NATIONAL ENERGY SECURITY ASSESSMENT IN A GEOPOLITICAL PERSPECTIVE

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Abstract

The possibility of ensuring the energy needed by a country is a fundamental requirement for the economic growth and social welfare of that country. The fulfillment of this need is particularly challenging for those countries that are characterized by a low level of energy self-sufficiency. The evaluation of energy security needs to consider different dimensions and is of the utmost importance as a benchmark to conceive and implement different policies. The assessment of the level of security should rely on science-based models that are able to track the rapidly evolving geopolitical scenarios, and to provide detailed information and quantitative indexes to policy decision makers. In this paper, an overarching methodology is outlined to evaluate energy security, in which its external and internal dimensions are considered and integrated: the security of the energy supply from abroad (external) and the security of national energy infrastructures (internal). Attention is then focused on the external dimension, and two indexes are defined, by means of a probabilistic approach, in terms of the expected value of supply and economic impacts. The methodology is then applied to the Italian case, considering different geopolitical scenarios, and conclusions are provided about the energy security of the country.

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1. INTRODUCTION

Energy security is a crucial issue for each and every country. It may be defined as the capability of ensuring the availability of different typologies of energy for the final uses, in the needed quantity, where requested, over short, mid and long time horizons. It is necessary to ensure access to the commodity sources, their transportation (using suitable corridors) to the country, the possible transformation into secondary commodities and its distribution inside the country itself, by means of appropriate infrastructures.

It should be underlined that – in general terms – the energy security of a country depends not only on the possibility of obtaining the needed amount of energy commodities by means of local production or by importing from abroad (supply side), but also on the flexibility in the end-use demand (demand side).

In countries characterised by a low self-sufficiency, such as Italy (24.1% in 2014), the security issues related to the acquisition of energy commodities, depending on geopolitical scenarios, is particularly critical. At the EU28 level, the energy self-sufficiency is about 46.5%. At the same time, the security of the internal transport/distribution of energy, related to the National infrastructures, is also relevant.

Thus, the evaluation of the level of energy risk, at a given point in time, and its evolution over a short time horizon, by means of science-based approaches, are crucial to define and improve defence and mitigation countermeasures. Instead, in the mid-long term, the analysis of the risk related to possible alternative scenarios allows strategical planning to be made in terms of new sources and new intra-national and infra-national infrastructures.

For these reasons, a methodological approach is proposed in this paper to assess, in a comprehensive way, the security of a country, through a quantification of the energy security, which is able to capture supply risks and provide the basis of a cost-benefit analysis.

The methodological contribution of this work is represented by the adaptation of the classical risk analysis approach, used in studies of industrial technologies and plants, to the analysis of the security of energy supply in a geopolitical perspective, and by the coupling of this new approach with a detailed characterisation of the energy corridors, which, in this way, makes it possible to take into account their spatial dimension and to embed it in the mathematical relationships defined to evaluate the risk parameter.

The risk indexes related to the single corridors and the overall national supply risk (both physical – in terms of energy losses – and economic) can thus be used to help support decision makers in assessing and ranking the criticalities of the energy system and in performing comparative scenario analyses of different strategical options that involve energy imports and infrastructures.

The relevance of the proposed approach, which links technical, geopolitical and economic considerations, lies in the fact that the energy supply of a country is affected by several aspects (economy, geopolitical relationships and security) that interact with each other and which need to be investigated in an integrated perspective. In particular, on one hand, the geopolitical situation can have a significant influence on the energy commodity costs, thus having an impact on the economy, and on the other can determine the county's level of energy supply security and have effects on the supply availability, which – in turn – again affects the economy.

The developed methodology is here illustrated with reference to the Italian situation.

The paper is structured as follows. The state of the art, related to the geopolitical risk indicators, is summarised in sec.2; the adopted methodological approach is described in sec.3; the results of an application to a case study, related to the energy supply to Italy, is presented in sec 4.

2. LITERATURE REVIEW OF ENERGY SECURITY INDICATORS

Over the last decade, the evaluation of the security and affordability of the energy supply has played an increasing role, and has been one of the main issues for policy makers, especially in high energy import dependent countries, like many of the European Union Member States, including Italy.

Several approaches have been proposed to quantify the level of security of supply to a country, most of which are based on the definition of numerical risk parameters that are able to take into account geopolitical aspects and/or country-dependent energy indicators. Kruyt et al. [1] performed a classification of some of the main energy indexes by distinguishing between ten simple indicators (including import dependency, reserve-to-production ratio and energy prices) and five aggregated indexes (i.e. the Oil Vulnerability Index (OVI), the Willingness to Pay Index, the IEA Energy Security Index (ESI), the Supply-Demand Index and the Shannon Index).

