values are obtained: H_1 and H_2 linked to Aphatanker data and H^*_2 based on MiSE data.

By comparing H_1 and H_2 two possible phenomena can be observed (Table 6):

- 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 there is a better distribution of commodity supply.
- Case 3: Shannon index equal to zero if there is only one supplier; this is the most critical situation because in case of failure of a corridor there is no alternative supplier (e.g. asphalt, bitumen, vacuum gas oil). Shannon indexes are equal to zero because there is only one supplier of these commodity.

Table 6: Diversification indicators of crude and oil products suppliers in 2019 (Source: Elaboration based on [11], [19], [10] , [12])

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 sulphur 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 Alphatanker match with the amounts reported by MiSE (e.g. imported crude per country in Figure 22 and Figure 23).

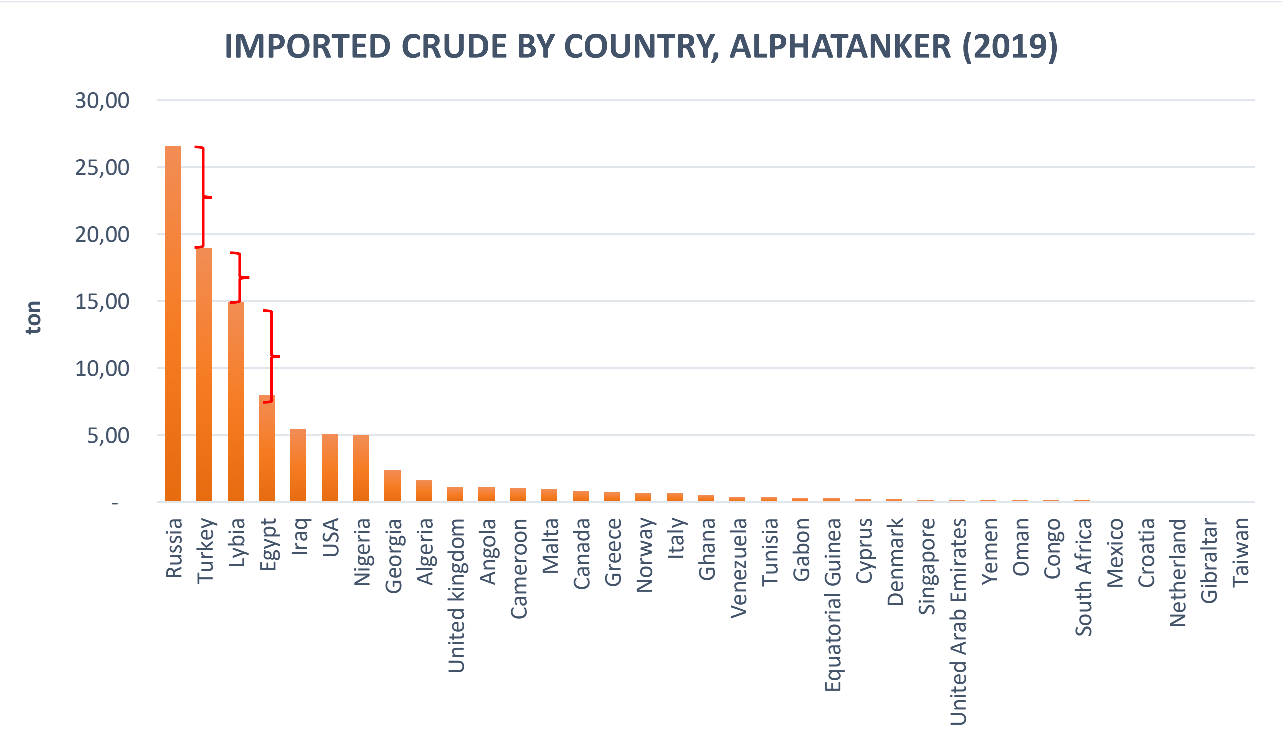


Figure 22: Imported crude oil by load country, 2019 (Source: Elaboration based on [10])

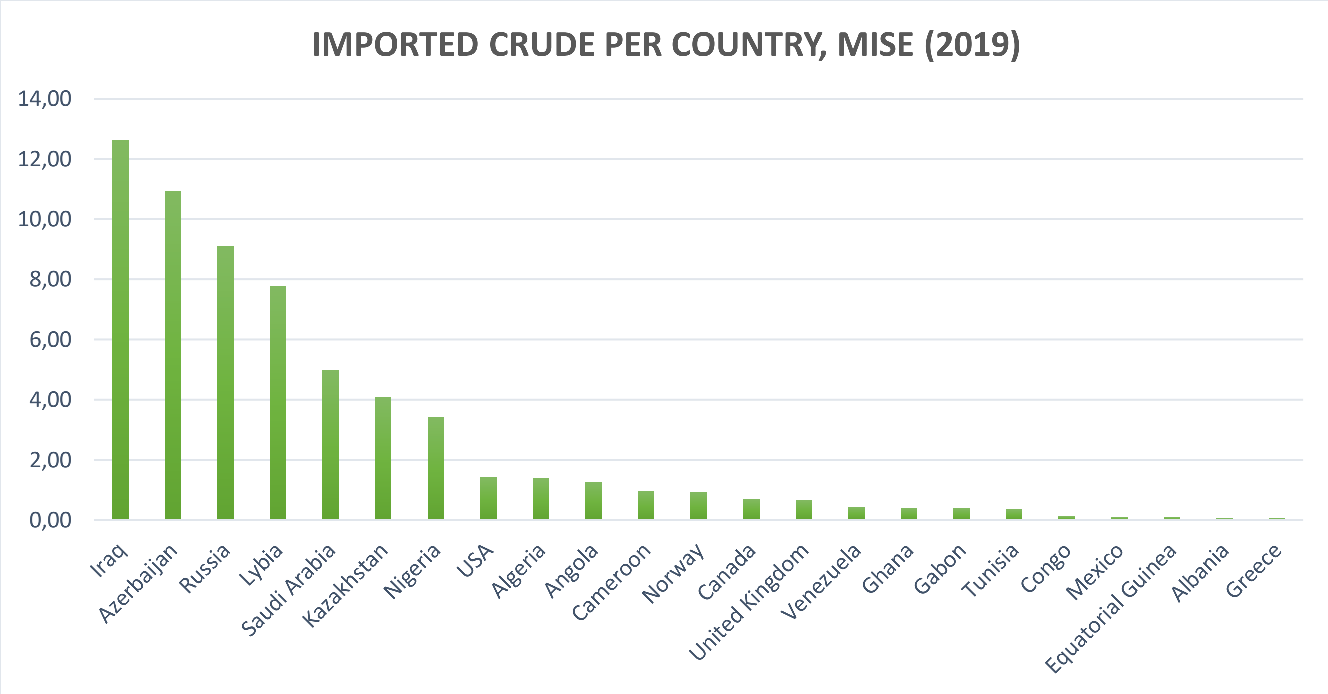
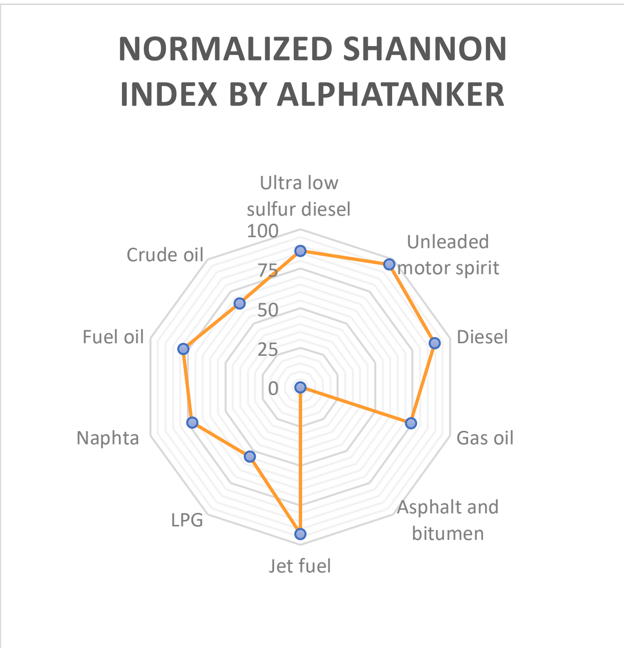


Figure 23: Imported crude oil by producing country, 2019 (Source: Elaboration based on [11], [19])

Indeed, Alphatanker accounts the total amount of commodity discharged in Italian ports even if only transiting whereas MiSE accounts the imported quantity destined for local use. As well as, radar graphics reported in Figure 24 and Figure 25 evidence that the overall distribution of oil commodity importations according to MiSE is more evenly balanced. For instance, bitumen and asphalt come solely from Spain according to Alphatanker (as opposed to MiSE, which accounts 5 different countries of origin), 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 accounts less suppliers than MiSE.



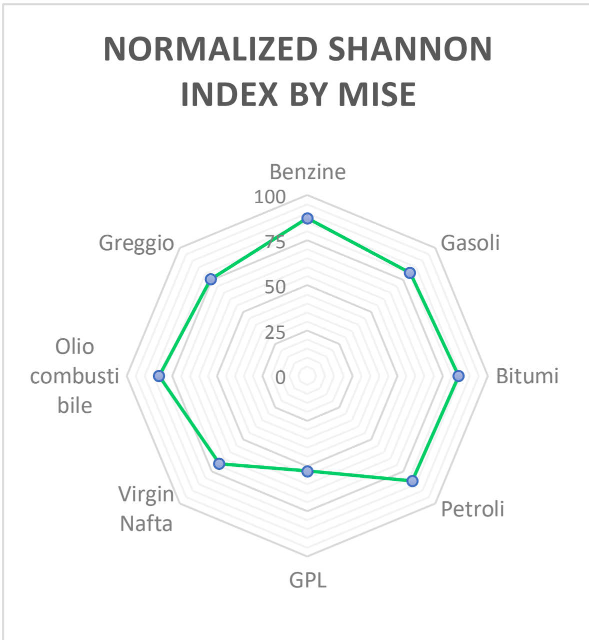


Figure 24 and Figure 25: Normalized Shannon indexes (Source: Elaboration based on [11], [10])

2.5 Oil infrastructures and refinery activity

In general, the main infrastructures involved in the oil supply are three: refineries, oil pipelines and ports. Indeed, unlike natural gas, the role of maritime traffic in the oil sector (especially crude oil) is crucial. This aspect is due to the strong dependence of Italy on oil exporting countries. In case of long distances, crude is generally transported by oil vessels whereas oil products both by vessels, tank vehicles or trains. Thus, 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, the most active Italian ports in the trading of petroleum products are often close to refineries. In fact, once refined, petroleum products are partly exported and partly used for internal consumption.

Actually, over the past 10 years has been recorded a progressive decline in demand for refined products (Figure 26) [19]. For this reason, several refining plants have been closed or converted into logistics centers (e.g. TAMOIL Cremona, IES Mantua, Refinery of Rome) or into bio-refineries (e.g. Gela and Porto Marghera).

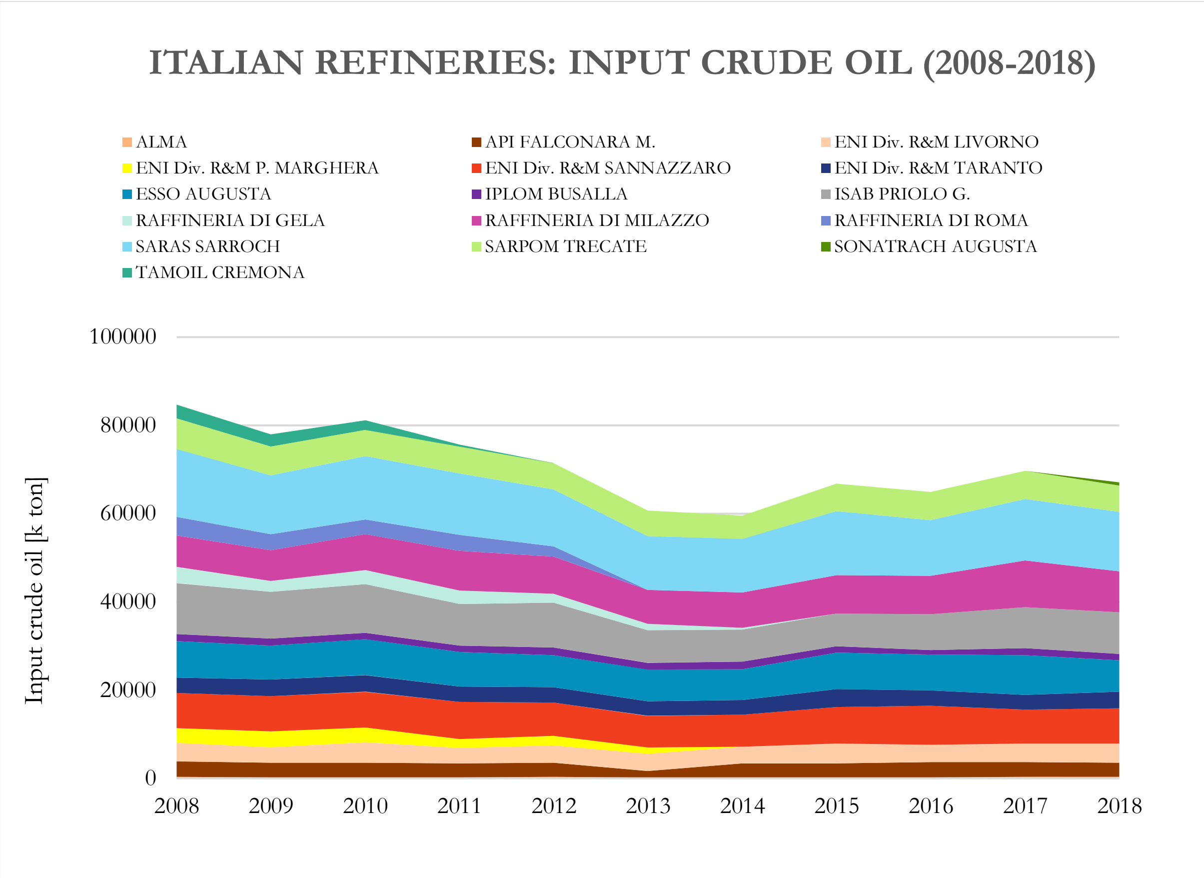


Figure 26: Historical data of Italian refinery activity (Source: Elaboration based on [19])

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. Currently, the refineries operating in Italy are those described below and represented in Figure 27.

In the north of Italy [22]:

- 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 fueling in Po area;
- the refinery of Sannazzaro de 'Burgondi (PV), managed by ENI;
- the Busalla (GE) refinery, in operation since 1943, now owned by Iplom. It specializes in the production of bitumen, diesel and fuel oil.

In the center of Italy:

- 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 bio methanol
- the Ravenna refinery, managed by Alma Petroli;
- the Falconara Marittima (AN) refinery established in 1933 and currently 99% controlled by Api.

In southern Italy:

- the Taranto refinery, active since 1964 and currently managed by ENI; according to Seveso directives is classified as a plant with high risk of accident.

In the islands:

- 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.

Data published in the annual report of Unione Petrolifera (2019), show that the most active refineries in the crude processing were (Figure 28): 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%).

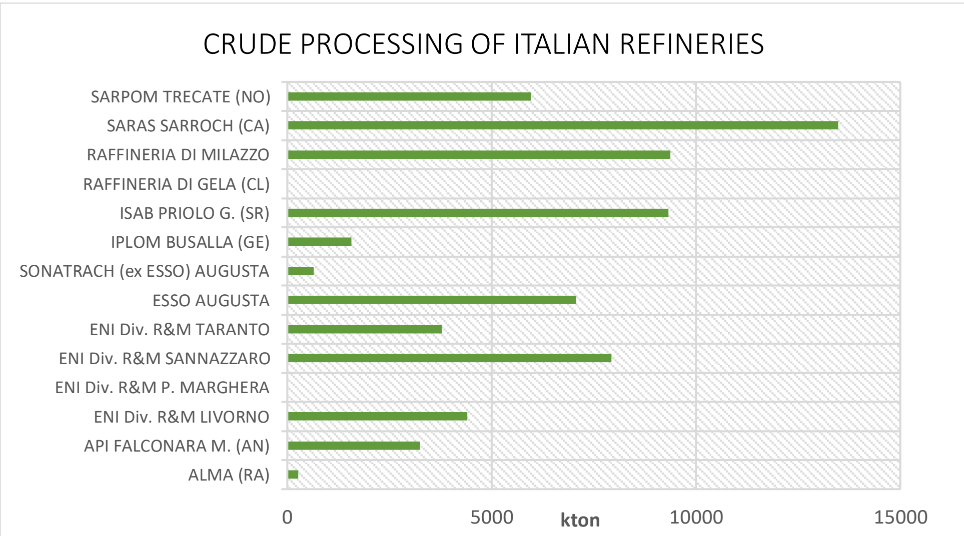


Figure 27: Crude processing by refinery, 2018 (Source: Elaboration based on [19])

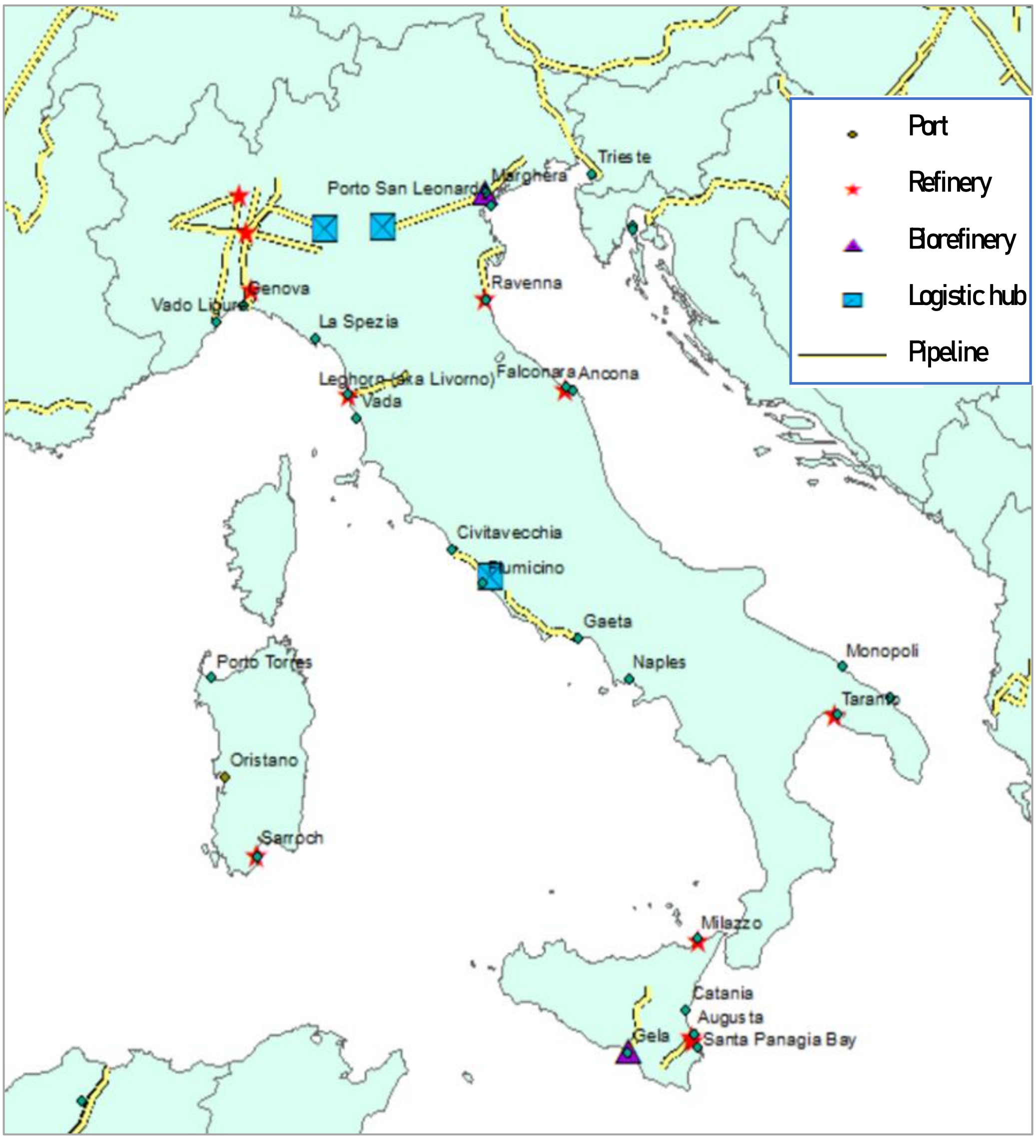


Figure 28: Italian oil infrastructure (Source: Elaboration with GIS based on [23], [22] [10])

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.

Foreign crude reaches Italy mainly by sea. As shown in Figure 29 Trieste is the busiest Italian port for the crude supply: in 2019 the discharged crude amount accounted for 40.5%. The reason lies in its strategic position: the port of Trieste is in fact directly connected to the oil pipeline (owned by the multinational company Trans-Alpinen Leitung - TAL) that connects Italy to foreign refineries (Germany, Austria and the Czech Republic). Actually, in 2019 the amount of crude oil transported through TAL reached 40.2 Mtoe [24].

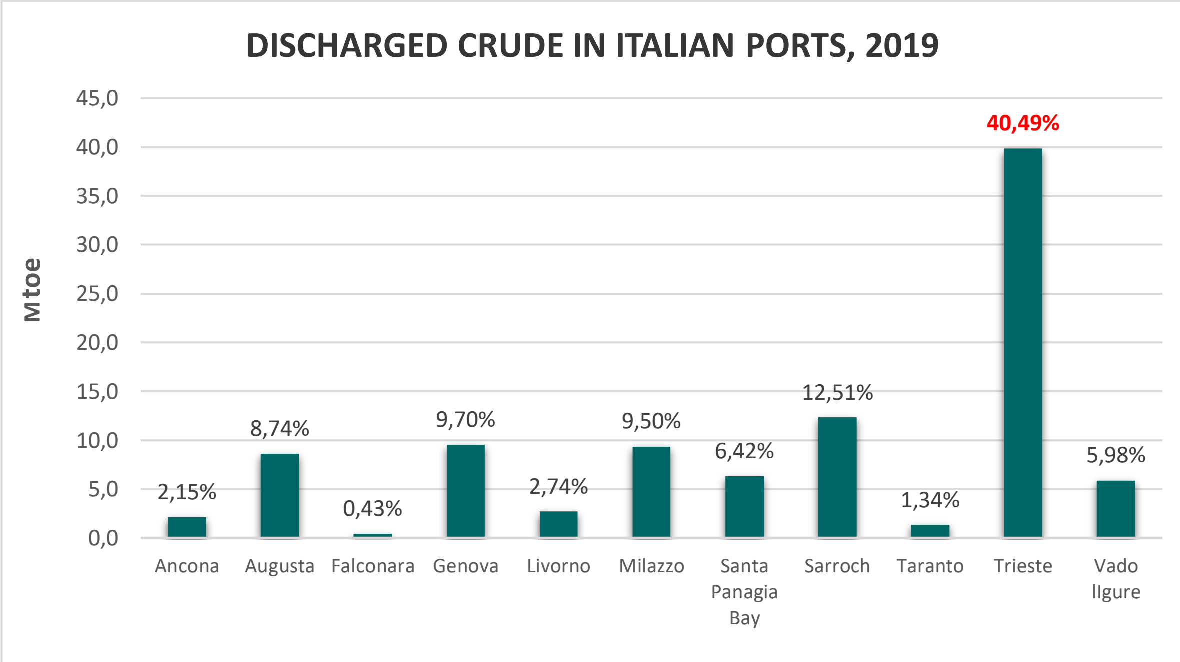


Figure 29: Discharged crude by Italian port (Source: Elaboration based on [10])

On the other hand, the maritime traffic of petroleum products is better distributed (Figure 30): Naples accounts only for 15,4% of the total supply of refined products (Figure--), followed by Marghera (13,3%) and San Leonardo (10,4%).

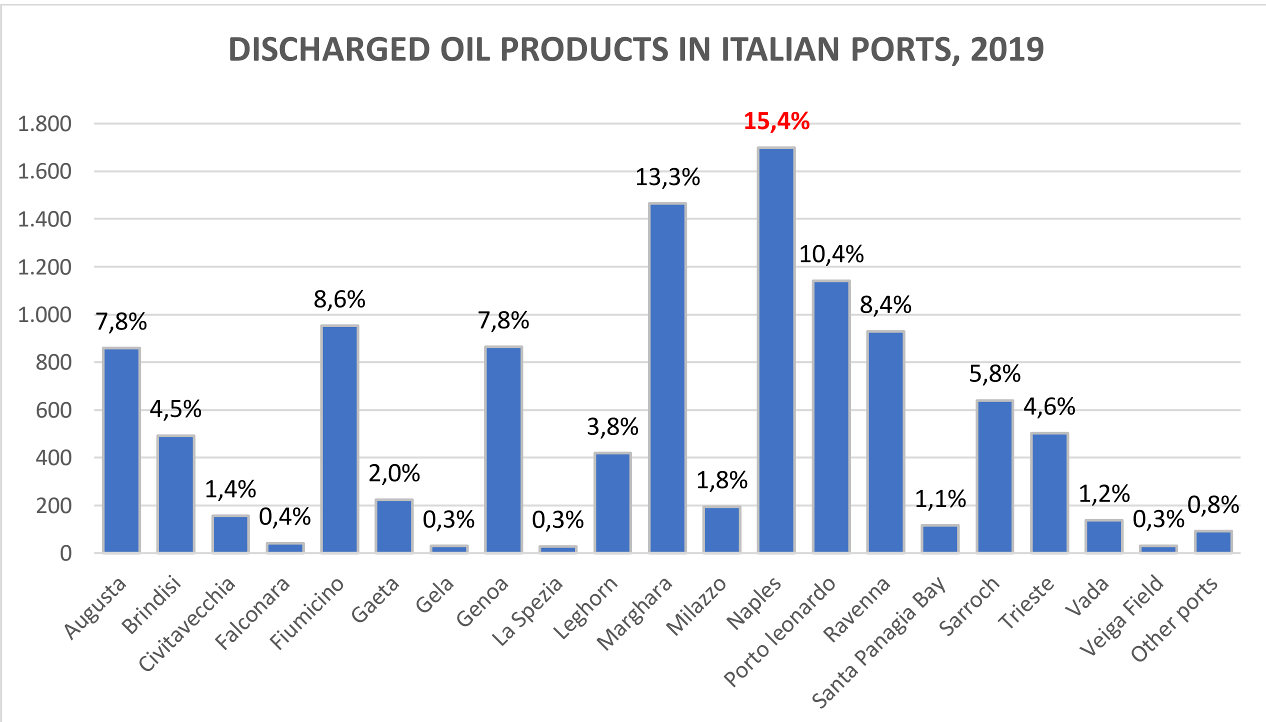


Figure 30: Discharged oil products by Italian port (Source: Elaboration based on [6])

Moreover, usually ports near to refineries are the most active such as 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 local or foreign refinery for further treatments or are collected in tanks and stored in specific areas within the port called "coastal deposits" *[25]* waiting to be sent to final consumers by tank trucks or tanker trains.

Studying in a more detailed manner the pathway followed by oil from vessel to port two discharge procedures can be distinguished [25]:

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 (e.g.: from the port of Sarroch to Saras refinery or from the port of Milazzo to the ENI-KUPIT refinery) or foreign refineries through an oil pipeline (e.g.: 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 be followed 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.

3 Risk Assessment of oil supply

In general risk assessment can be defined as a "systematic use of available information to identify hazards and to estimate the risk to individual, property and the environment" [26].

Besides, considering a more detailed definition, risk assessment a multi-step process consisting on [26]:

- risk identification: process of finding, recognizing and characterizing risk scenario
- risk analysis: process which includes risk estimation and provides the basis for risk evaluation
- risk evaluation: process of comparing the results of risk analysis with risk threshold to determine whether the risk and/or its magnitude is acceptable or tolerable. This step is crucial to make decisions about risk treatment measures.

The aim is to deal with potential accidents not with events still occurred, therefore, risk assessment is a preventive approach. Risk can be defined as the combination of the likelihood (or probability) ξ of occurrence of a specified hazardous event ε and its adverse consequence C [27].

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

If ξ =1, the event will certainty occur, whereas if ξ =0 the event will not occur. While the likelihood is dimensionless, the consequence C of the hazardous event may be expressed in different unit of measure depending on the context of application of risk assessment (e.g. in terms loss of energy or money, delay time, number of deaths etc.).

The event can be classified into three main categories [28]:

- category 1: high frequency and low consequence event. It occurs so often and regularly that is possible to predict the number of similar accidents in the near future.
- category 2: occurs less often than the category 1 but has a higher impact. To estimate such event is not sufficient to base the assessment on the number of past accidents but it is necessary to perform a more detailed risk analysis on the causes and consequences.
- category 3: high impact and low probability event, known also as HILP event. In this case, basing risk analysis on the historical data is meaningless. It is necessary to carry out a detailed analysis of each component of the system.

3.1 Energy risk analysis of Italian oil supply

Since the aim of this dissertation is the risk assessment of the Italian oil supply, the consequence is the loss of commodity and the hazardous event is the failure of oil supply. In particular, the supply failure may involve the maritime or the captive corridors. The risk analysis results in the quantitative estimation of risk related to each corridor and to each commodity. This final value, expressed in terms of loss of energy, quantifies the security of the Italian energy supplies. According to the three main categories of event, the open-sea and captive accidents are included into the second category. Indeed, since a probabilistic approach based on historical data will be useless, a detailed focus on the causes and the consequences of the hazardous event must be carried out.

However, before proceeding to the description of national security assessment, two different types of risk must be distinguished [29]:

- Internal risk: related to the security level of national energy infrastructures
- External risk: related to the security level of the energy supply from abroad

Internal risk depends on the availability of the domestic resource and on the resilience of the national transmission and distribution system against possible internal attacks. The external one, on the contrary, includes the security of supplying infrastructure and geopolitical stability of both the supplier and crossed countries. The combination of internal and external risk gives the so-called National Energy Security Index R_n [29]:

$$R_n = w_1 * R_{int} + w_2 * R_{ext}$$

$$w_1 = 1 - \frac{Supply_{ext}}{Supply_{tot}} \qquad w_2 = \frac{Supply_{ext}}{Supply_{tot}}$$

Where:

- w_1 is the weight coefficient for the internal risk and quantifies the share of internal supply derived from the domestic production of a certain commodity;
- w_2 is the weight coefficient for the external risk and quantifies the share of external supply coming from foreign countries.

The Figure 31 is an explanatory map which summarizes the model adopted for external energy risk assessment.

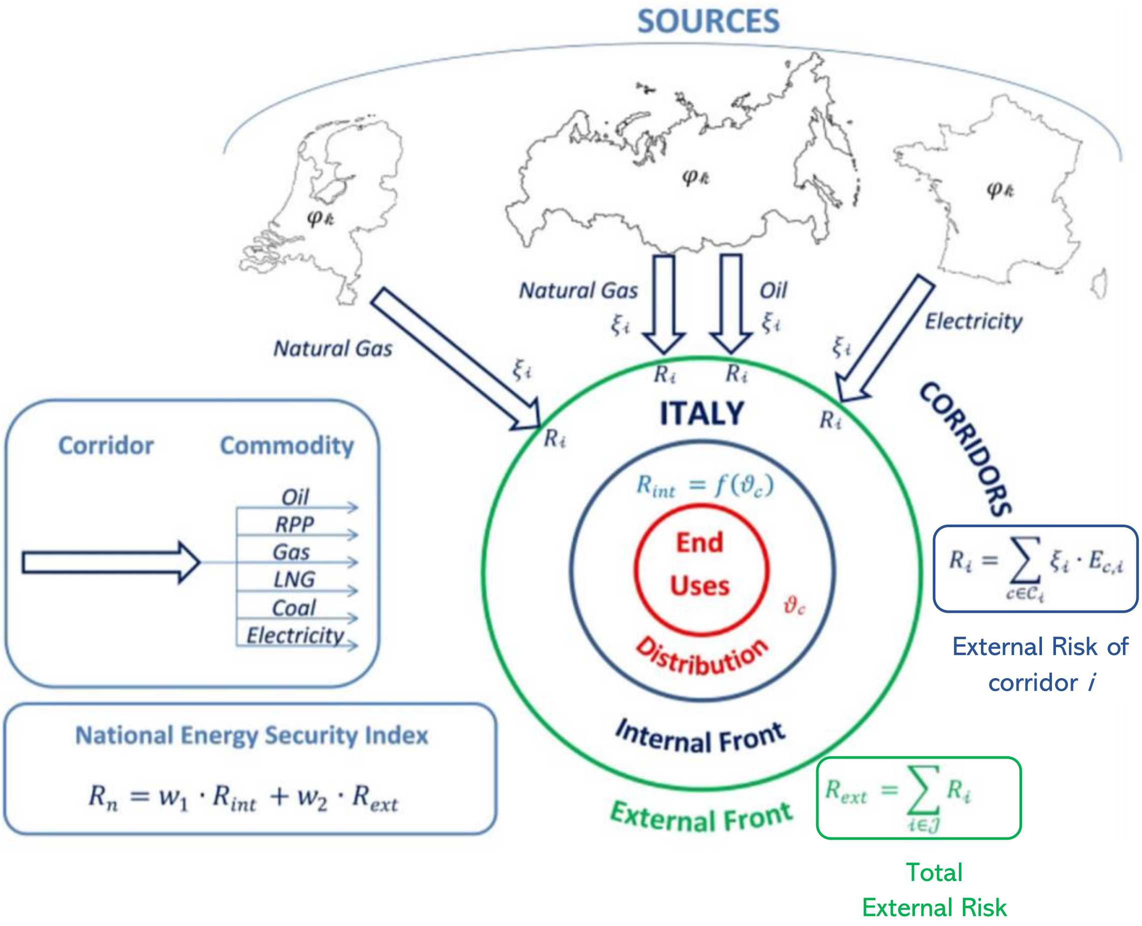


Figure 31: National Energy Security assessment (Source: Elaboration based on [29])

Since Italy is a net importer of oil, thus more vulnerable to accident related to supplier countries and to disruption of supplying corridors, external risk is more relevant for assessing the level of energy security. Therefore, the internal risk index has been disregarded.

The external risk R_{ext} related to a single commodity c is defined as the sum of the risks of all corridors delivering that commodity. Each corridor i is characterized by a certain length depending on the pathway that the commodity travels from the origin country to the Italian entry point from the foreign production field.

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

In particular, given a specific commodity c, the total external risk of a commodity depends on two independent components:

- overall risk related to the all the maritime routes, $R^c{}_{opensea}$
- overall risk related to the all the captive corridors $R^c{}_{captive}$

$$R^c{}_{ext} = f\left(R^c{}_{opensea}; R^c{}_{captive}\right)$$

The maritime risk depends on the sea route by oil tankers whereas the captive risk depends on the probability of disruption of pipelines which connect oil supplier country with the national entry point (e.g. ports, refineries etc.)
Starting from the general definition of risk as the combination of likelihood and consequence of a hazardous event, the external risk related to each corridor i can be expressed in two possible ways:

$$R^c{}_{opensea\ i} = \xi_{opensea\ i} * E^c{}_i$$

$$R^c{}_{captive\ i} = \xi_{captive\ i} * E^c{}_i$$

Where

- $R^c{}_{opensea\ i}$ and $R^c{}_{captive\ i}$ are the external risks related to open sea and captive corridors i which transport commodity c
- $\xi_{opensea\ i}$ and $\xi_{captive\ i}$ are the probabilities of failure related to open sea and captive corridors i
- $E^c{}_i$ is the amount of commodity c transported by the corridor i and expressed in terms of energy

The product of ξ_i and $E^c{}_i$ related to a generic corridor i corresponds to the estimated amount of commodity (or energy) subjected to risk of loss.

The failure probability of a corridor is obtained through a "failure tree" in which all the sensitive parameters (nodes) are linked together with Boolean operators (Figure 32).

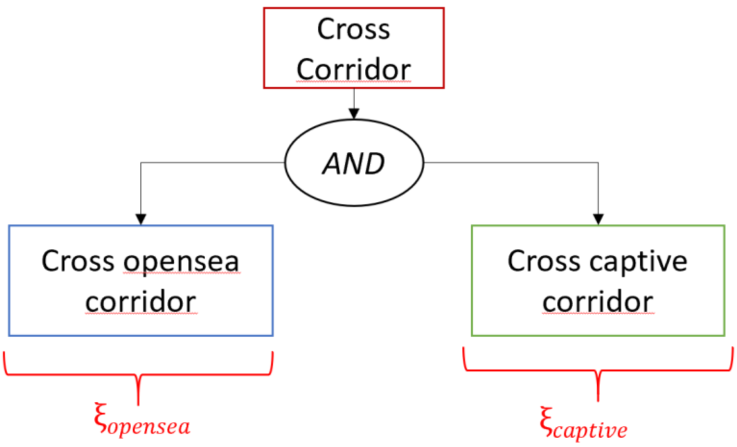


Figure 32: Conceptual map of risk assessment

Nevertheless, failure tree may be considered as a "success tree" simply by converting ξ_i into its complementary ω_i, the probability of supply success.

$$\omega_i = 1 - \xi_i$$

The top event is the probability of success of crossing the entire corridor i and depends on the success of crossing the open sea $(\omega_{\text{opensea}})$and the captive $(\omega_{\text{captive}})$ corridors. As a general rule, AND operator is used in case of an independent relation between nodes instead the OR operator expresses a dependent relation. Thus, since crossing open sea and captive routes are both necessary conditions for success of supply, they are linked by an AND.

In mathematical terms, success tree can be resumed in the following expression:

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

Where

- ω_{i} is the probability of success of corridor i
- $(1 - \xi_{OpenSea})$ is the probability of success of maritime branches forming the total open sea corridor
- $(1 - \xi_{Captive})$ is the probability of success of pipeline branches forming the total captive corridor

Both $\xi_{OpenSea}$ and $\xi_{Captive}$ depends on very different variables, thus they are described separately in the following chapters.

Since all available data are referred to oil commodity discharged in Italian ports, a backward approach has to be performed: thus, each corridor has to be traced backwards from the destination point to the country of origin as conceptually resumed in the Figure 33 below.

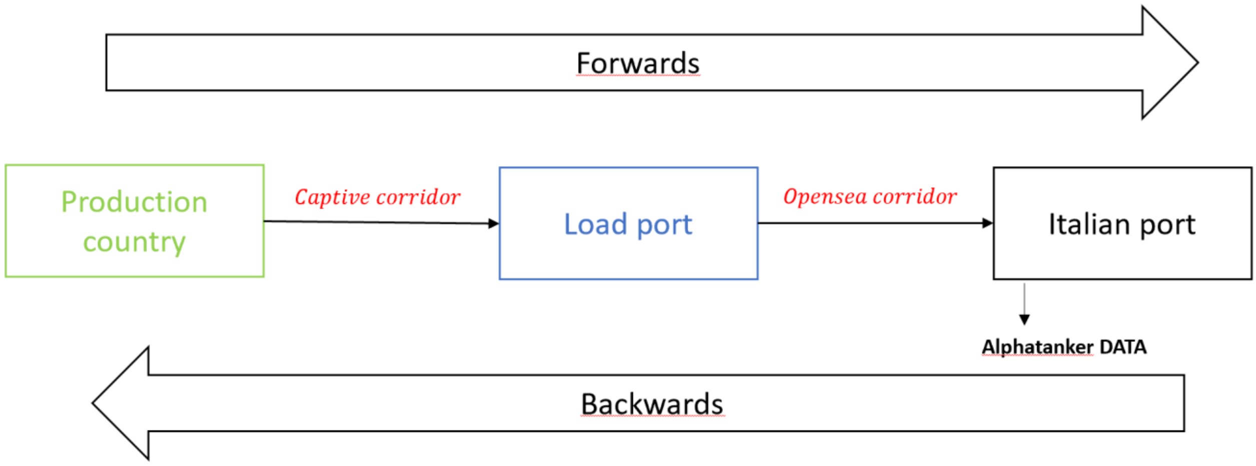


Figure 33: Forwards and backwards approaches (Personal elaboration)

Actually, this backwards process requires three fundamental preliminary steps:

a. Selection of time and commodity domains: crude and oil products input in Italian ports recorded in 2019
b. Choice of data provider: Alphatanker for maritime trade database and EWA for pipeline database
c. Collection and sorting of Alphatanker data (e.g. foreign load ports, national discharge ports, journey duration etc.) and EWA data (e.g. crossed countries, capacity, etc.)

3.2 Georeferencing process

After three previous steps, georeferencing process can be performed. Since country of origin and final entry point are not sufficient information to estimate the risk index, a specific focus on corridor's itinerary has to be performed through GIS software. The aim is to trace the entire corridor pathway followed by the transported commodity from the origin to Italian entry point. Conceptually it is easy to outline of commodity's pathway as illustrated in the figure below (Figure 34).

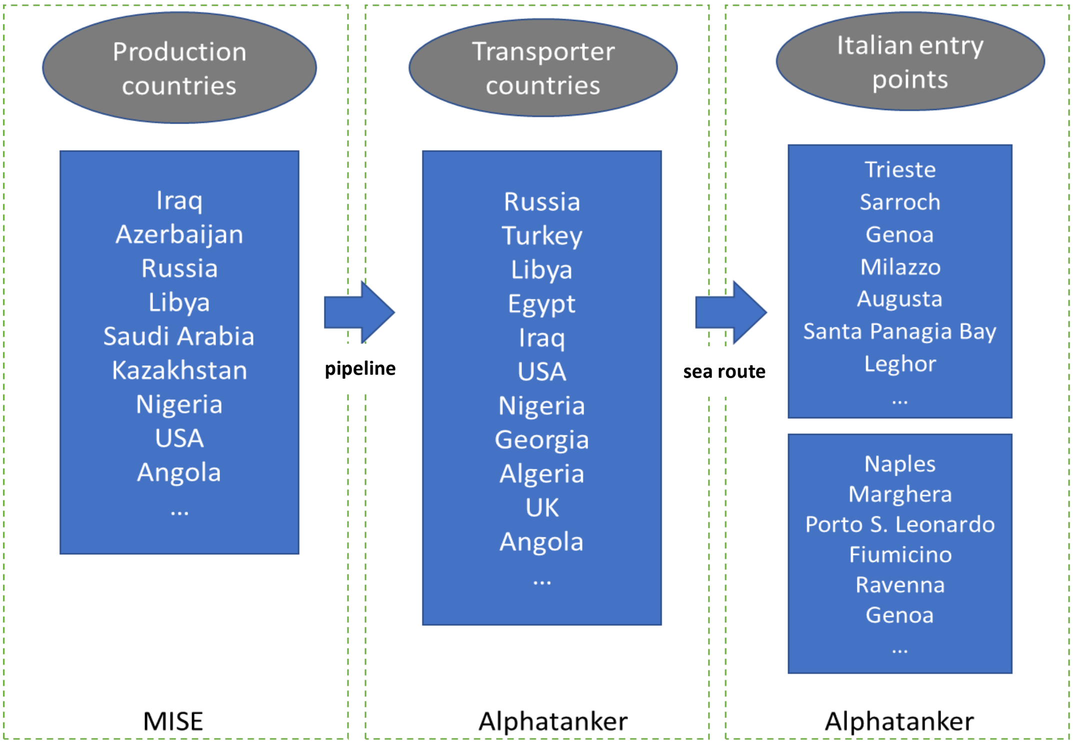


Figure 34: Flow chart of oil supply

However, risk calculation needs high level of detail which this conceptual scheme does not comply with. For this reason, Alphatanker and EWA dataset were combined whereas MiSE dataset was neglected since it does not provide any information about the corridors. First, relevant points such as ports and refineries were georeferred, secondly both captive and open sea pathways were manually traced backwards starting from the end point (Italian port) and going back to the oil field (source of crudes) or the refinery (source of oil products). In order to merge correctly captive branches with corresponding maritime routes, a detailed analysis of commodity exchanges was processed. This procedure was performed for both crude and oil products supply. In the Figure 35 is illustrated an example of GIS's output resulted from trace-back process of a corridor from oil field in Azerbaijan (red area) to Italian ports (red point) along pipelines (brown line) and sea routes (blue dotted line).

Figure 35: Result of backwards tracing of oil corridor (Source: Elaboration with GIS based on [23], [10])

Thanks to digitalizing process, information about lengths and pathways of specific corridor can be easily extracted from GIS shapefiles. In addition, technical data about refineries and ports provided by different data-sources can be collected into excel tables which can be joined to the shapefiles.

In the Figure 36 and 37 are illustrated digitalized pathway of maritime route of crude and petroleum products supply and in Figure 38 are reported captive corridors (pipelines).

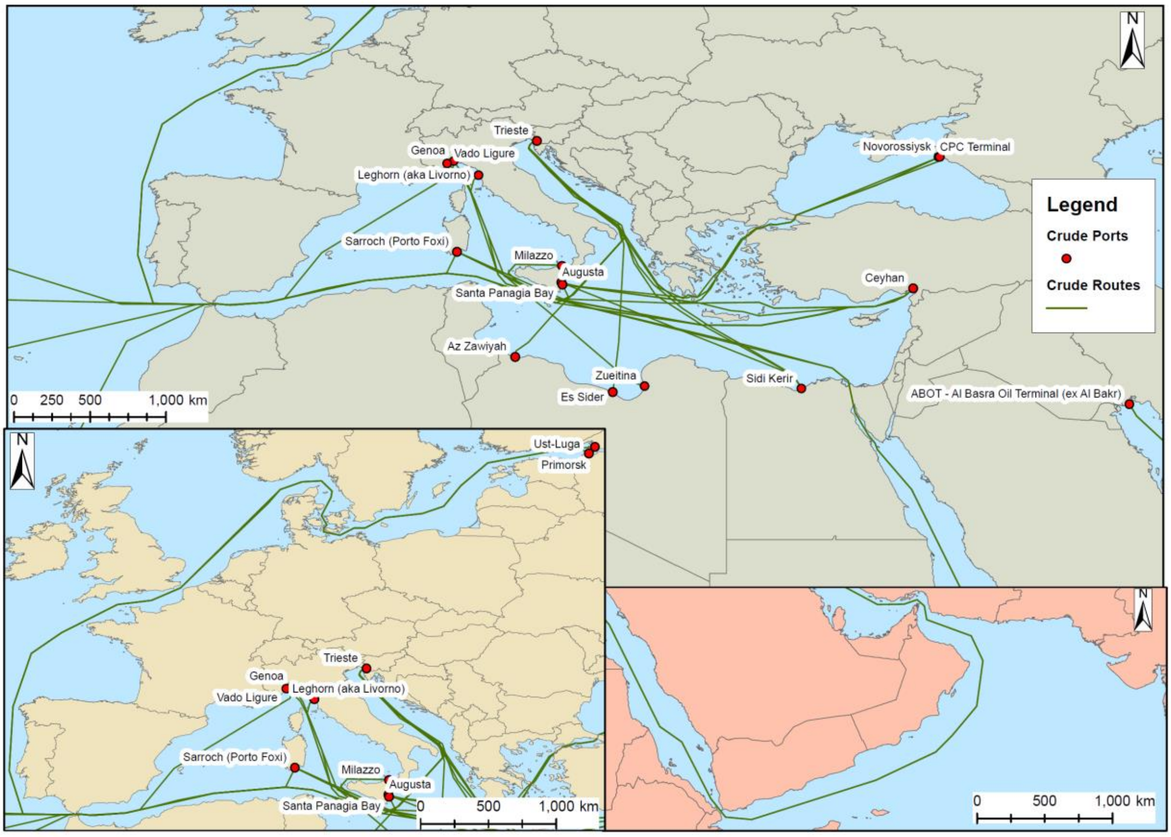


Figure 36: Mapping of crude oil supply towards Italy (Source: Elaboration with GIS based on [10])

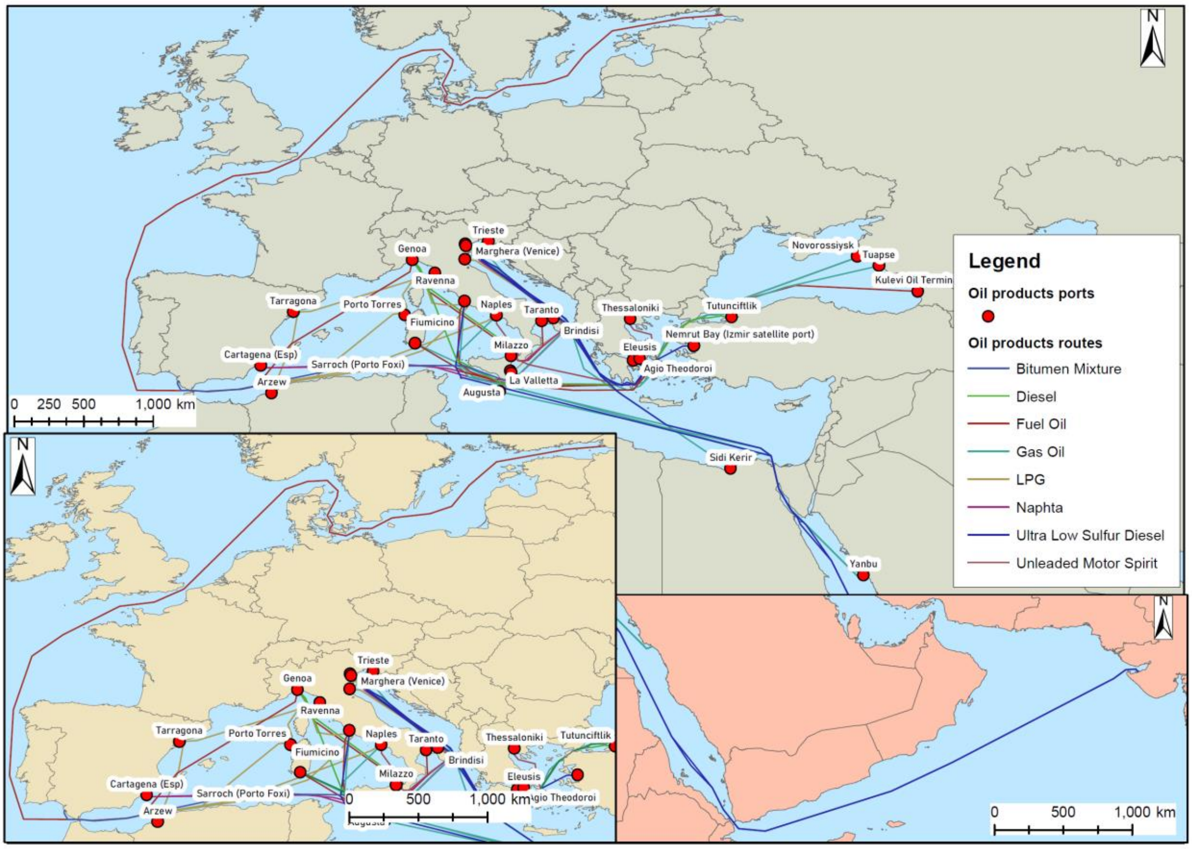


Figure 37: Mapping of oil products supply towards Italy (Source: Elaboration with GIS based on [6])

Figure 38: Mapping of oil pipelines (Source: Elaboration with GIS based on)

Georeferencing process, therefore, is a necessary step which provides "key-data" for risk assessment. For instance, length of corridor branches and crossed countries along the route are two fundamental variables which deeply affect open sea risk, thus they must be considered.
Once completed backtracking process, probability of failure of captive and open sea corridors can be obtained from two different models which will be described in the following chapters.

3.3 Open sea corridors

The risk assessment of maritime corridors is crucial for national energy security since Italy is characterized by a heavy foreign dependence on oil supply, especially on crude oil, which is generally imported by sea. Oil products, as well, are partly delivered by sea but also by rail, road or pipeline. The transport is carried out by oil tankers that are classified as "bulk cargo", ships designed for carriage of unpackaged goods. There are two main type of oil tankers: crude tankers and product tankers. In addition, is commonly used a further classification according to the vessel's deadweight tonnage (DWT). This attribute measures the vessel's weight carrying capacity [30]. As a general rule, oil tankers with higher DWT transport crude, instead of lower DWT vessels which transport refined oil products.

After georeferencing step, further specific attributes are referred to each open sea corridor. The Table 7, referred to the port of Livorno, is reported below as explanatory illustration of the process of route characterization.

Table 7: Characterization of Livorno's oil corridors (Source: Elaboration based on [10])

<table>
<tr><td colspan="9">Livorno: CRUDE SUPPLY (2019)</td></tr>
<tr><td>Load Country</td><td>Load port</td><td>Intake [ton]</td><td>Intake per country [ton]</td><td>Sea Duration [day]</td><td>$\frac{Intake}{DWT}$ [-]</td><td>$\frac{Intake}{n° \, trip}$ [ton]</td><td>Power $\left[\frac{TOE}{year}\right]$</td><td>Power $\left[\frac{MWh}{year}\right]$</td></tr>
<tr><td>Egypt</td><td>Sidi Kerir</td><td>1,567,944</td><td>1,567,944</td><td>5.19</td><td>0.71</td><td>78,397</td><td>1,567,944</td><td>18,235,189</td></tr>
<tr><td>Greece</td><td>Kali Limenes</td><td>77,593</td><td>77,593</td><td>4.10</td><td>0.69</td><td>77,593</td><td>77,593</td><td>902,407</td></tr>
<tr><td rowspan="2">Libya</td><td>Az Zawiyah</td><td>85,054</td><td rowspan="2">162,683</td><td>6.65</td><td>0.74</td><td>85,054</td><td>85,054</td><td>989,178</td></tr>
<tr><td>Marsaxlokk</td><td>77,629</td><td>9.49</td><td>0.72</td><td>77,629</td><td>77,629</td><td>902,825</td></tr>
<tr><td>Russia</td><td>CPC Terminal</td><td>85,133</td><td>85,133</td><td>14.87</td><td>0.74</td><td>85,133</td><td>85,133</td><td>990,097</td></tr>
<tr><td>Turkey</td><td>Ceyhan</td><td>719,013</td><td>719,013</td><td>6.19</td><td>0.71</td><td>79,890</td><td>719,013</td><td>8,362,121</td></tr>
<tr><td colspan="2">Total</td><td>2,695,410</td><td>2,695,410</td><td>[-]</td><td>[-]</td><td>[-]</td><td>[-]</td><td>[-]</td></tr>
</table>

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.

Considering the huge number of total routes, the process of digitalization is performed to those corridors whose share of supply is greater or equal to the cut-off threshold set equal to 1% of the total commodity supply recorded in 2019 (Table 8).

Table 8: Digitalization of crude and oil products corridors (Source: Elaboration based on [10])

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 further corridors whose share was lower than 1% have been digitalized in order to have at least one corridor for each products type.

3.3.1 Maritime hazards

The investigation of the possible causes that can lead to a maritime corridor failure resulted in the identification of the following hazardous factors

a) Shipping in national or in international water
b) Piracy and armed robbery
c) Presence of chokepoints
d) Ships disruption

The navigation is globally ruled by the "United Nations Convention on the Law of the Sea" [31], signed in the 1982 at Montego Bay, Jamaica. Nowadays, 164 countries ratified the treaty. The aim was to establish the authority on the maritime zones to coastal countries through a systemic zoning of the sea. Nowadays is still adopted this classification which includes four main categories:

1. Territorial water: 12 nautical miles (NM) from the coast
2. Contiguous zone: 24 NM from the coast
3. Exclusive Economic Zone (EEZ): 200 NM from the coast
4. Continental platform: until 350 NM or until 100 NM from the isobath of 2500 m.
5. International water: above EEZ or Continental platform

Navigation rules may be resumed into three main 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 compliance with the law into its EEZ (Figure 40) and, in case of war, to lock the navigation in its water.

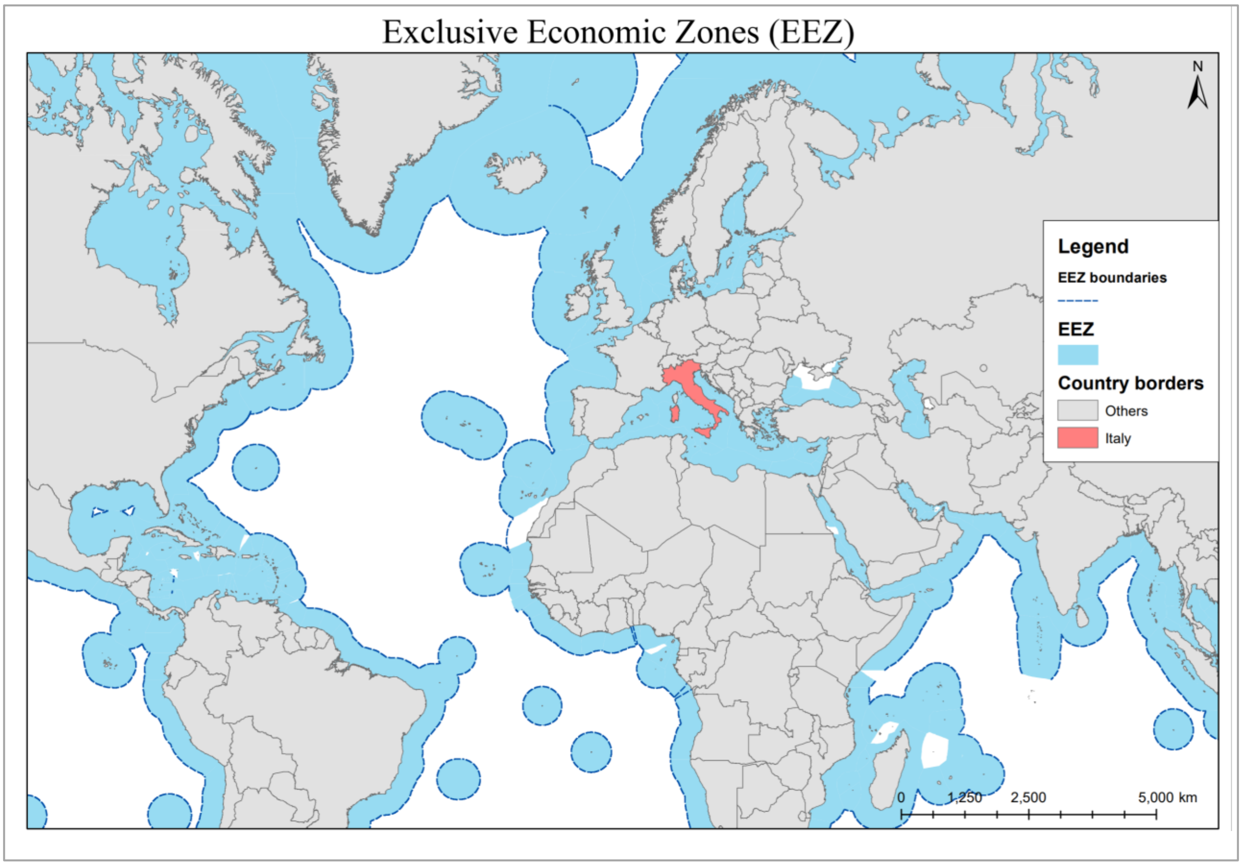


Figure 39: Exclusive Economic Zones (Source: Elaboration with GIS based on [32])

Therefore, the probability of failure of the corridor crossing a specific EEZ depends on the geopolitical stability of the corresponding sovereign country. In this dissertation the Worldwide Governance Indicator (WGI) [33] were considered to calculate the reference geopolitical risk index φ_k. Indeed, φ_k is obtained by the arithmetic mean of six minor WGI indexes which range between 0 and 100:

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

1. Voice and Accountability: citizens' participation in the selection of the government, freedom of expression, free media, freedom of association
2. Political stability and absence of violence: political instability and/or politically motivated violence
3. Government effectiveness: quality of the public services, civil services, credibility of the government
4. Regulatory quality: ability of the government to implement policies and regulation that promote private sector development
5. Rule of law: quality of contract enforcement, properties right, police, court, probability of crime and violence

6. Control of corruption: capture the perception of the extent to which power is exercised for private gain

As well, criminal activities in sea can lead to vessel disruption and consequently to failure of supply. The definition of piracy and armed robbery are provided by the *International Maritime Bureau (*IBM) [34]:

- 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 (ICC) that tries to counteract illegal activities in maritime trade. Even though IBM reports in real time piracy and armed robbery events all over the world, it does not provide a specific security index. However, a reference piracy index can be found in "The state of maritime piracy" [35], a publication of "stable sea programme" promoted by the international foundation "One Earth Future". The index of piracy and armed robbery η_k ranges between 0 and 100 (Figure 41):

- 100 corresponds to the absence of any piracy and armed robbery attacks
- 0 corresponds to the maximum frequency of piracy and armed robbery attacks.

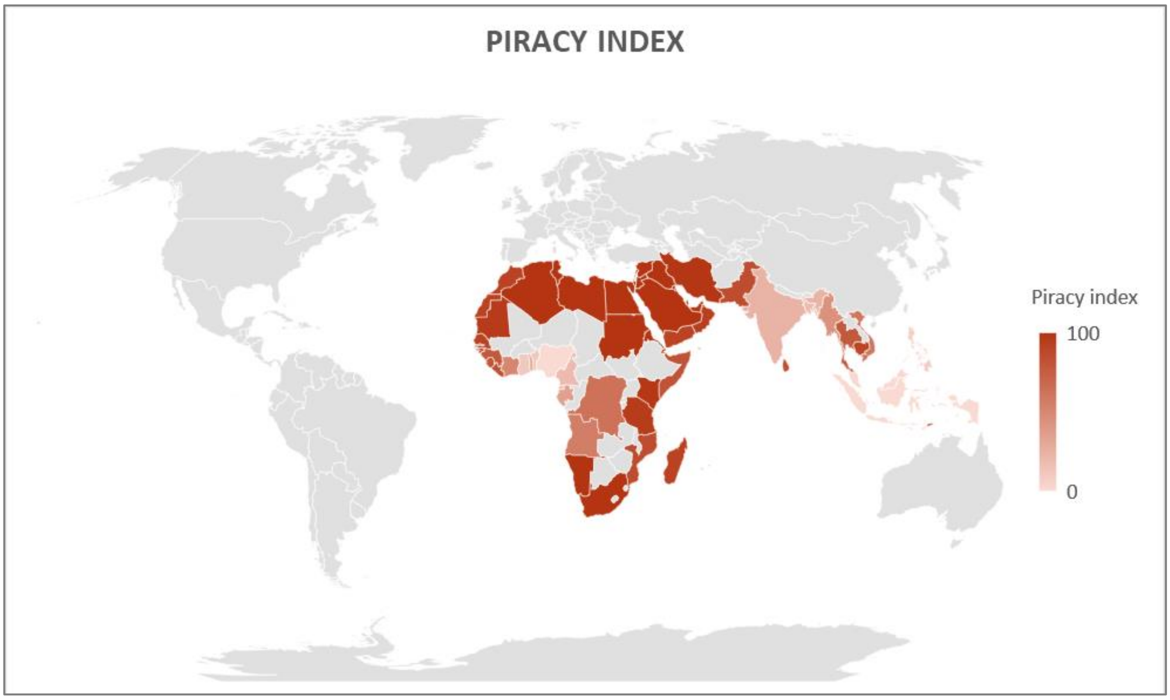


Figure 40: Piracy index (Source: Elaboration based on [35])

It is obtained by an empirical expression which takes into account only piracy events occurred within a distance of maximum 1000 km from the coast. Furthermore, a logarithmic function id used to normalize the distance and then, only the 25 closest piracy attacks are selected. The choice of logarithmic expression derives from the fact that, the closer to shore occurs a piracy event the more serious is considered the threat. In fact, each attack is multiplied by a weighting factor which decreases with increasing normalized distance. In addition, even if more than 25 attacks were considered, the final piracy index did not change significantly.

$$\eta_k = \frac{\sum_{i=0}^{25} d_i * (25-i)}{\sum_{i=0}^{25} (25-i)}$$ piracy index of country k

$$\tilde{d_i} = \frac{Ln\left(\frac{d_i}{100}+1\right)}{Ln\left(\frac{1000}{100}+1\right)}$$ normalized distance from the coast

As well, the presence of a chokepoint affects the probability of failure of maritime routes. Especially in case of strait crossing, many ships are forced to pass through a narrow channel. The most important chokepoints are illustrated in the map of Figure (--).

Two types of chokepoints can be distinguished (Figure 42):

1. Maritime chokepoints which correspond to straits: narrow channels bounded by coast that connect two larger areas of sea [36]
2. Non-traditional chokepoints which are characterized by high ships traffic because of their strategic locations even though they are not really straits [36].

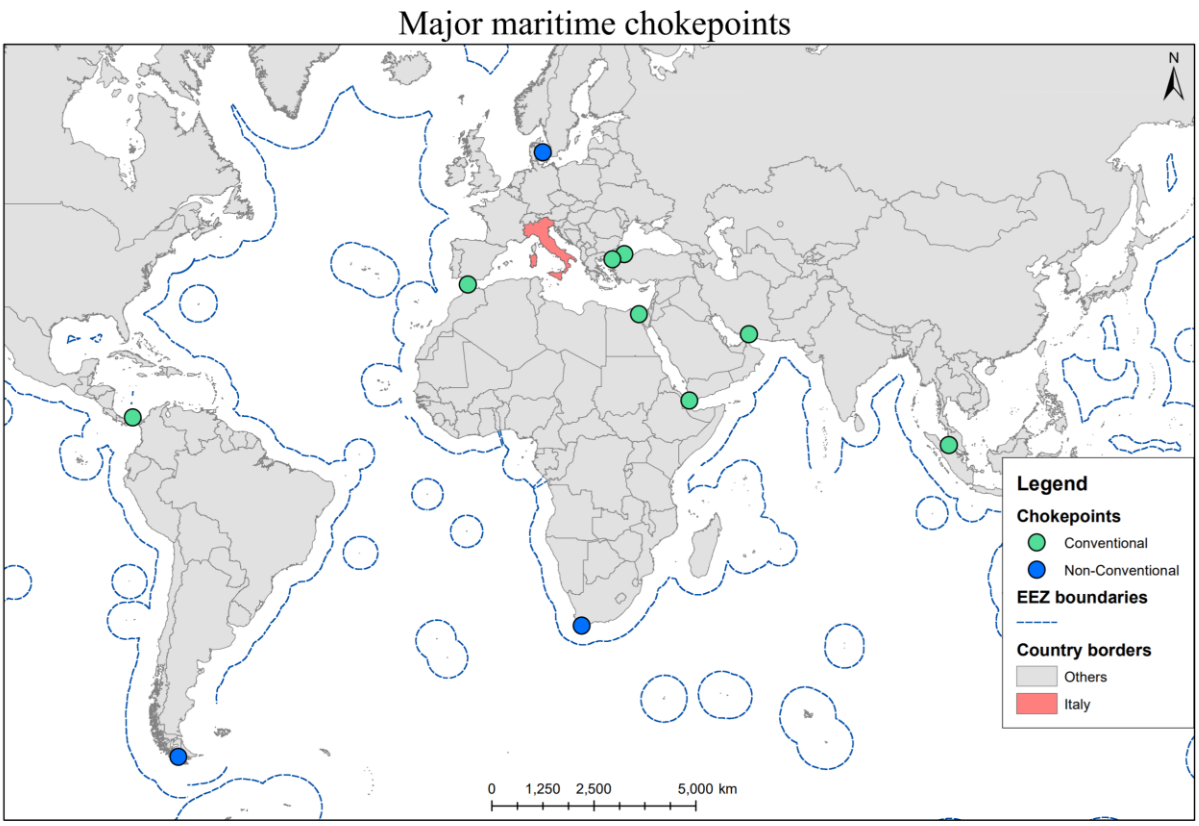


Figure 41: Major conventional and non-conventional chokepoints (Source: Elaboration based on [37])

In particular, straits deserve particular attention in terms of marine traffic security due to their width which forces the passage through a narrow space increasing the risk of ships collision. For this reason, the International Maritime Organization (IMO) [38] introduced a Traffic Separation Scheme (TSS), in order to regulate ships traffic and reduce the risk of collision. Length, as well, increases the probability of vessel disruption while crossing the strait.

In addition, in case of political or economic conflicts, countries close to strait may affect maritime security by imposing high fee or other adverse measures. Therefore, geopolitical stability of coastal countries which sovereign straits is another crucial hazard factor that has to be considered in the risk assessment of maritime route.
Moreover, due to its intrinsic vulnerability straits, and in general chokepoints, are often subjected to piracy attacks. Thus, in order to perform a quantitative assessment of national energy security related to oil supply, only chokepoints with higher oil flux heading to Italy has been selected. According to Alphatanker data, oil tankers which arrive to Italian ports pass through seven main straits:

1. Gibraltar: connects the Atlantic Ocean to the Mediterranean Sea and separates the Iberian Peninsula from Morocco.
2. Turkish straits: Dardanelles which connects The Sea of Marmara with the Mediterranean and Aegean Seas and separates European Turkey from Asian Turkey; Bosphorus which connects the Sea of Marmara to the Black Sea.
3. Suez: due to its length, actually is not a strait but a canal; it connects the Red Sea with the Mediterranean Sea.
4. Bab-el-Mandeb: connects the Red Sea with the Indian Ocean and separates Yemen from Eritrea and Djibouti.
5. Hormuz: located between the Persian Gulf and The Gulf of Oman and separates Iran from United Arab Emirates and Oman.
6. Malacca: connects the Indian Ocean with Pacific Ocean. It is one of the most important shipping lanes in the world even though has low impact on Italian oil supply as shown in Figure 43.

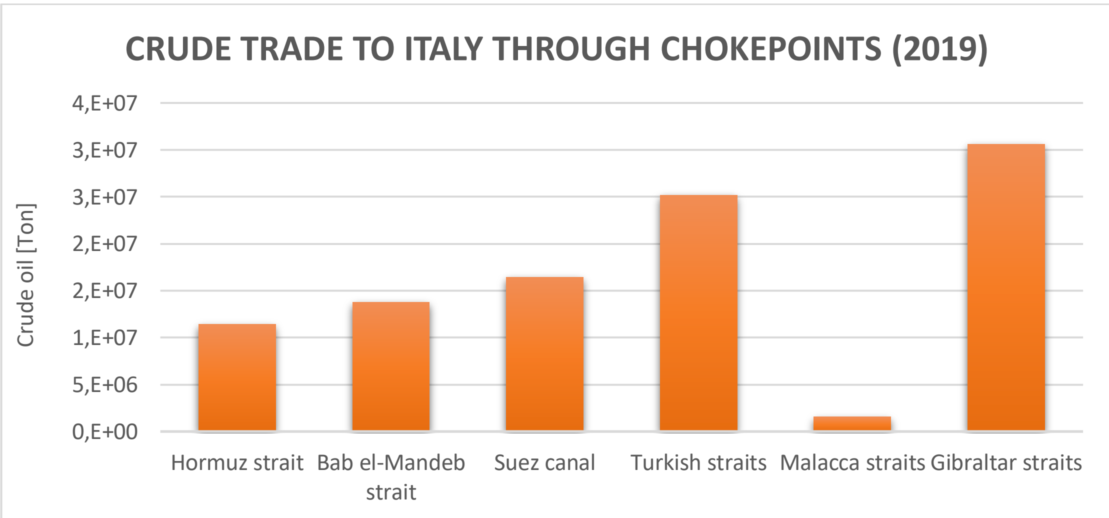


Figure 42: Crude trade through chokepoints towards Italy (Source: Elaboration based on [10])

In Table 9 are resumed the results of main chokepoint characterization: length, width, depth and accessibility are the four main parameters considered.

Table 9: Chokepoints characterization (Source: Elaboration based on [37])

Strait characterization					
Strait	***Sovereign country***	***Length [Km]***	***Width [km]***	***Depth [m]***	***Accessibility***
Hormuz	Iran/Oman	60	30	220	Free
Bab el-Mandeb	Djibouti/Yemen	130	40	180	Free
Suez	Egypt	193	0.22	24	Custom fee
Bosphorus	Turkey	30	0.7	40	Free
Dardanelles	Turkey	68	1.2	100	Free
Malacca	Malaysia/Singapore/Indonesia	800	50-180	200	Free
Gibraltar	Spain/Morocco	60	14	286	Free

Thus, chokepoint disruption, defined as the ships inability to cross it, may be caused mainly by to two factors:

1. Geopolitical risk of the coastal countries close to the chokepoint, φ_k
2. Piracy activity η_k

The probability of chokepoint failure, hence, can be considered as a function of these two parameters:

$$\xi_{cp} = f(\varphi_k; \eta_k)$$

Nevertheless, since chokepoint disruption is a rare event but with serious adverse effects, the failure of a chokepoint can be considered as a "High-Impact Low-Probability" (HILP) event. As a consequence, probabilistic approach cannot be adopted in absence of historical data from which obtain a probability density function (pdf). For this reason, chokepoint required an ad hoc model of risk illustrated in the chapter (--).

Finally, ship failure analysis was performed by using the data published by Allianz [39], the largest insurance company dealing with maritime traffic.
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 is reported in table in Appendix D. However, this parameter is neglected in the overall risk quantification due to:

- Very low number of ship failure with respect to the total ships involved in maritime traffic (Figure 44).

- No correlation between geographical area and failure.
- No-significant indicator for calculation of open sea corridor's probability of failure.

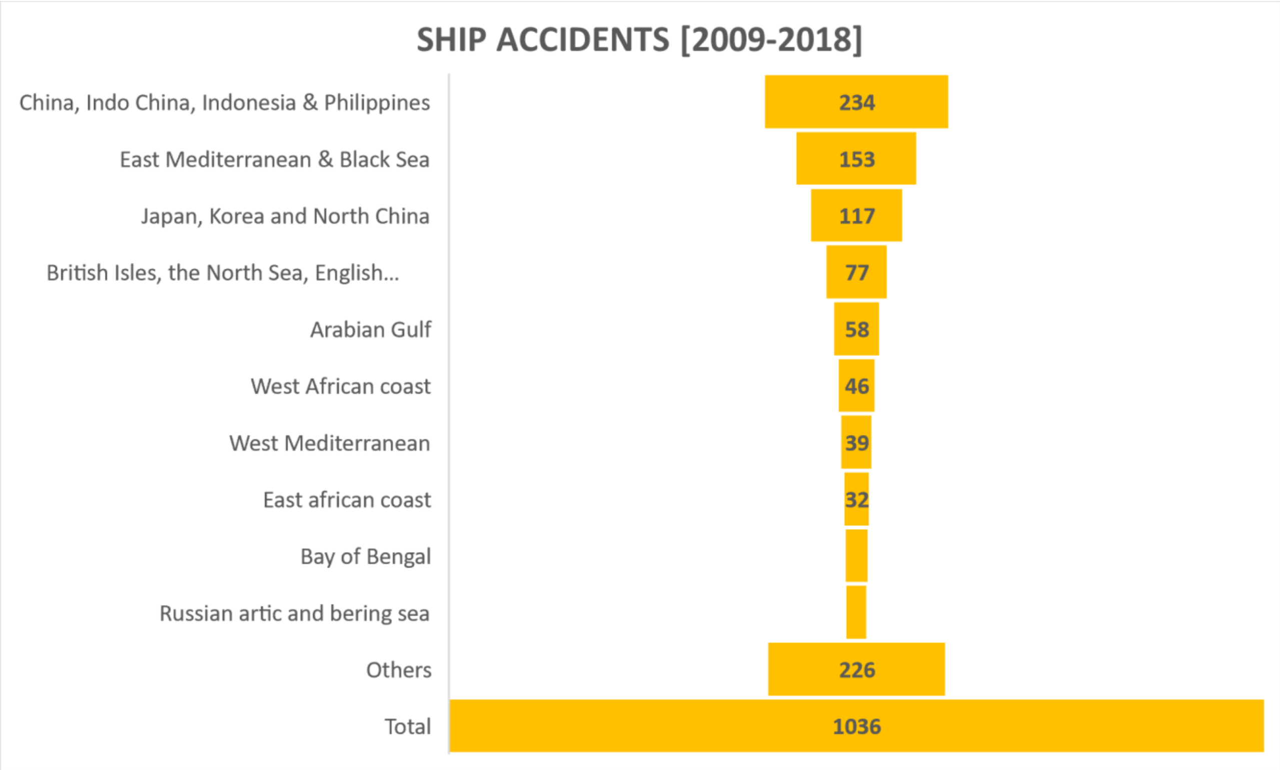


Figure 43: Historical ship accidents by macro-area (Source: Elaboration based on [39])

3.3.2 Quantification of probability of failure

The probability of failure of a maritime corridor is a dimensionless value between 0 and 1 that describes the likelihood of failing shipping related to a specific open sea corridor. On the contrary, the probability of shipping success indicates how likely is that a commodity, passing through a specific corridor, reaches the destination point. The necessary condition to succeeds cross sea route is that the transported commodity overcomes all countries and chokepoints present along the way. In graphical terms, this relation is represented by the so-called "fault tree" which shows that success of maritime route depends directly on those hazardous factors identified in chapter 3.3.1

Hence, the final mathematical expression must take into account dependency on these affecting factors (Figure 45):

- geopolitical risk of crossed countries;
- piracy index;
- length of maritime branches and presence of chokepoint.

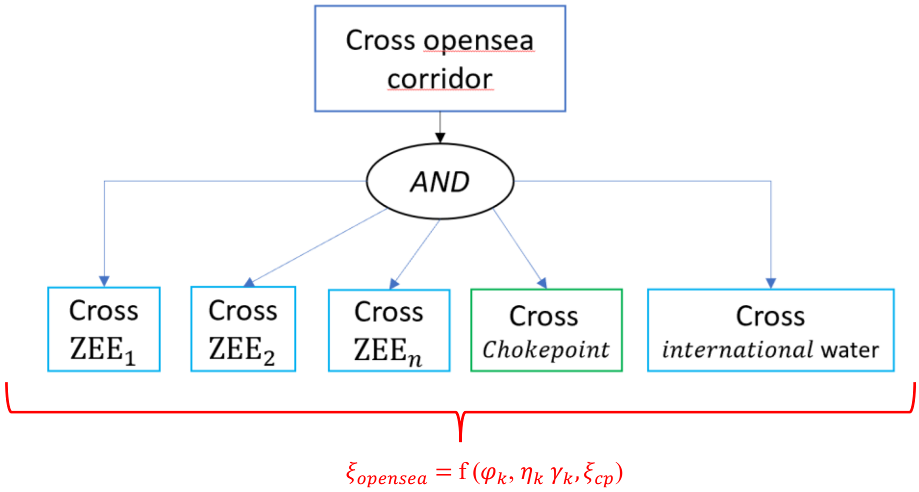


Figure 44: Conceptual map of open-sea corridor failure assessment

First, since in literature still exists geopolitical risk index φ_k, as a result of the arithmetic mean of six minor WGI indicators, but without any reference to piracy activity. Since crude is mainly transported by open sea, disregarding piracy index may lead to an underestimation or overestimation of effective geopolitical risk. Therefore, maritime risk assessment needs a specific index as maritime geopolitical risk index.

Thus, piracy index provided by the publication of "One Earth Future" and the existing geopolitical risk index were combined in order to obtain an aggregated indicator φ_k' defined as arithmetic average between φ_k and η_k:

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

Each coastal country is characterized by a new aggregated parameter which summarizes in one single value both geopolitical risk index and piracy index as illustrated in the Figure 69 in Appendix D.

Then, since in literature also there is no a specific index in case of shipping in international waters, arithmetic average of φ_k' between all global coastal countries is used to define a reference index for maritime geopolitical risk related to international waters.

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

Where:

- K total amount of coastal countries
- φ'_k maritime geopolitical risk of the k country

Nevertheless, in order to consider the contribute of each sea branch to the final results, a weighting factor γ_k is introduced. In this way, the contribution to the overall probability of failure of the single branch is proportional to its length.

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

Where

- l_i length of a branch
- L_{tot} is the total length of the corridor (both captive and open sea)

The final formulation implemented with additional weighting factor is the following:

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

Where:

- $\left(1 - \frac{\varphi_k'}{100}\right)$ is the probability of success of crossing country k
- $\prod_{k_i \in K_i}\left(1 - \frac{\varphi_k'}{100}\right)$ is the probability (of independent event) of success of crossing all the country k involved along the corridor route
- $1 - \prod_{k_i \in K_i}\left(1 - \frac{\varphi_k'}{100}\right)$ 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 $\overline{\varphi'}$

The probabilities of crossing different countries along the sea corridor are independent from each other, as indicated by the AND operator in the fault tree, because vessels must cross successfully all the countries in order to reach the final destination. That means that if only one cross fails, all the route fails. In mathematical terms, this aspect is considered by using product operator.

In the radar graph (Figure 46) φ'_k an φ_k are compared: Somalia, Sudan and all the other countries characterized by very frequent piracy attacks result with greater φ'_k. On the contrary, countries with no significant presence of piracy presents lower value of φ'_k. This result is optimal to model maritime risk because in this way both political stability of and vulnerability to piracy attacks of crossed countries are taken into account.

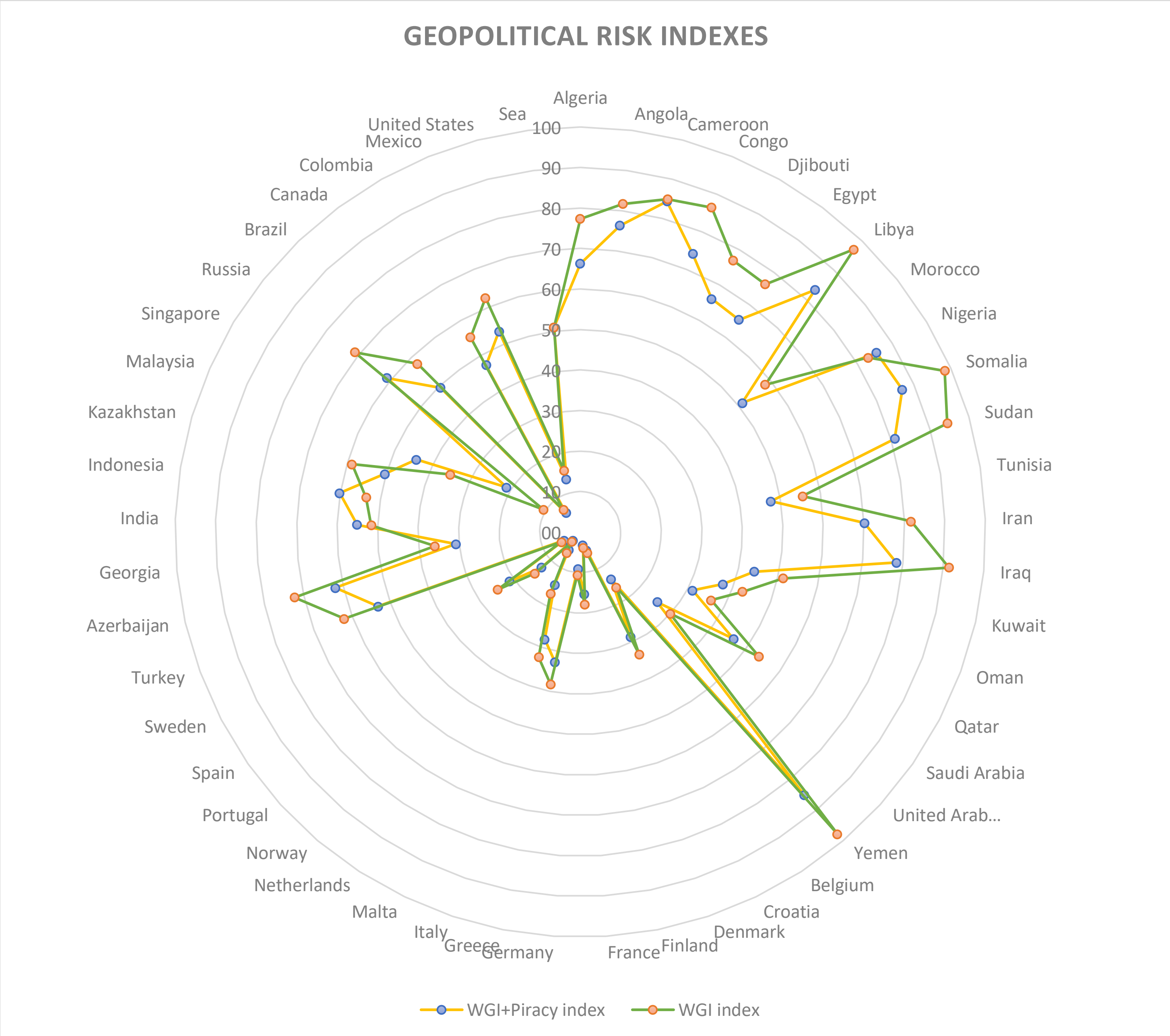


Figure 45: Comparison between geopolitical and maritime geopolitical indexes (Source: Elaboration based on [35], [33])

In addition to this, another element that deserves particular attention is the chokepoint. Actually, in terms of mathematical description, crossing a chokepoint is considered separately with respect to crossing territorial or international waters even if it has the same logical role according to the fault tree. Indeed, from a theoretical point of view, the strait is assumed as a "punctual element", despite the sea branches. Thus, a different assessment is performed in order to consider the chokepoint influence in terms of probability of maritime corridor failure.

In general, the probability of chokepoint failure was defined as the product between two factors: L_{cp} directly connected to the political stability of coastal countries close to the chokepoint and $\dot{\alpha}$ which reflects intrinsic vulnerability of a chokepoint due to its physical characteristic.

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

Where:

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

Since chokepoint closure is a rare event, adopting a probabilistic approach is meaningless. The reason why likelihood of chokepoint failure is supposed to be very low is mainly due to:

- Low number of past critical events
- International agreements related to marine traffic
- International task force guarantee chokepoint security and reliability

A bibliographical research [40], [41], resumed in the following table (Table 10), highlight the main critical events occurred in the last century which had involved a partial or total failure of the straits more relevant for Italian oil supply: Hormuz, Bab el-Mandeb, Suez, Gibraltar, Turkish Straits and Malacca. Total closure results a very rare occurrence. Partial closure, which consists on the reduction of world marine traffic or the closure for a specific country, appears more common. Nevertheless, chokepoint closure overall is considered an HILP event.

Table 10: Historical straits closure (Source: Elaboration based on [40], [41])

Chokepoints	***Failure***	***Type of Failure***	***Failure duration***
Hormuz	Tank war	Partial	8 years
	Iran-USA economic conflict	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

Thus, historical data are not sufficient to build a PDF and a probabilistic approach cannot be adopted. Therefore, maritime geopolitical risk of coastal countries close to chokepoint is chosen as an approximation of probability of failure. In case of more than one coastal country, L_{cp} was calculated as the arithmetic mean of ${\varphi'}_k$.

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

Table 11: Chokepoint likelihood of disruption (Source: Elaboration based on [33])

Chokepoints	**Sovereign country**	φ'_k	L_{cp}
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	

The results in Table 11 show that Bab el-Mandeb and Suez are the most critical chokepoint. Nevertheless, L_{cp} only takes into account political stability of coastal countries with no reference to physical characteristics of chokepoints itself. Length and width, actually, plays an import role: longer is the channel, higher will be the probability of ship collision, piracy attack and other adverse events; on the contrary, wider is the chokepoint, the less likely a total closure would be. In the following expression is introduced a new parameter α_{cp} defined as vulnerability index. It describes the intrinsic tendency of the chokepoint to be less or more susceptible to a hypothetical closure.

$$\alpha_{cp} = \frac{length_{cp}}{width_{cp}}$$

However, vulnerability index cannot be used in combination with L_{cp} without a previous normalization. Hence, logarithmic normalization is performed on α_{cp} in order to obtain a coefficient ranging between 0 and 1, $\dot{\alpha_{cp}}$:

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

In this way, each chokepoint can be characterized by a specific vulnerability index corresponding to its intrinsic morphology. Despite L_{cp}, $\dot{\alpha_{cp}}$ does not depend on the political context, indeed, it reflects only physical characteristics of the chokepoint. Finally, chokepoint probability of failure is calculated (Table 12).

Table 12: Chokepoint probability of failure

	Vulnerability			Likelihood	Probability of failure
Strait	***Length [Km]***	***With [km]***	$\dot{\alpha}_{cp}$	L_{cp}	$\xi_{cp} = L_{cp} * \dot{\alpha}_{cp}$
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

Thanks to the combination of likelihood with vulnerability index, probability of failure results more representative of effective risk related to a chokepoint crossing. Results, indeed, show that not only Hormuz and Bab el-Mandeb are characterized by high probability of failure but also Suez, due to its length that makes it very vulnerable to hacking and threats or ships collision.

Once defined the probability of failure related both the cross a chokepoint and cross EEZ or international water, then, the overall formulation of the open-sea probability of failure is obtained:

$$\xi_{OpenSea} = 1 - [(1 - \xi_{cp)} * (1 - \xi_{route})]$$

Where

$1 - \xi_{cp}$ is the probability of successfully crossing the chokepoint

$1 - \xi_{route}$ is the probability of successfully ship along EEZ and international water

In order to achieve the success of overall open sea corridor, all sea branches and chokepoints has to be crossed. Even if only one fails, entire sea corridor fails as well.

3.4 Captive corridors

Currently, in Italy there only one active pipeline: *Trans Alpinen Leigtung (TAL)* that links terminal of Trieste with eight foreign refineries in Germany, Austria and Czech Republic [24]. Great amount of crude pass through this pipeline. However, since it is an export channel, it is neglected in this dissertation because, from the Italian point of view, TAL does not affect the overall external risk.

Nevertheless, there are other foreign pipeline not directly connected to Italian boundaries which may have a strong impact not only on the Italian energy risk supply but also on global energy security. The characterization of foreign pipelines mainly involved in the oil trade toward Italy is performed through processing data provided from the purchased platform Energy Web Atlas (EWA). The results highlight that generally exporting ports are supplied by oil pipeline systems. Indeed, they represent the cheaper alternative to open-sea transport and allow to handle millions of oil tonnes every year.

3.4.1 Captive hazards

As for the maritime route, also the captive corridor probability of failure depends on the geopolitical stability of the crossed country. The geopolitical index is used with no further combination with piracy and armed robbery index, since it would be meaningless to consider maritime geopolitical risk for captive corridors. In particular, pipelines which cross more than one country, deserve particular attention because different values of geopolitical risk index have to be considered to calculate the overall geopolitical risk. Despite, for the internal pipelines, only one geopolitical risk index is considered since it is the same along all the pipeline.

Thus, before proceeds to calculation of probability of failure of captive corridor, two preliminary steps have to be performed:

1. Characterization of each pipeline with specific attributes
2. Definition of a reference index according crossed countries along pipeline's pathway

The first step was carried out by collecting data from EWA database and selecting pipelines potentially involved in the trade of crude and oil products towards Italy. Then, starting from selected data is built a table containing characterising information about each pipeline (Table 13) such as commodity delivered, start point, end point, capacity and total length.

Table 13: Characterization of main pipelines (Source: Elaboration based on [23])

Pipelines characterization					
Name	***Commodity***	***Start Point***	***End point***	***Total Length [km]***	***Capacity [ton/y]***
Baku-Tbilisi-Ceyhan pipeline (BTC)	Crude oil	Sangachal (Azerbaijan)	Ceyhan (Turkey)	2204	49.3
Iraq-Turkey pipeline	Crude oil	Kirkuk (Iraq)		1225	78.9
Caspian pipeline consortium (CPC)	Crude oil	Astrakhan (Kazakhstan)	Novorossiysk (Russia)	2149	34.5
Northern 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 (Kazakhstan)	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
Egyptian internal pipeline	Crude oil	Egypt	Egypt	830	[-]
Iraqi internal pipeline	Crude oil	Iraq	Iraq	1421	[-]
Libyan internal pipeline	Crude oil	Libya	Libya	780	[-]

The second step, though, requires the use of a GIS software application and consists on dividing each pipeline into many captive branches as the number of crossed countries in order to associate to each captive corridor a unique geopolitical risk. Then, length of each branch l_i is calculated thanks to specific GIS function "Calculate Geometry" (Figure 47).

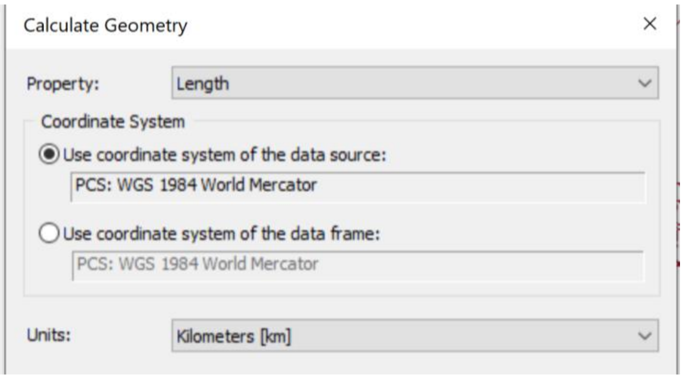


Figure 46: Screen shot of GIS interface: Calculate Geometry

By joining table of pipelines attributes with table of branches length and geopolitical risk φ_k, is possible to calculate failure of captive corridor disruption.

3.4.2 Quantification of probability of failure

As well, captive corridor probability of failure derives from fault tree but despite of marine corridor it does not depend on piracy index. The only influencing factors are geopolitical risk of crossed country and the corresponding length of branch into the country. Actually, probability of failure of a single branch corresponds to the geopolitical risk index of crossed country: $\xi_{\text{branch}} = \varphi_k$

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

Also, in this case, the product operator relies on the assumption that each event of branch disruption is independent from the others. As for the maritime route, indeed, probabilities of cross different countries are linked by AND operator which means that they are independent from each other (Figure 48).

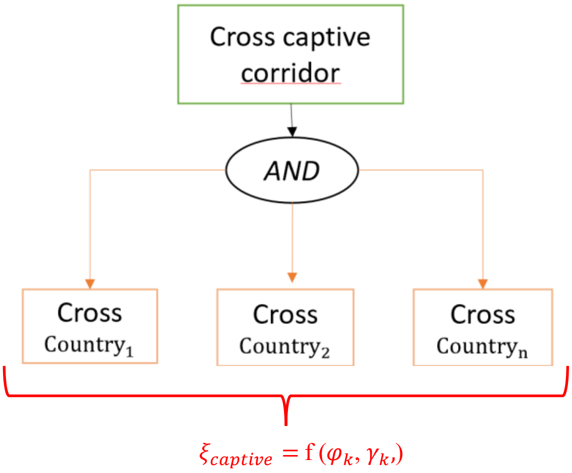


Figure 47: Conceptual map of captive corridor failure assessment

Thanks to the second steps, length of each branch is calculated and joined with a single value of geopolitical risk index. Hence, is possible to calculate the overall probability of captive corridor by giving a weight to the captive branches: the longer is the branch the more it affects the total $\xi_{Captive}$. As for maritime probability of failure a weighting factor γ_k is introduced, in this way the contribution of the single branch to overall probability of captive corridor failure is proportional to its length.

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

Once obtained probability of failure of both sea routes and captive branches, overall probability of failure of the entire corridor is calculated with the following function which combines together $\xi_{opensea}$ and $\xi_{Captive}$:

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

On the contrary, the probability of success results as follow:

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

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

The figure below (Figure 49) summarizes the conceptual relation between all the mentioned probability of failure: $\xi_{opensea}$, $\xi_{Captive}$, ξ_{route} and ξ_{branch} .

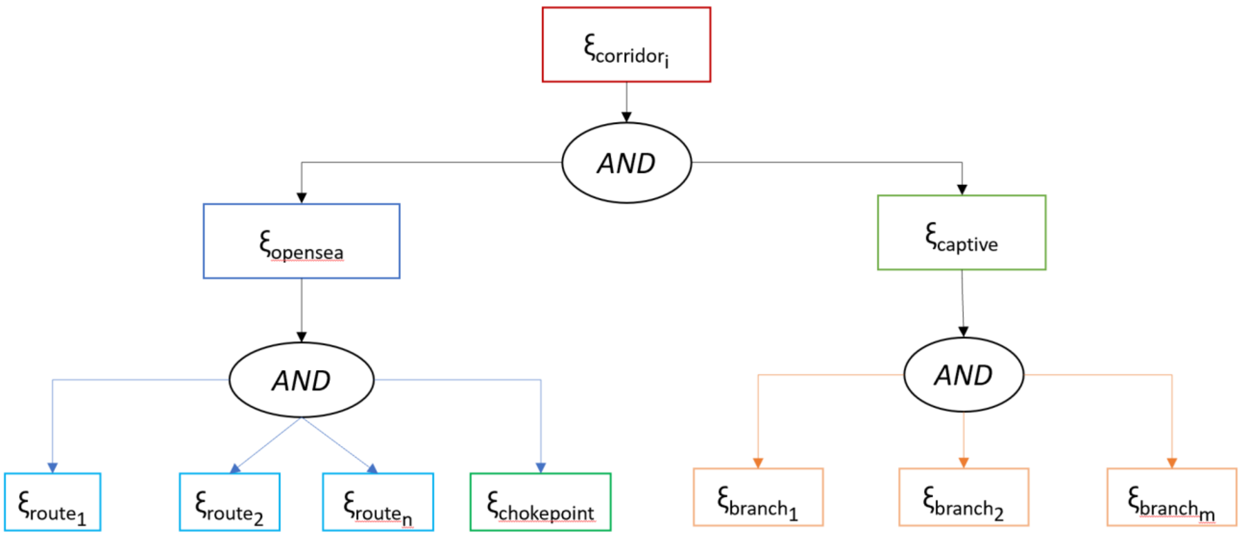


Figure 48: Conceptual map of overall corridor failure assessment

3.5 External risk quantification

In the final step, corridor risk can be obtained by multiplying the probability of failure with the corresponding consequences expressed in terms of loss of energy [29].

$$R_i = \xi_i * E_i$$

Where

- E_i is the energy transported through the corridor i

Even if the mathematical formula is defined, it is not possible to proceed directly to risk calculation. Indeed, many data related to crude and oil product pipelines are missing (e.g. type of commodity transported, commodity flux, pipeline capacity etc). Therefore, further preliminary assumptions and evaluations are required in order to try overcoming the limit imposed by lack of available data.

3.5.1 Energy flux sorting

Since energy risk is directly proportional to energy transported, once defined the overall probability of corridor failure, a further step is required in order to join each corridor with a specific amount of energy. This information can be easily extracted from digitalized sea routes whereas it results very challenging from pipeline routes. Indeed, each sea route is characterized by amount of commodity delivered, therefore the corresponding quantity of energy is derived from the product between tonnes of commodity with lower heating value (LHV) of specific commodity considered.

$$E^c{}_i = \frac{T_i^c * LHV^c}{3.6\ GJ}$$

Where:

- $E^c{}_i$ is the energy flux through the generic corridor (MWh)
- T_i^c is the amount of commodity transported (toe)

Otherwise EWA data do not provide any information about flux of commodity transported. The only available values are the capacity of major pipelines. Nevertheless, energy assignment is a complex process because the amount of commodity transported a single sea route can have several possible origins from different countries. Actually, major ports are linked to oil producing countries not provided of outlet to the sea. Therefore, the energy of the maritime corridor has to be split in as many components accordingly to the possible countries of origin. What is more, this procedure results even more challenging for oil products since capacities of oil products pipeline are missing in EWA dataset. For this reason, risk model cannot be applied for captive corridor transporting oil products. Thus, risk estimation of oil products supply is limited to the open sea corridors. An explanatory example of energy assignment is illustrated below.

Ceyhan is one of the major ports which delivers to Italian ports crude oil. According to MiSE, Italy do not import any Turkish crude, thus all the exported amount is coming from foreign countries. Once performed a detailed study of oil exchange from/to Turkey, exported crude oil was attributed to Azeri and Iraqi oil fields. Therefore, the total amount of crude oil departing from Ceyhan is expected to be split into two pipelines: the Baku-Tbilisi-Ceyhan (BTC) pipeline and the Iraq-Turkey-Pipeline (ITP).

In mathematical terms, the risk related to each corridor is expressed as shown below:

Iraq-Ceyhan-Italy:
$\mathrm{Risk}_{\mathrm{Azerbaijan}} = [1 - (1 - \xi_{BTC}) * (1 - \xi_{\mathrm{OpenSea}})] * E_{Azerbaijan}$

Azerbaijan-Ceyhan-Italy:
$Risk_{Iraq} = [1 - (1 - \xi_{ITP}) * (1 - \xi_{\mathrm{OpenSea}})] * E_{Iraq}$

Where the sum of the energy coming from Azerbaijan through BTC (E_{BTC}) and from Iraq through ITP (E_{ITP})is equal to the energy transported in the sea corridor Ceyhan-Italy (Figure 50).

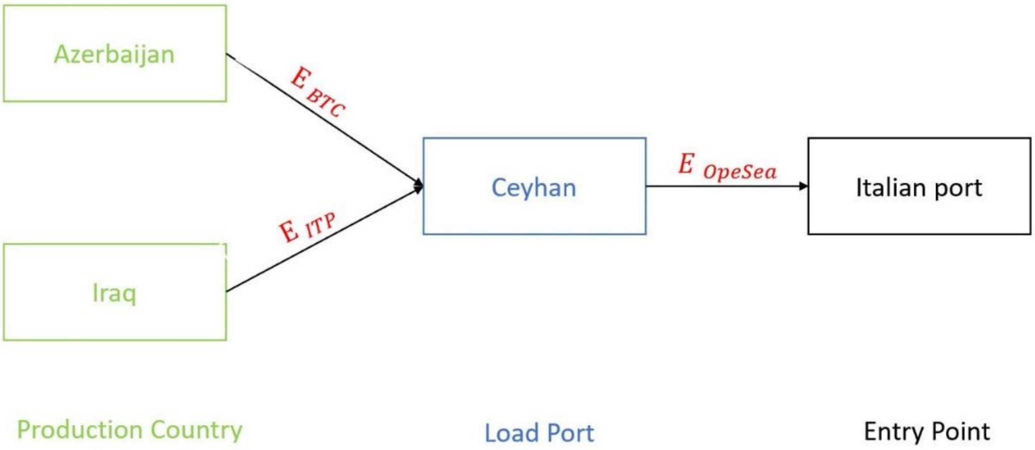


Figure 49: Flow chart of crude supply from Iraq and Azerbaijan

Where:

$$E_{Azerbaijan} = E_{BTC}$$

$$E_{Iraq} = E_{ITP}$$

Nevertheless, as previously said, EWA data about pipelines are not complete. The proposed solution for crude captive corridors consists on splitting energy according to the available capacities collected in the table of characterization of pipelines (Table 13). However, the energy splitting process is carried out with specific assumptions:

- All the crude oil reaches the load port through pipelines systems. The eventually wheel or rail transport are assumed to be negligible.
- If there are no "international pipelines" all commodity is assumed to belong to the same country of load port
- In absence of any information about crude oil pipeline feeding a load port, a captive length of reference is obtained by considering the country size:

$$\overline{Length} = (Area_{country})^{\frac{1}{2}}$$

- Supply diversification is performed by multiplying $E_{opensea}$ with the characteristic share related to the corresponding pipeline:

$$\%_{pipeline} = \frac{Capacity_{\text{pipeline}}}{C_tot}$$

Where C_{tot} is the total capacity of pipelines linked to the load port.

- Backwards investigation of oil tracking ends at the expected producing country, eventual further travels cannot be traced back due to the lack of information (e.g. Crude from Baku in Azerbaijan may come from Kazakhstan after crossing Caspian Sea).

Thanks to these approximations is possible to assign a specific flux of energy to each pipeline:

$$E_{Azerbaijan} = \%_{BTC} * E_{opensea}$$
$$E_{Iraq} = \%_{ITP} * E_{opensea}$$

Energy diversification procedure, though, is applicable only to pipeline whose capacity is provided by EWA dataset (Table 14)

Table 14: Crude suppliers diversification (Source: Elaboration based on [23])

Supplier crude diversification					
Load port	***Total crude export [ton]***	***Pipeline***	***Capacity[ton/y]***	***Pipeline share***	***Supply diversification [ton]***
Ceyhan	18,855,927	BTC	49	0.38	7,252,280
		ITP	79	0.62	11,603,647
CPC terminal	14,223,666	CPC	35	1.00	14,223,666
Novorossiysk	3,763,253	NEO	5	0.63	2,352,033
		JSC	3	0.38	1,411,220
Primorsk	4,786,280	BPS 1	77	1.00	4,786,280
Ust-Luga	3,428,269	BPS 2	50	0.67	2,295,771
		UAS	25	0.33	1,132,498
Supsa Marine Terminal	2,405,907	WREP	49	1.00	2,405,907

The product captive corridors are neglected in the analysis because the EWA dataset do not provide information about which type of commodity t is transported neither about capacities of most of the oil products pipelines. Therefore, available data are not sufficient to achieve reliable results, hence, risk calculation can be applied only to maritime corridors. Anyway, if missing details about pipelines were provided, the model would work successfully: thus, the only limit of the developed risk model is due to the lack of information.

3.5.2 Corridors grouping

Finally, the last issue to be resolved was the number of sea corridors to digitalize. Indeed, once of the first step before risk calculation consists on tracing manually through GIS software all sea corridors from foreign load ports to Italian ports. Since the overall sea routes were 433, and most of them had a very low contribute to the total open sea supply, otherwise tracing all routes, minor routes were associated with the major ones. Thus, firstly, the main important sea routes were digitalized (Figure 51 and Figure 52): 24 routes for crude and 30 routes for oil products. Since total amount of commodity considered were 56% for the crude oil and 46% for the oil products, by performing a route grouping process, larger share of the oil supply was included in the overall digitalized maritime trade.

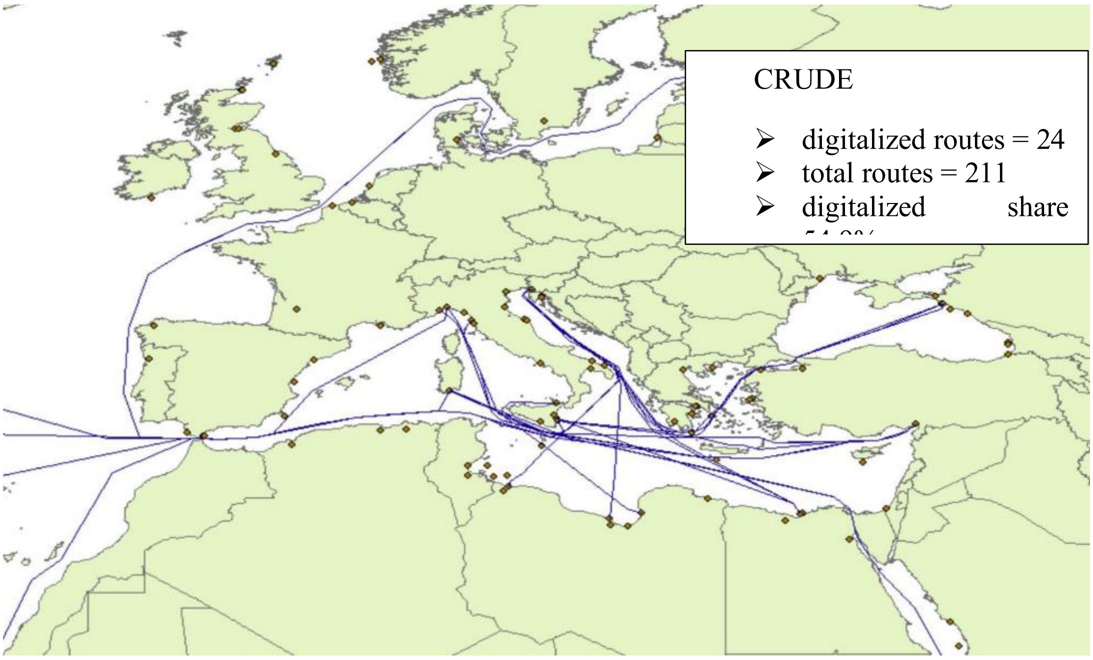


Figure 50: Mapping of crude maritime routes (Source: Elaboration based on [10])

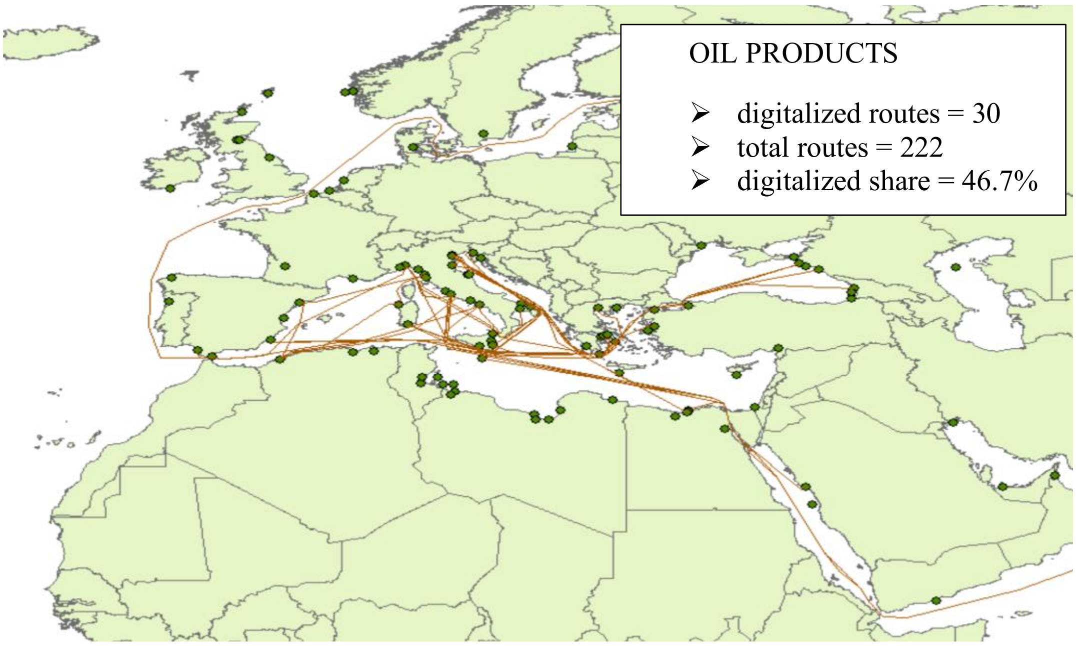


Figure 51: Mapping of oil products maritime routes (Source: Elaboration based on [6])

From a conceptual point of view, grouping process means that sea routes with the same country of origin are grouped together, otherwise, in mathematical terms, it means that weighted average probability of failure is calculated by considering the major corridors starting from the same country as shown below:

$$\overline{\xi_k} = \frac{\left(\xi_{\mathrm{corridor}_1} * \mathrm{Energy}_1 + \xi_{\mathrm{corridor}_2} * \mathrm{Energ}y_2 + \xi_{\mathrm{corridor}_n} * \mathrm{Energy}_n\right)}{\sum \mathrm{Energy}_i}$$

Afterwards, $\overline{\xi_k}$ is assigned as reference value to all minor corridors starting from the country k. Indeed, it is assumed that sea routes starting from the same country have similar pathway and consequently similar probability of failure. As a result, this grouping procedure gives more relevance to the most important routes while neglecting the contribute of minor ones to the overall probability of failure. Nevertheless, the accuracy of risk model may be improved simply by enhancing the number of digitalized sea routes.

Table 15: Corridors grouping process

Grouping corridors					
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	0.40	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	0.54	14,933,449
	Es Sider - Trieste	5,562,303	0.527		
Total		**24,111,526**			**33,877,109**

This process allows to consistently increase the analysed percentage of the crude oil and oil product market as shown in the table below (Table 16)

Table 16: Improvement of considered intake through corridors grouping

Grouping process					
Crude oil intake [toe]		***Share***	***Oil products intake [toe]***		***Share***
Digitalized routes	54,032,629	55%	***Digitalized routes***	3,806,707	47%
Grouping	80,700,394		***Grouping***	5,303,560	
Total	98,413,190	82%	***Total***	8,149,760	65%

3.5.3 Results of risk model: current Italian situation

In order obtain a valid model applicable to maritime and captive corridors, several intermediate steps were required and different variables had to be considered and studied in detail. A conceptual map which summarizes the main steps is reported below (Figure 53):

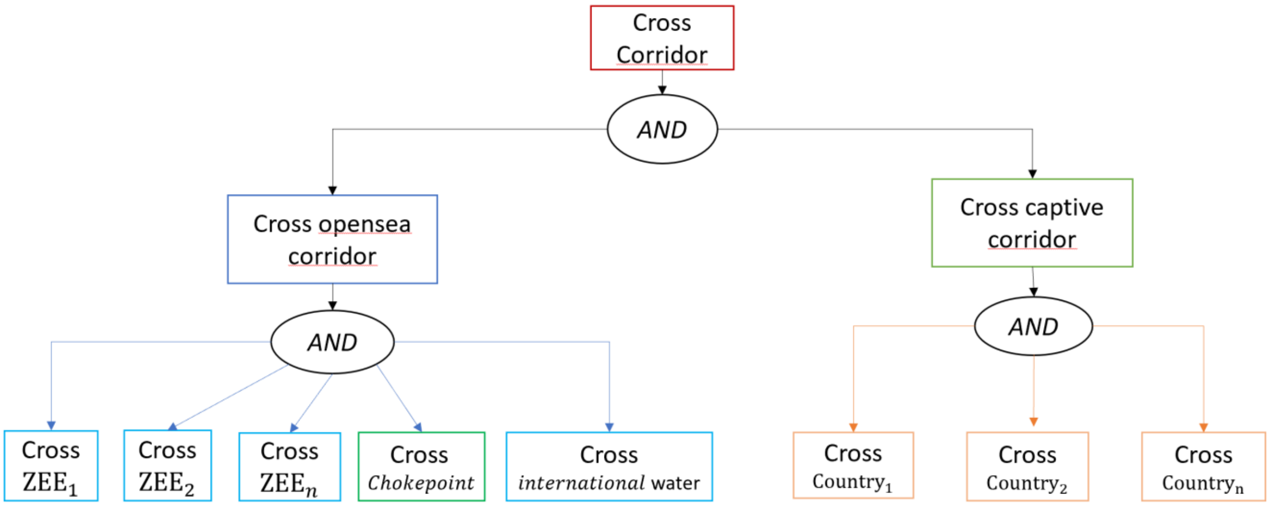


Figure 52: Overall conceptual map for risk assessment of oil corridors

Once succeeded all these steps, calculation of external energy risk is performed. The results show an overview of Italian oil supply situation in 2019 which has been considered as reference scenario (REF) for further comparison with hypothetical future scenarios of risk.

The results of the crude oil and oil products market are illustrated in two different graphs (Figure 54 and Figure 55) where each corridor, resulted from grouping process, is characterized by three parameters: probability of failure ξ_i, energy transported E_i, external risk E_i:

- probability of failure is dimensionless and represent the weighted average of grouped corridors

➢ energy flux (TEP) is the total amount of commodity transported during the 2019 from the specific load country according to Alphatanker data
➢ external risk is the overall amount of energy exposed to the risk of failure.

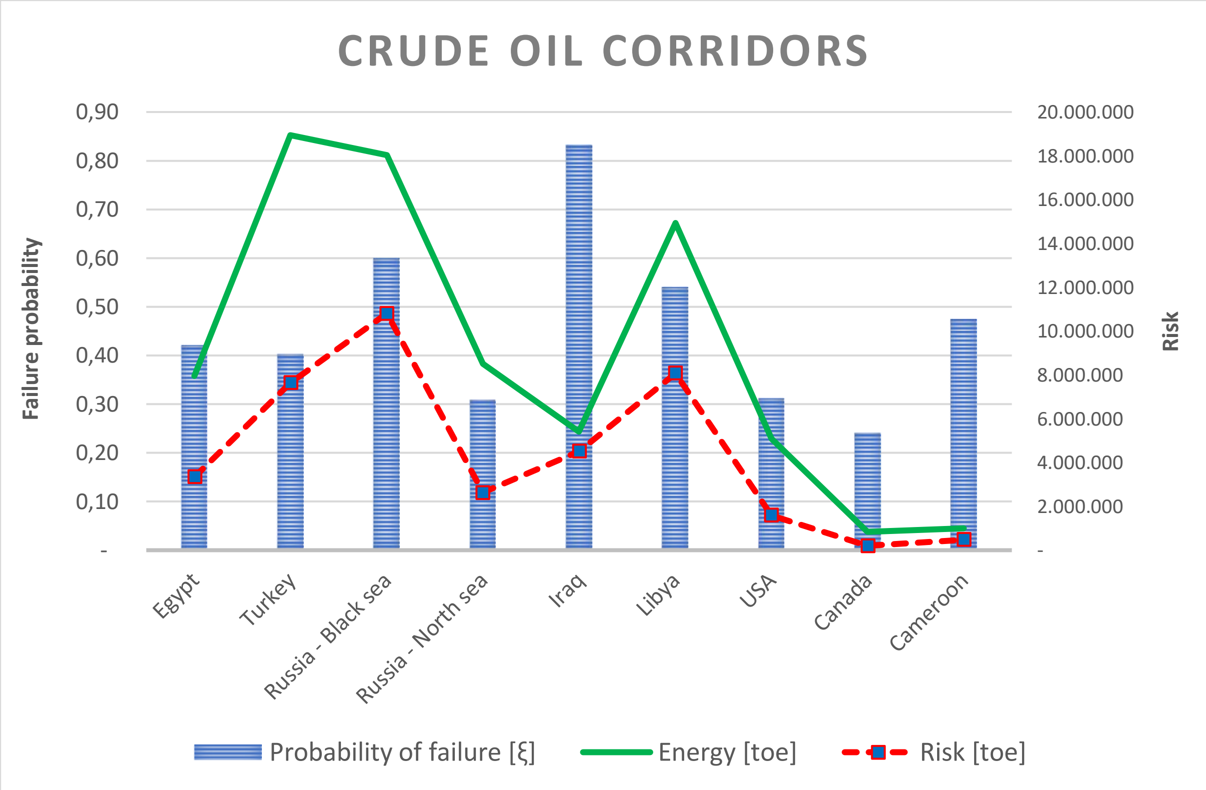


Figure 53: Results of risk assessment of Italian crude oil corridors (Source: Elaboration based on [10], [23])

According to the Figure 54 crude oil supply presents both a positive and a negative side. The negative one is that Italy results strongly dependent on Turkey, Russia and Libya, all three characterized by a rather high probability of failure. This implies high risk of crude oil supply failure. On the other hand, the good side is that, due to the high value of $\xi_{\text{Iraq-Italy}}$ corridor (ξ=0.82), Italy decreased as much as possible the direct sea importation from Iraqi ports. Actually, according to MISE, the first crude provider of Italy is still Iraq, but the imports of Iraqi crudes come from Ceyhan (Turkey) that is linked with the Iraqi oil fields through the Iraq-Turkey pipeline. The probability of failure of this alternative corridor is lower ($\xi_{\text{Turkey-Italy}} = 0.4$) and consequently Italian energy risk decreases as well.

As regards oil products, the external risk is not comprehensive of both captive and open sea corridors due to the lack of information. However, for a comprehensive report of result obtained by risk model application, the results are reported in the Figure 55.

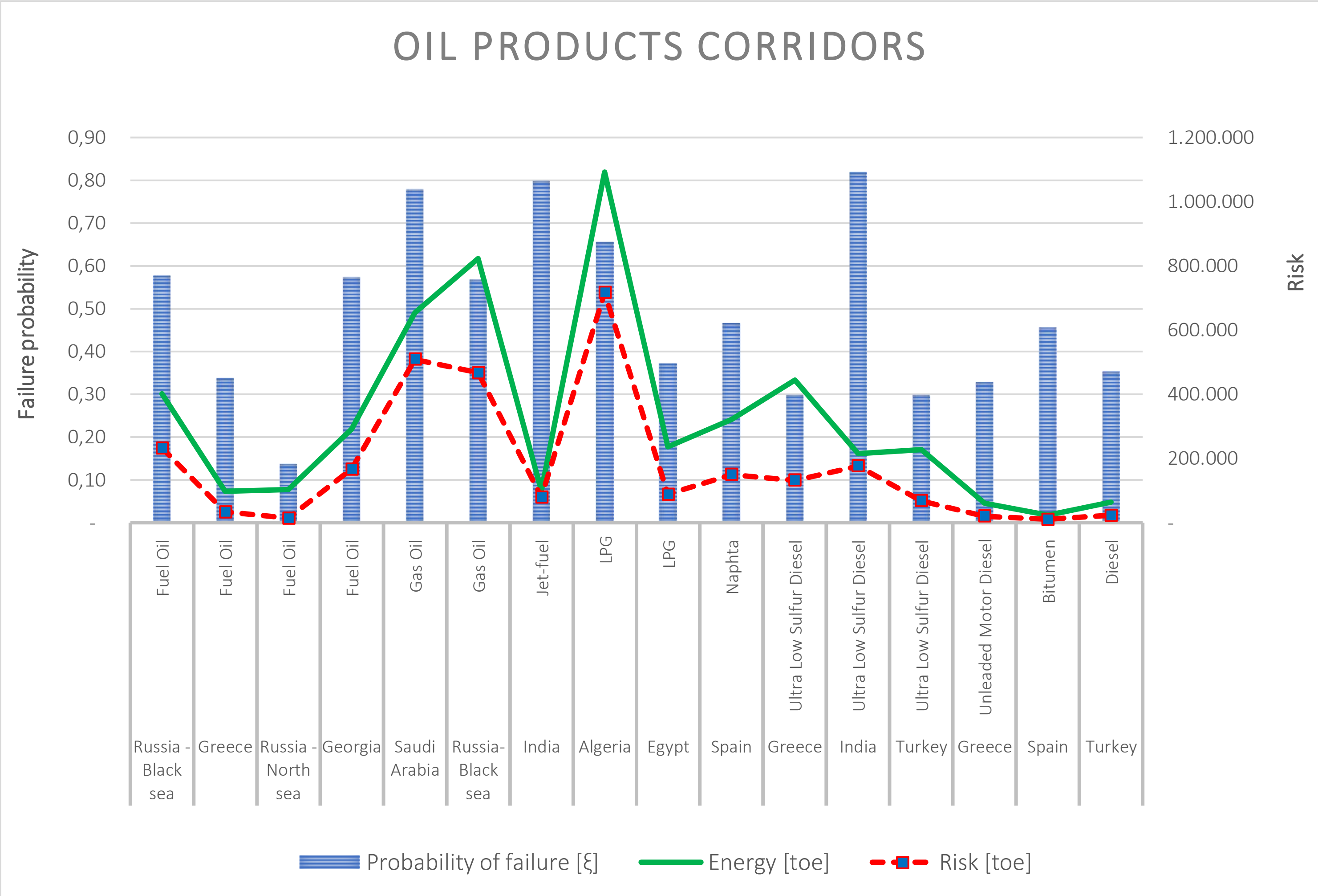


Figure 54: Results (**) of risk assessment of Italian oil products corridors (Source: Elaboration based on [6], [20]). *(**) Results do not include the risk related to the captive routes due to the lack of information available for oil products pipelines*

In conclusion, overall reference scenario is summarized in the Table 17: in 2019 shares of potential energy loss resulted equal to 49% of total crude supply while 56% of total oil products supply. According to this model, Italian oil supply needs, especially for crude which accounts for the major part of oil demand, an improvement of imports from more safety corridors such as North Russia, USA or Canada and a consequently decrease of imports from Libya, Egypt and Black Sea countries.

Table 17: Overall National External Risk related to oil supply

Commodity	***Energy Supply in 2019 [toe]***	***National External Risk [toe]***	***Share of expected energy loss***
Crude oil	80,594,653	39,374,128	49%
Oil products	5,374,521	3,013,275	56%

4 Impact assessment of risk scenarios

The aim of this thesis was to develop a model risk to determine the Italian security level related to oil supply. But apart from that, the main goal was to implement a model able to provide a quantitative assessment of potential risks related to future scenarios even not really occurred. If scenario analysis is applied to energy risk assessment, it provides an estimation of impacts both in terms of energy loss, in case of adverse events, and in terms of energy recovered, in case of mitigation measure. In this way, risk model can be used as a tool to support political decision making: by analysing and comparing alternative future scenarios and their possible effects in order to enhance management of energy supply and to guarantee a prompt and effective emergency response when contingencies occur.

4.1 Scenarios definition

Energy risk assessment involves a large number of variables such as political instability, economic situation, cultural factors and social issues but many of them are unpredictable and interact with each other. As a consequence, even though this dissertation attempts to estimate impacts of several realistic scenarios, the proposed method takes into account only a part of the overall complexity of security system.

Two main categories of risk scenario will be discussed: potential risk scenario and actual risk scenario. The first kind of scenario includes events which cause a variation of total risk but without an effective loss of energy. For instance, the eventual worsening of diplomatic relations between Russia and the European Union could lead to an increase of the probability of failure associated to the corridor starting from Russia. The second one, instead, includes events that really occur, such as a chokepoint or a corridor disruption, and cause an effective loss of energy from a corridor. In this case, mitigation measures are required in order to limit the damage on energy supply. So, applying scenario analysis, several alternative mitigation measures are compared with the aim to define the best one which achieves effectively a rapid recover of energy.

4.2 Corridor and chokepoint failure

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, thus, belongs to the class of actual risk scenario. In order to estimate the loss of energy, failure probability of the considered corridor is assumed equal to 1. In order to counterbalance the adverse impacts on oil supply, the solution proposed consists on increasing oil import from alternative ports which are selected according to the following criteria:

- Failure of corridor does not affect the normal activity of selected ports
- Since the mitigation measure have to be planned in a very short time increasing import from a load port cannot exceed +50% with respect to the normal conditions.
- Selected ports have to be linked to oil fields producing of crude with similar characteristics (API and percentage of sulphur) to the crude oil not supplied.

- Since priority is to cover the loss of energy as fast as possible, ports closest to Italy are preferred.

Closure of a chokepoint, as well, is considered an actual risk scenario, even though it does not necessary involve the completely loss of energy transported by the corresponding corridor. Indeed, in some cases, 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 on recovering the lost energy from other ports not affected by the closure of the chokepoint. Since the severity of the impact may vary according to the availability of alternative pathways, a new index of impact I is introduced. A detailed analysis on impact of chokepoint failure is carried out to consider this aspect. In particular, available pathways may be classified into two main categories:

- Alternative pipelines
- Alternative sea routes

Therefore, an alternative pipeline could be used to deliver a certain amount of commodity in case of chokepoint disruption. In order to define the availability degree related to a specific pipeline, the share of available capacity is defined as a new parameter which is obtained from the ratio between the unused capacity of the alternative pipelines (provided by --- 2016, EIA) over the total trade flow through the chokepoint.

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

Instead, the availability of alternative sea routes depends on the delay caused by the route deviation in case of chokepoint failure. The lower is the delay the higher is the availability degree. It is obtained from the ratio of average additional distance, previously calculated by using the opensource platform Marine Traffic, with a reference value of oil tanker's velocity that is set equal to 13 kn (24km/h). All chokepoints crossed by oil corridors towards Italy are characterized with these two parameters: share of alternative capacity available and delay as summarized in Table 18:

Table 18: Characterization of chokepoints (Source: Elaboration based on [23])

Chokepoints	***Alternative pipeline***	***Available capacity [%]***	***Delay [day]***
Hormuz Strait	Petroline ACOP	21.1	-
Bab el -Mandeb	-	-	23.5
Suez Canal	SUMED	19.0	23.5
Turkish Straits	-	-	-
Gibraltar Strait	-	-	31.1
Malacca	-	-	2.9

In order to combine delay with available alternative capacity, days were converted into a dimensionless value ranging between 0 and 1 by applying the following normalization:

$$D = \frac{60-x}{60} \qquad \begin{cases} x & if\ x < 60\ days \\ 60 & if\ x \geq 60\ days \end{cases}$$

Where:

- x is the effective delay due to deviation route (days);
- 60 is a reference value which is referred to the EU's Oil Stocks Directive (2009/119/EC) [42] which states that EU countries must maintain emergency stocks of crude and/or petroleum products equal to at least 61 days of consumption.

Italy, as a member of the European union, has to comply with this European legislation. Managing Italian emergency oil stocks is entrusted to the "Organismo Centrale di Stoccaggio Italiano" (OCSIT) [43].

From the empirical expression which combines C_p with D, a new index is introduced: impact of chokepoint I_{cp}:

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

Where:

- C_p is the overall available capacity of alternative pipelines
- D is the normalized delay due to deviation of route

As shown in the Figure 56, I_{cp} rises with increasing of delay whereas the higher is C_p the more growth of I_{cp} is slowed and overall impact is mitigated.

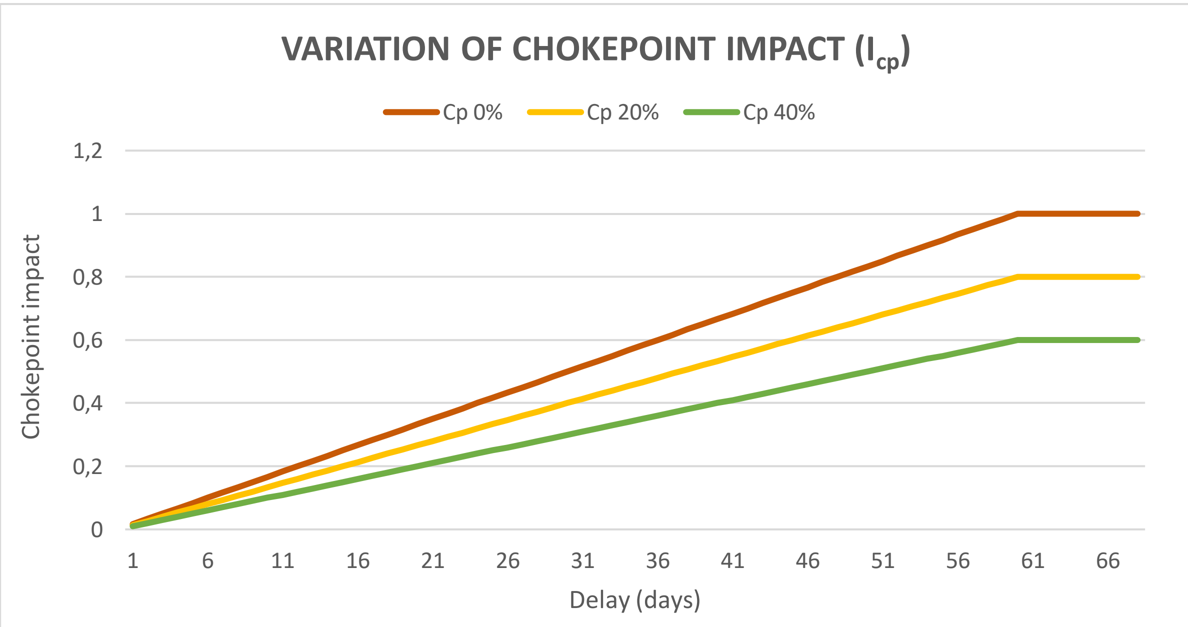


Figure 55: Variation of chokepoint impact according to available capacity and days of delay .

Three explanatory cases can be analysed:

- C_p = 0% represents the most critical situations: no available pipeline capacity and maximum I_{cp}=1 (it means that all energy will be lost);
- C_p = 20% illustrates the middle case: the impact is decreased with respect to previous condition, indeed maximum I_{cp} reaches 0.8 (it means that the major part of energy will be lost otherwise a small part will be saved thanks);
- C_p = 40% shows the best case in which the maximum impact is I_{cp}=0.4 and majority of energy will be saved.

In addition, a classification of impact is obtained by applying the empirical expression of I_{cp} to the major chokepoints involved in Italian oil supply. Turkish straits resulted to be the most critical chokepoints due to the lack of alternative routes in case of straits closure. Malacca Strait, on the contrary, the lowest impact. since few days of delay are required to bypass the strait in case of closure.

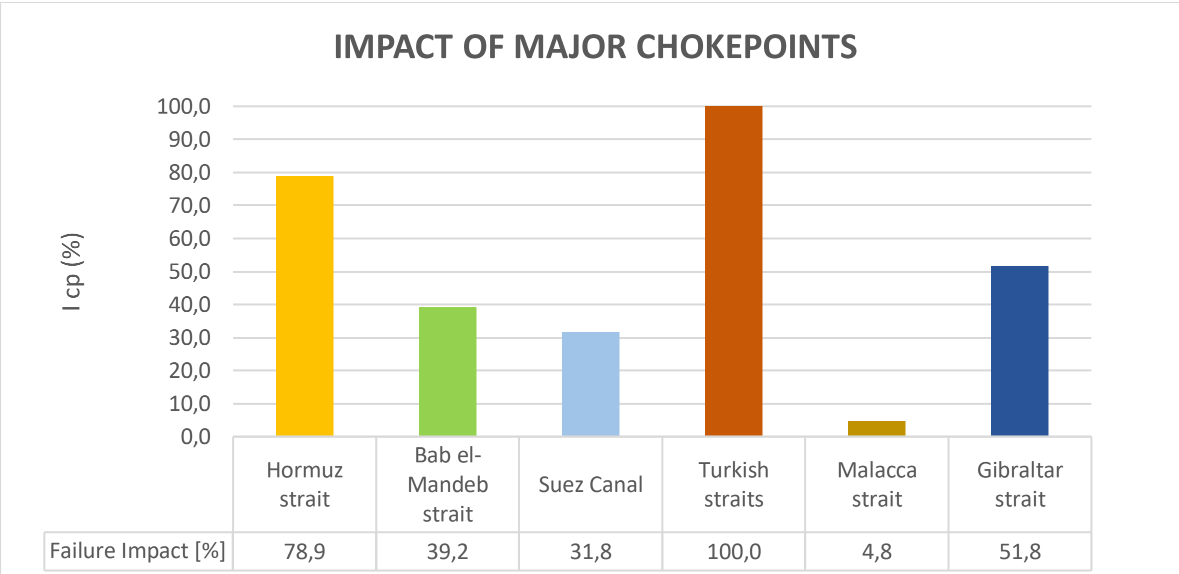


Figure 56: Ranking of chokepoints impact

The product between the impact index and the amount of commodity passing through the strait correspond to the energy potentially lost in case of chokepoint failure.

4.3 Quantification of potential and actual threats

In this dissertation four possible adverse scenarios are implemented to test the reliability of the risk model applied in the Italian energy security framework.

Scenario 1 (SC1) simulates the worsening of Libyan situation due to civil war and a consequently increase of geopolitical risk.

Scenario 2 (SC2) simulates the deterioration of relation between Russia and Turkey due to the rapture of demilitarization agreement signed in 2018 which involved on one side the rebel Syrian groups, sustained by Turkey, on the other the Assad government, supported by Russia. As a consequence, Russian and Turkish geopolitical risk indexes increase.

Scenario 3 (SC3) simulates several terroristic attack of Yemen rebels supported by Iran against Saudi Arabian oil fields. As a result, the Saudi Arabian crude export is reduced of 30%.

According to Alphatanker data, there are no export from Saudi Arabia because the extracted crude is sent to Egyptians ports through CORC and SUMED pipeline, thus the decreasing crude export is associated to Egypt's crude export instead of Saudi Arabia.

Scenario 4 (SC4) simulates the disruption of Hormuz strait resulting from the deterioration of Iranian relations with USA:

- Killing of Iranian general Qasem Soleimani;
- Further sanctions imposed by USA on Iran's oil exports.

The failure of the Hormuz strait brings an effective loss of crude oil. Italy has to reply with a prompt emergency response. The planned mitigative measure consists on increasing import from other ports according to the selection criteria defined in the chapter 5.2 (Es Sider, Novorossiysk and Ceyhan)

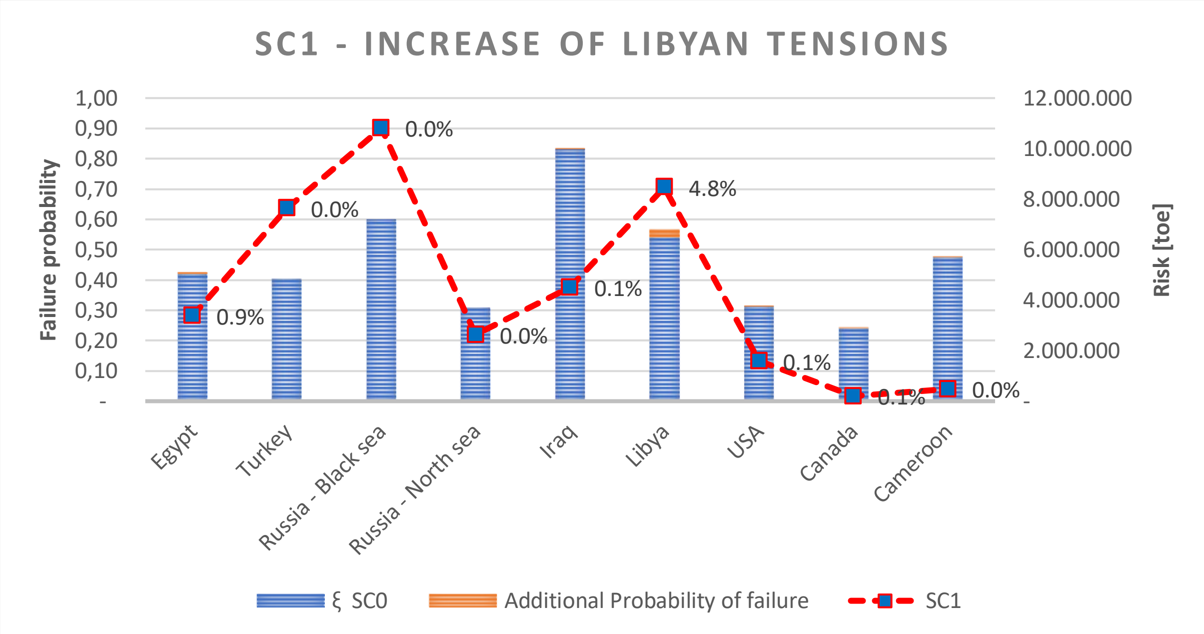
The Table 19 illustrates the overview of 5 alternative scenarios considered and their potential effects. Scenarios 3,4,5 include also mitigation measures since they belong to the category of "actual risk scenario".

Table 19: Risk scenario definition

Code	Event	Type	Definition	Mitigation measures
SC1	Libya civil war	Potential risk scenario	Increasing geopolitical risk of Libya (+30%)	[-]
SC2	Increasing tension between Russia and Turkey	Potential Risk scenario	Multi-increasing geopolitical risks of Syria, Turkey and Russia (+30%)	[-]
SC3	Iranian attack to Saudi Arabia	Actual risk scenario	Partial loss of crude supply from Saudi Arabia (-30%)	Increase import from: Es Sider (+15%); Az Zawiyah (15%); Zueitina (20%);
SC4	Hormuz closure by Iran	Actual risk scenario	Hormuz closure: loss of crude supply from Persian Gulf	Increase import from: Es sider (+20%); Novorossiysk (+15%); Ceyhan (+15%);
SC5	Tengiz field (Kazakhstan) closure	Actual risk scenario	Temporary closure of Tengiz field: -60% of crude supply from Kazakhstan	Increase import of Azeri crude from: Ceyhan (+40%); Novorossiysk (+25%);

1. Libya civil war (SC1)

Further worsening of political instability in Libya leads to a geopolitical risk index growth of +30%. According to the risk model results, this scenario causes an 1.08% increase in overall national external risk (Figure 59). In this case, total risk increasing is moderate because the reference scenario (SC0), as well, is characterized by a high probability of failure related to Libya. Since this is a potential risk, mitigation measures are not applicable because no loss of energy occurred but is only expected a rise in probability of failure related to Libyan corridor.



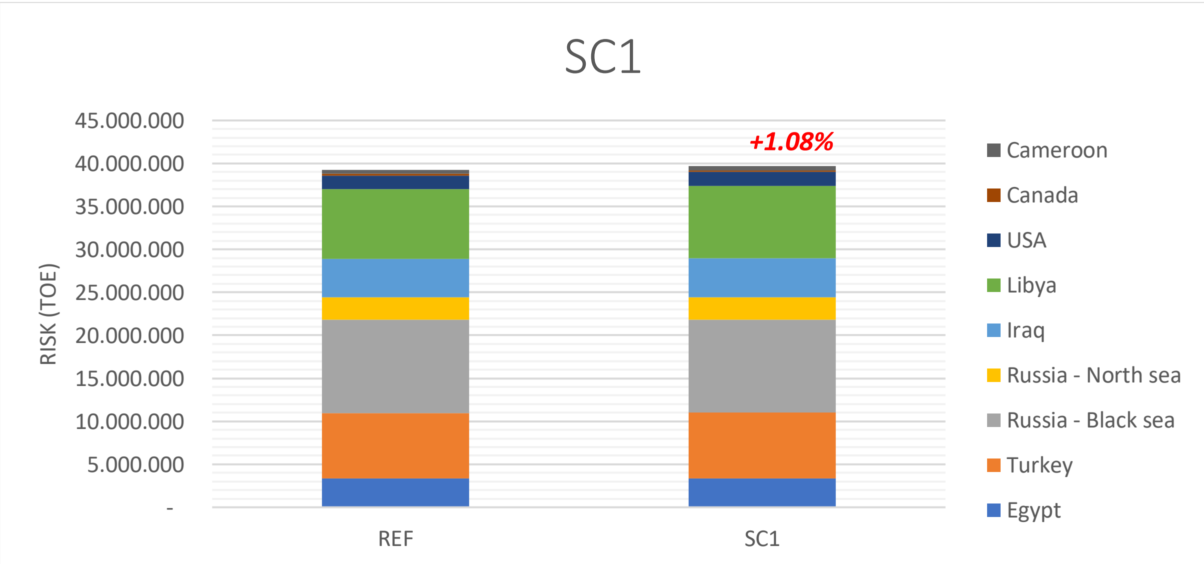
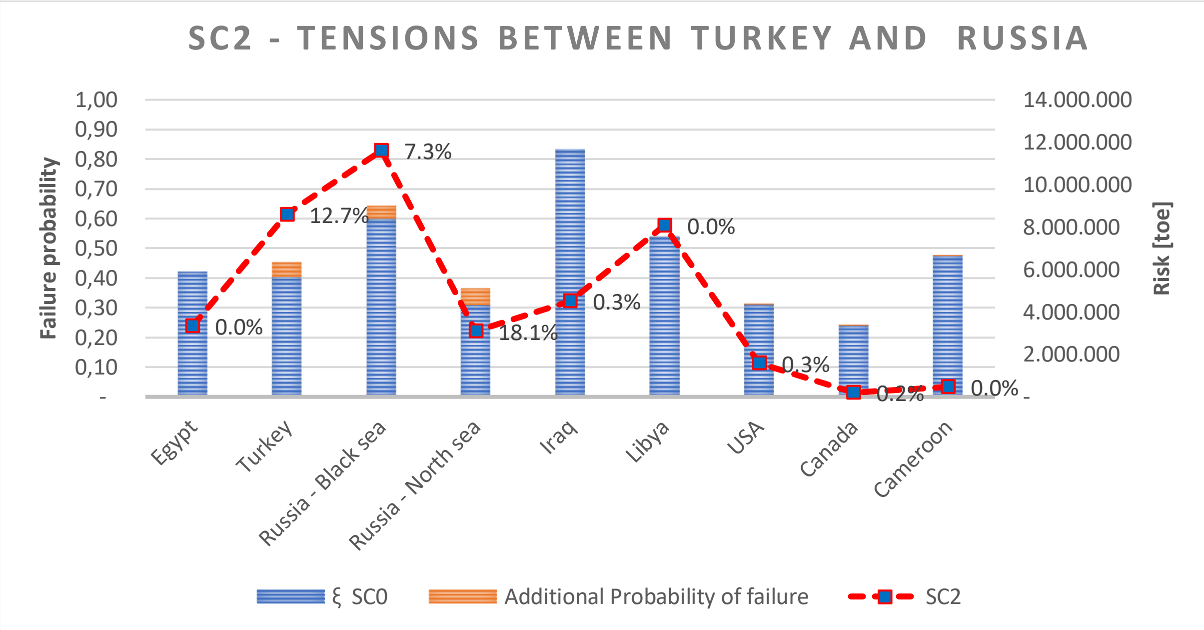


Figure 57 and Figure 58: SC1-Increase of Libyan geopolitical risk

2. Tension between Russia and Turkey (SC2)

Syrian extremist attacks against Assad government causes further deterioration of Turkish and Russian diplomatic relations. Indeed, on one side, Russia is a backer of Assad regime since

2015 and wants to keep him in power and to support a peace deal with broad consensus among Syria's moderate factions. On the other side, Turkey is one of the main backers of the Syrian opposition. This event results in an increase of geopolitical risk of both Russia and Turkey. This scenario causes a +5.73% of overall national external risk with respect to reference scenario (Figure 61). Otherwise, by comparing SC2 with SC1, the impact results to be much higher because Turkey and Russia account for almost 50% of the total Italian crude supply. Hence, variations on probability of failure of Turkish and Russian corridors affects strongly the total risk. As for scenario 1, also scenario 2 is a potential risk scenario, thus, no loss of energy is considered neither mitigative measures are taken into consideration.



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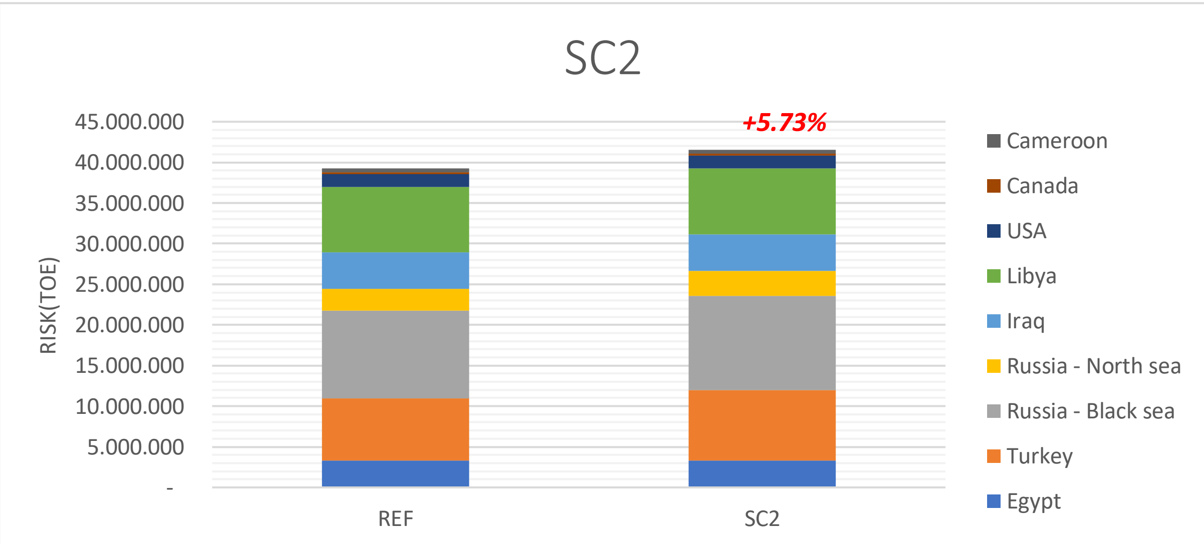
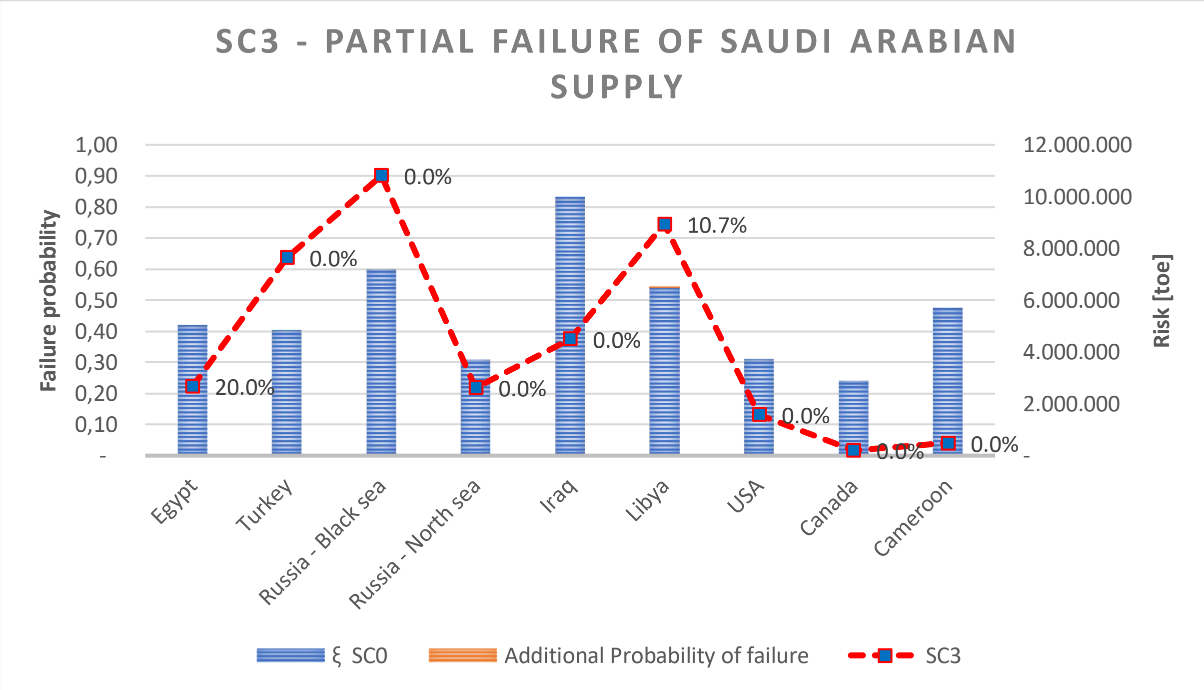


Figure 59 and Figure 60 : SC2 - Increase of Russian and Turkish geopolitical risk

3. Partial failure of Saudi Arabia supply (SC3)

Iranian and Saudi Arabian conflicts in Yemen leads to a -30% in the Saudi Arabian crude exports. This reduction has an impact on the Egyptian ports oil trade that registers a decreasing of the 20%. As a consequence, national external risk increases of +4.05% (Figure 63) since 1.5 million tons of crude are lost. In this case, an effective loss of energy is occurred, hence, a mitigative measure is proposed:

M1) increase crude supply from Libyan ports of Es Sider, Az Zawiyah and Zueitina. The mitigative operation is able to contain the growth of the energy risk (+0.5% with respect to the reference scenario instead of + 4.05%).



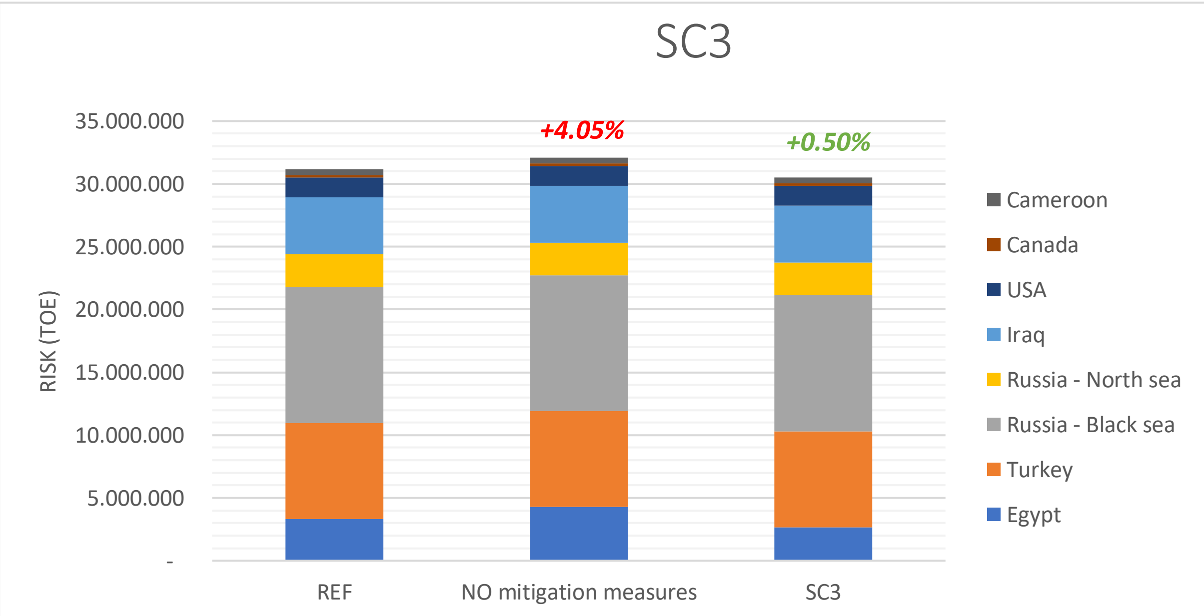
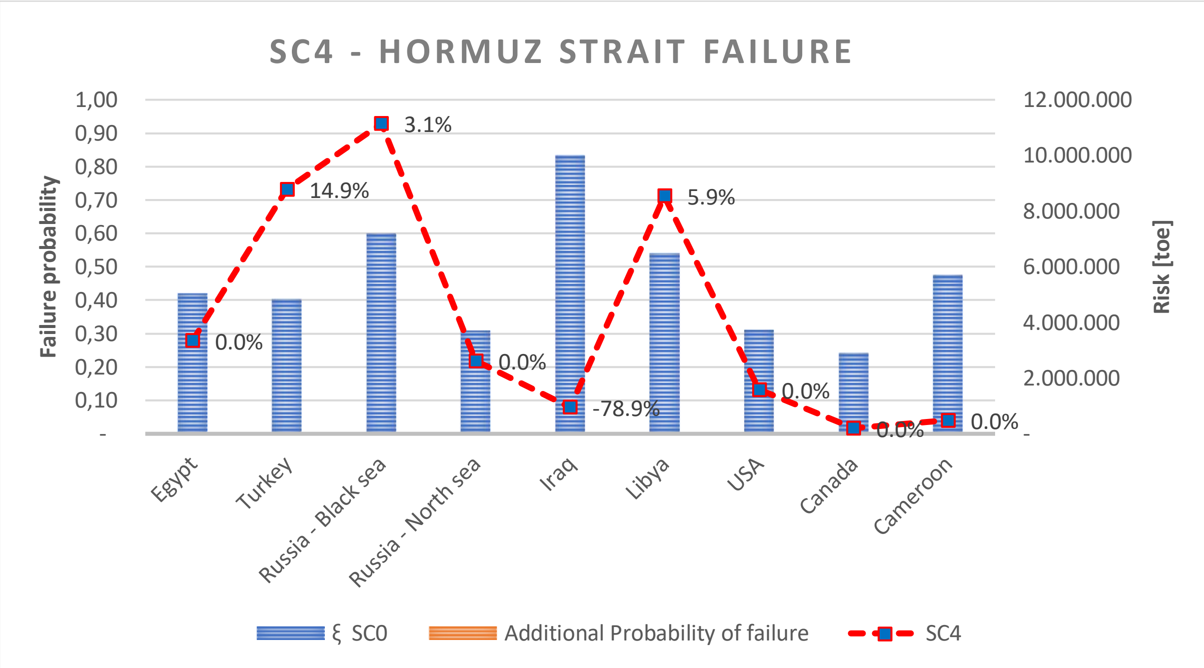


Figure 61 and Figure 62: SC3 – Partial failure of Saudi Arabian crude supply

4. Hormuz failure (SC4)

Iran closes the Hormuz strait. All the crude suppliers in the Persian Gulf cannot overcome Hormuz. As a result, 78.8% of energy transported by the corridor Iraq-Italy is lost and the overall risk increases of 1.79%. However, the suggested mitigative measure reduces the overall risk of 4.1% (Figure 65) by incresing crude supply from Libya and Russia: Es sider +20%, Novorossusk +15% and Ceyhan +15%.



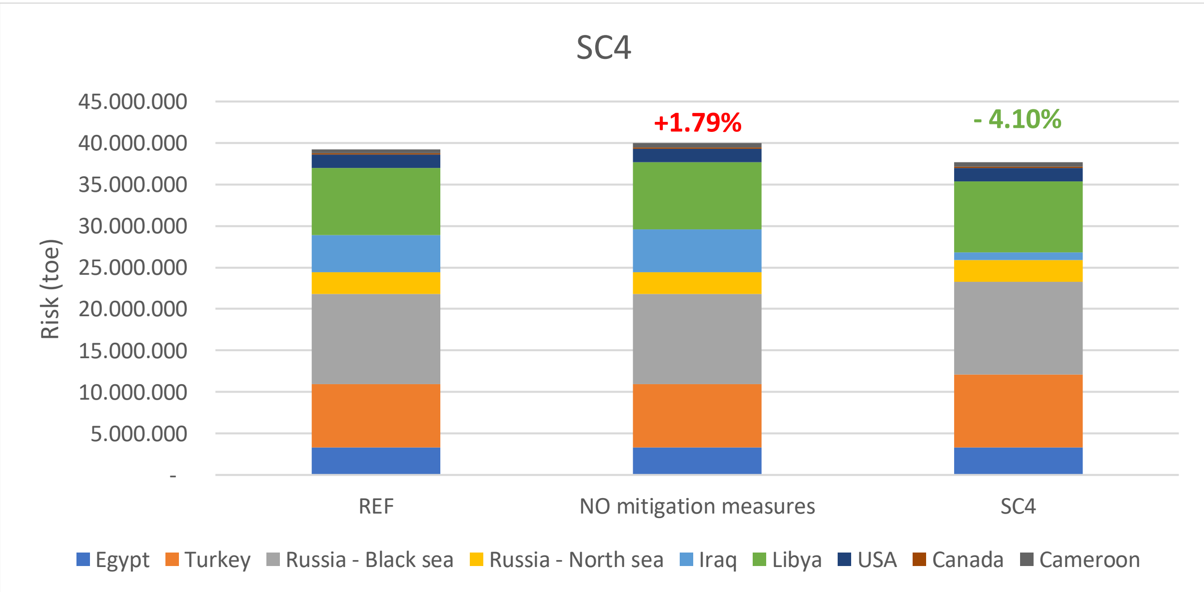
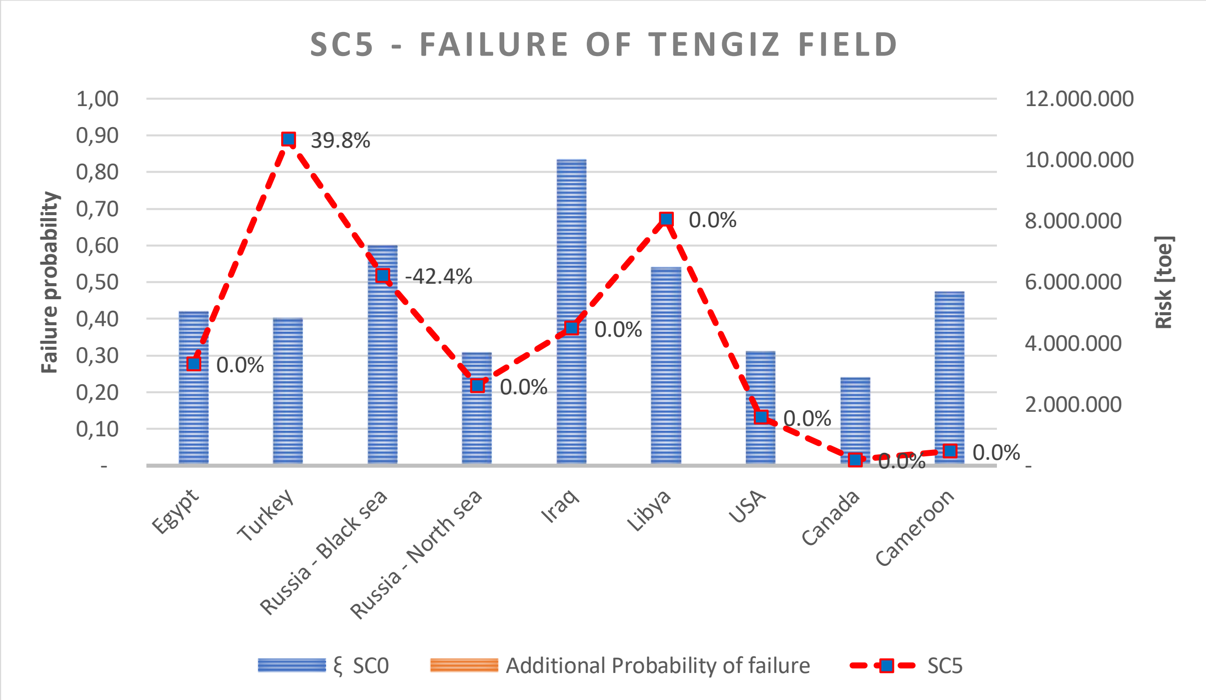


Figure 63 and Figure 64: SC4 - Failure of Hormuz Strait

5. Failure of Tengiz field (SC5)

A sharp increase in the number of Covid-19 cases among workers at Kazakhstan's Tengiz oil field forced to temporary interrupt production. As a consequence, crude supply from Kazakhstan decreases of -60% and this leads to an increase of overall risk of +8.70% (Figure

67). In order to mitigate this impact is proposed the following measure: M1) increase of Azeri crude oil import delivered by Ceyhan port (+40%) and Novorossiysk (+25%) port. As a result, the national external risk decreases successfully and reach -3.94% with respect of reference scenario.



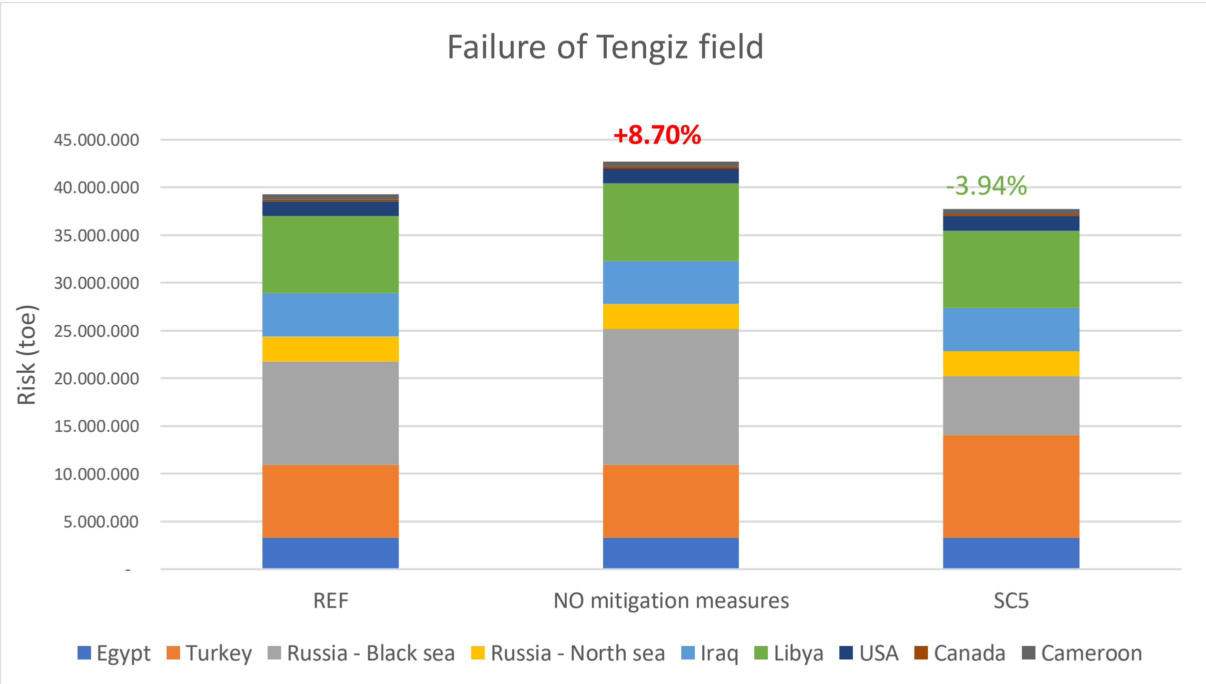


Figure 65 and Figure 66: SC5 - Failure of Tengiz crude supply

The comparison between overall risk resulted from different scenarios is reported in Figure 68. Final results show the risk variation related to each scenario. On one hand potential risk scenarios, do not include mitigation measures but only present an increase of total risk of supply failure with respect of reference scenario. On the other hand, actual risk scenarios include two different cases:

- without mitigative measures, total risk increases (SC3*, SC4*. SC5*);
- with mitigative measure, total risk decreases because is performed a re-distribution of energy which has been lost due to supply failure (SC3, SC4, SC5).

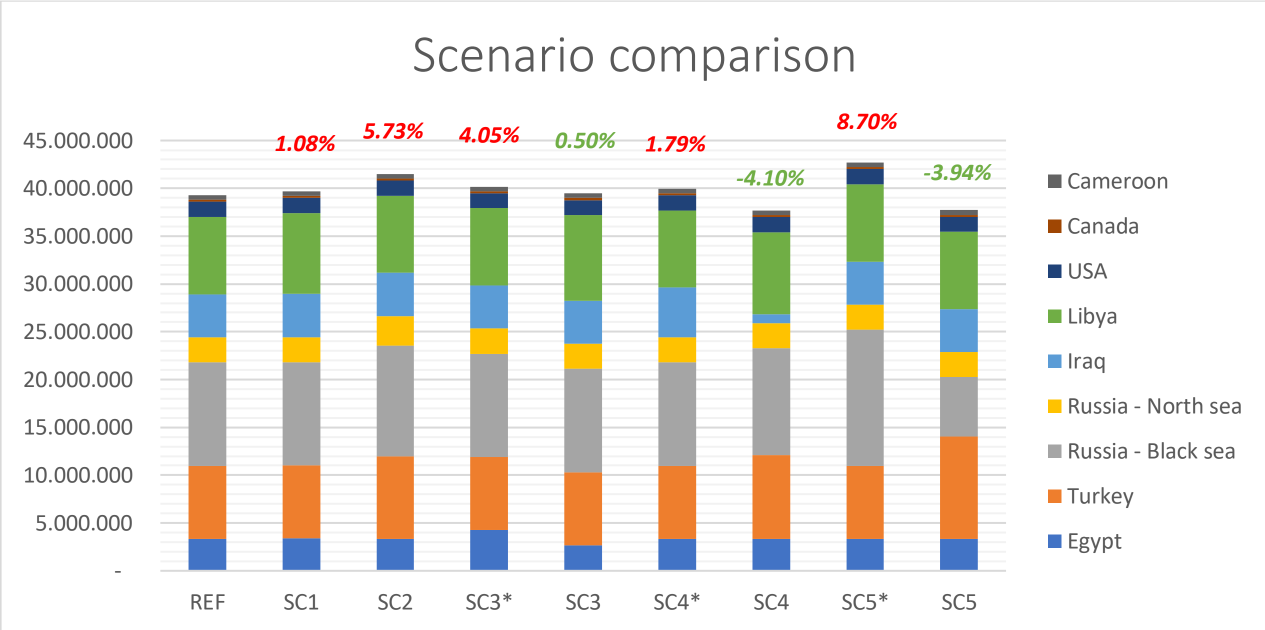


Figure 67: Comparison of alternative scenarios

5 Conclusions

According to statistics, oil still plays a crucial role in the Italian energy mix and therefore also in the national security. However, energy reliability cannot be considered independent of other factors such as socio-political interdependencies among supplier countries, complexity of energy market and physical characteristics of oil infrastructures. Indeed, there are many hazards that must be taken into high consideration such as geopolitical conflicts, commercial disputes, terrorist attacks and infrastructure failure. Furthermore, Italy as a net importer of crude, is strongly subjected to these threats; this fact makes a detailed assessment of energy security even more crucial in order ensure the national security. The thesis aimed at implementing an integrated science-based methodology in order to respond to this need. As a result, a risk assessment model has been developed and then applied to the Italian specific case. The performed quantitative evaluation of energy risk produced two different outcomes according to MiSE data and Alphatanker data. This is justified by the fact that often many oil producing countries rely on close load ports which export oil commodity to Italy: hence, there are few main ports which account for the major part of imported commodity. This unbalance lead to lower Shannon index according to Alphatanker data as opposed to MiSE which results in a quite good differentiation degree. However, for a complete assessment of oil diversification both of the Shannon indexes must be taken into account because one does not exclude the other. As for the Italian energy risk, the results show that Italy is characterized by an overall low security level since it imports the majority oil commodity from countries with high geopolitical risk index (e.g. Iraq, Turkey, Libya, Egypt, etc.).

To sum up, this thesis aimed to support Italian political decision making by developing a model able to assess the actual level of risk related to oil supply in terms of loss of energy which is easily comprehensible for policy decision makers. Actually, the true highlight of this model is that it can be applied not only for oil supply assessment but also for other kinds of commodity. In addition, this methodology can provide a realistic overview of the actual level of energy security but most importantly it can simulate both the impact of contingencies such as oil infrastructure disruption or corridor failure both the effect of short-term mitigative measurements. However, the level of detail and the reliability of results are deeply affected by the limited available information, especially about oil products, which forces to strong assumption and approximation such as energy flux sorting and grouping of similar routes.

In the future, to conclude, it could be interesting to optimize the developed mathematical expression with further economic indicators able to characterize and to model price fluctuations and its consequence in terms of energy risk; moreover, it would be worthwhile to implement a platform which periodically downloads data and automatically performs all calculations and finally displays results in an easy to understand way through pdf, thematic maps and graphs.

Appendix A: Glossary and definitions

Name	Symbol	Definition	Formula	Unit	Reference projects and source
Commodities	C	Set of energy commodities	$C = \{\ldots, c_c, \ldots\}$	-	Alphatanker, MISE
Corridors	I	Set of energy corridors	$I = \{\ldots, i_i, \ldots\}$	-	Alphatanker, PE, EWA
Countries	K	Set of countries: • Supplier countries • Countries crossed by corridors	$K = \{\ldots, k_k, \ldots\}$	-	Alphatanker, MISE
Ports	P	Set of ports: • discharge port • load port	$P = \{\ldots p_p \ldots\}$	-	Alphatanker
Voyages	V	Set of voyages	$V = \{\ldots, v_v \ldots\}$	-	Alphatanker
Maritime Routes	M	Set of maritime voyages	$M = \{\ldots, m_m \ldots\}$		Alphatanker
Chokepoints	C_p	Set of chokepoints	$C_p = \{\ldots, c_p \ldots\}$	-	AD-DE
Pipelines	P_p	Set of pipelines	$P_p = \{\ldots, p_p \ldots\}$		EWA
Refineries	R	Set of refineries	$R = \{\ldots, r_r \ldots\}$		DA-ED, UP
Sea Duration	D_m^c	Average sea duration of maritime route m associated to a commodity m	-	day	Alphatanker
Corridor Length	L_i	Overall length of a single corridor	-	km	GIS, Alphatanker,EWA
Branch Length	l_i	Length of a single branch	-	km	GIS, Alphatanker,EWA
Weighting factor	γ_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_m^c	Average vessel's filling percentage of commodity c associated to the maritime route m	$F_m^c = \frac{T_m^c}{DWT} * 100$	%	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	φ_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	η_k	Piracy index provided by "One Earth Future" in the publication "The state of maritime piracy"	-	-	One Earth Future
Maritime Geopolitical Risk	φ'_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	$\overline{\varphi'} = \frac{\sum \varphi'_k}{K}$	-	DA-ED
Probability of Failure of Maritime Route	ξ_{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	α_{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	ξ_{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	ξ_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	ω_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	Ω^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	Ω^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	$S^c = \sum_{i=1}^{I} S_i^c$ Where: ▪ 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	$R^c{}_n = R^c{}_{int} * w_1 + R^c{}_{ext} * w_2$ Where: $R^c{}_{int}$: overall internal risk related to: ▪ availability of national energy resources ▪ resilience to possible internal attacks against the infrastructures w_1= Weight coefficient for the internal risk 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.	$H = -\sum_i h_i^c * ln(h_i^c)$ $H = \frac{H}{\ln(Z)}$ Where ▪ 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 [44]:)

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, 21b, 21c,21d, 21e: Crude characterization by country (Source: Elaboration based on [11])

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 [11])

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 Italian crude suppliers (Source: Elaboration based on [19])

Imported crude per country, 2019 (UP)		
	[kton]	
Iraq	**12.615**	**20,0%**
Azerbaijan	**10.942**	**17,3%**
Russia	**9.095**	**14,4%**
Libya	**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 [11], [10])

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	
Libya	**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 [22])

NAME	LOCATION	TYPE	STATE	AUTHORIZED CAPACITY [10^6ton/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 [19])

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 (Ml)	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 (Ml)	16	ESSO
Trecate (NO) - Turbigo (Ml)	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 (Ml)	112	SIGEMI
Lacchiarella (Ml) - 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 [10]))

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

Appendix D: Geopolitical and maritime security assessment

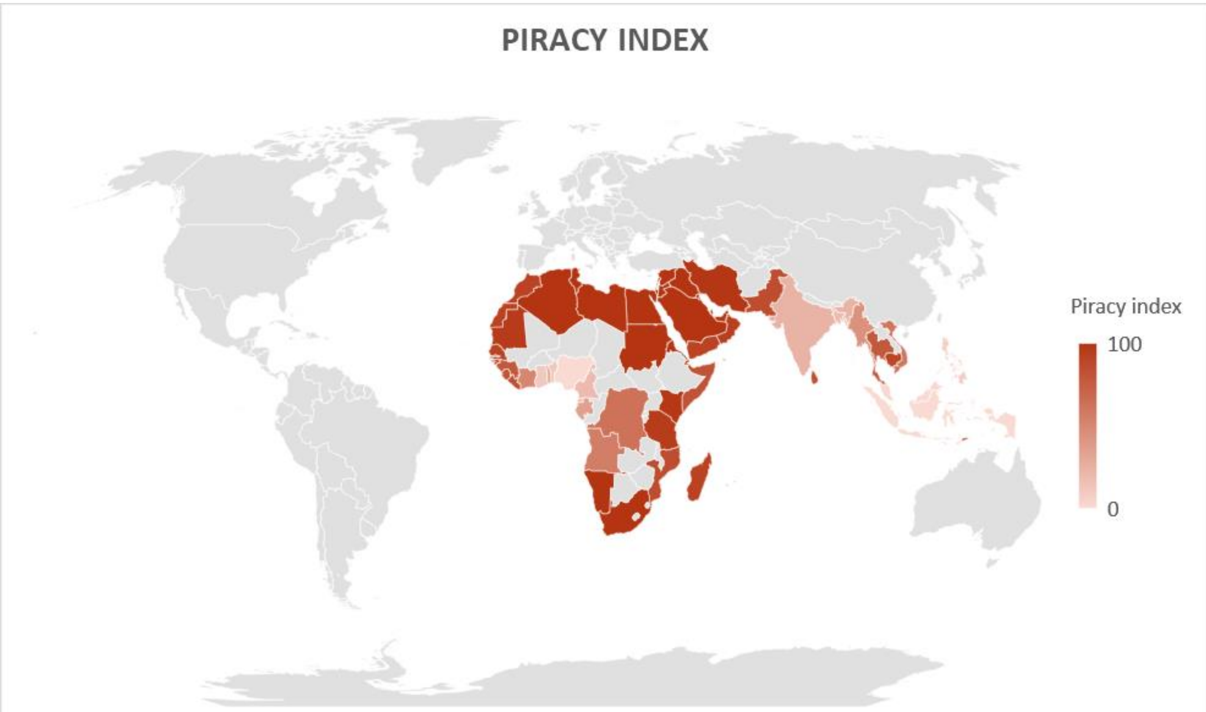


Figure 68: Piracy index distribution (Source: Elaboration based on [35])

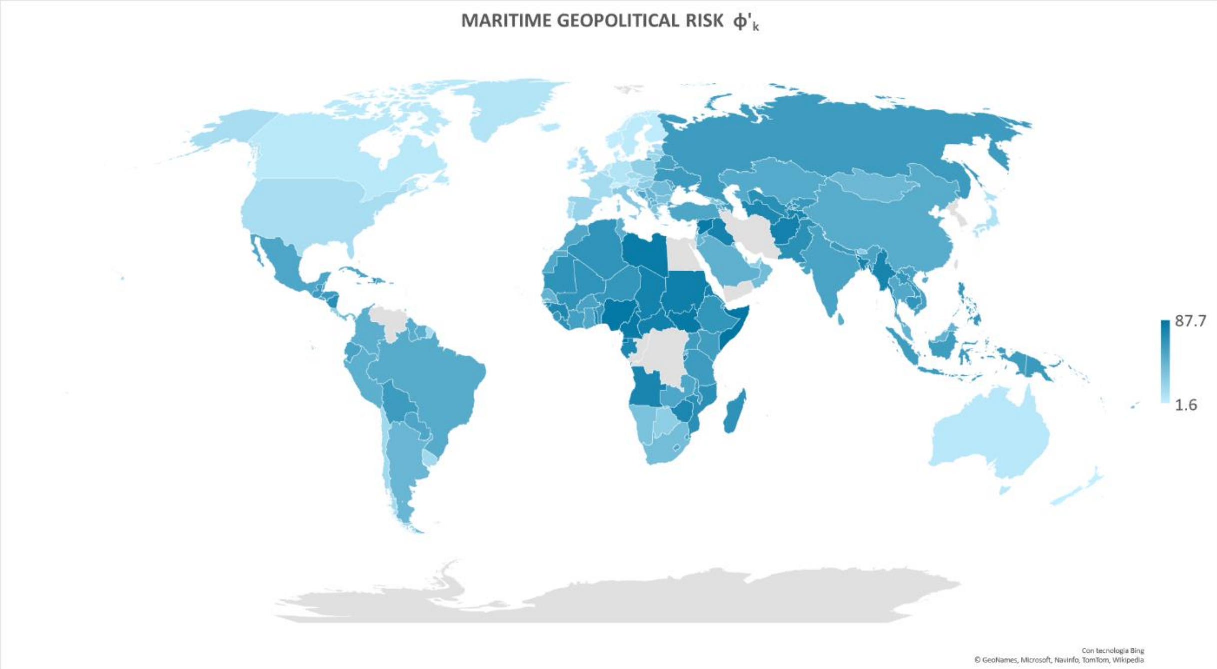


Figure 69: Maritime geopolitical risk index (Source: Elaboration based on [33], [35])

Table 31: Historical events of ship loss (Source: [39])

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	

Appendix E: Matlab code

```
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
```

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