Referring to these five indexes, Gupta [2] evaluated an overall oil vulnerability index (OVI) that depends on the combination of seven indicators, related to oil supply and consumption and to the economic level of the receiving country (GDP per capita, oil import dependency, oil consumption per GDP unit). Bollen [3] based his study on a cost-benefit analysis, and this led to the definition of a "Willingness to Pay" function that measures the percentage of GDP that the analysed country is willing to pay in order to decrease its risk. IEA ESI [4] evaluated the effects of the supply market concentration on energy commodity prices, taking into account the geopolitical risk rating of the supply countries. Scheeepers et al. [5,6] analysed the Supply-Demand Index, defined on the basis of experts' judgement by means of scoring rules, and focused on the whole energy chain (including conversion, transport, supply and demand of energy in the mid-long term). The Shannon-Wiennier Index (SWI) [7], which quantifies diversification by taking into account the share of each commodity in the fuel mix composition, is also used to evaluate energy security. Martchamadol et al. [8] performed an analysis of the state of the art, in which several indicators were taken into account. Among these indicators, the following can be mentioned: the WEC Assessment Index (AI) [9], which evaluates energy security by means of five indicators (including net energy imports and diversification of the energy supply); the WEC Energy Sustainability Country Index (ESCI) [10], which is based on 22 indicators, including oil reserves, stock and energy security; the APERC study [11], which considers five indicators (such as the net import dependency, the net oil import dependency and the oil import dependency from Middle Eastern countries); the UNDESA Energy Indicators for Sustainable Development [12]; the Global Network on Energy for Sustainable Development (GNESD) indicator [13]. They also developed a new composite index, the Aggregated Energy Security Performance Indicator (AESPI) [8], which ranges between 0 (low security) and 10 (high security), and which is built using 25 indicators. These indicators are evaluated on the basis of the historical data series of the population, the GDP, the energy production, the net import and consumption, the power generation capacity, the transformation and transmission losses, and the coal, crude oil and natural gas emission factor values.

Most of the energy risk indicators are assumed steady over time. Apart from the above mentioned AESPI index, only a few other indexes, such as the Supply-Demand Index defined by Scheepers et al. and the Composite Indicator developed by Badea et al. [14], have taken into consideration a forecasted time evolution. These indicators were both based on energy projections from the PRIMES model, and are used by the European Commission to evaluate the EU Trends up to 2030 [15]. The study by Checchi et al. [16] also focused on the long-term evaluation of the security of energy supply, referring to the results of the PRIMES model, but it did not set any index to quantify this evaluation.

Among the indicators based on time series analyses, the International Index of Energy Security Risk (IIESR), set up by the U.S. Chamber of Commerce Institute for 21st Century Energy [17], allows the security level of 25 large consuming countries throughout the world to be compared on a yearly basis. This approach refers to the identification of eight index categories (including reserves and the production of oil, natural gas and coal, and energy imports). A set of 29 metrics was defined for each of these categories. The 1980-2012 time horizon was taken into account for all of the metrics; moreover, each of these metrics was normalised with reference to the 1980 OECD value. The normalised metrics were then weighted, using the International Weightings Index, which gives the percentage contribution of each category to the total, in order to calculate the overall IIESR value. Sovacool [18] defined an indicator for the evaluation of the energy security of a country, referring to the European Union, the United States, China, India, Japan, South Korea, Australia, New Zeeland and ten countries belonging to the Association of Southeast Asian Nations (ASEAN). For this purpose, five fundamental dimensions of energy security were identified (availability, reliability, technological development, sustainability and regulations). In turn, these dimensions were subdivided into 20 components, each of which was related to a metric. Frondel et al. [19,20,21] proposed and implemented a methodology aimed at classifying countries (in particular those belonging to the G7) on the basis of the risk level related to the primary energy commodity supply in the mid-long term; the authors defined, for each commodity, a risk indicator expressed as a function of the probability of commodity flow disruption for the various exporting countries, and of the square value of the percentage contribution given by each exporting country and by the local production to the energy demand fulfilment in the analysed country. In turn, the supply unavailability for a certain country was evaluated on the basis of considerations associated with the geopolitical situation and economic stability, while the share values for the exporting countries were correlated to the Herfindahl index [22], which measures the import concentration for a specific commodity.

Guivarch et al. [23] analysed the possible evolution of energy security in Europe from a decarbonisation perspective, by taking into account the time evolution of a set of indicators (based on the concepts of resilience, robustness and sovereignty) in the case of different scenarios. A study focusing on the impacts of alternative climate mitigation policy scenarios on South Korea, Japan and China was instead performed by Matsumoto et al. [24] by means of a computable general equilibrium model.

Valdés Lucas et al. [25] explored, over a long-term time horizon, the correlation between the deployment of renewables and energy security, considering several indicators related to three energy policy dimensions: competitiveness, security of supply and environment.

Biresselioglu et al. [26] considered natural gas supply security and the evolution of different indicators (including the number of supply countries, the total volume of gas imported and the fragility of supply countries over the 2001-2013 period in order to build a Supply Security Index (SSI) through an application of the Principal Component Analysis (PCA) technique. Another study – carried out by Flouri et al. [27] – focused on natural gas, and was devoted to exploring, using a Monte Carlo simulation approach, how a disruption in the natural gas supply from Algeria, for geopolitical reasons, could affect the natural gas supply security of the EU: this analysis in particular highlighted the relevant role played by the diversification of suppliers in increasing energy security.

Kisel et al. [28] described the different methods and indicators that are adopted to assess energy security and to delineate energy policies, and they proposed an Energy Security Matrix that is able to organise the most significant indicators in a structured way from the point of view of operational and technical resilience, technical vulnerability, economic dependence and political affectability in different sectors.

Among the other studies that have focused on the relevance of the geopolitical element in the evaluation of the risk related to the energy supply, those carried out by Correlje and van der Linde [29], Costantini et al. [30], Hedenus [31] and Umbach [32] can be mentioned. The FP-7 European project "Risk of Energy Availability: Common Corridors for Europe Supply Security" (REACCESS) [33] developed tools that can be used to conduct a quantitative assessment of the geopolitical risk for scenario analyses. In this project – characterized by the link between three forecasting TIMES-based [34] optimisation energy models – a risk index (steady over time and ranging between 0 and 100) was defined for all the commodity source countries and for all the countries crossed by the above mentioned corridors. This index is a function of the socio-political, energetic, political-institutional and economic security level of the country, and it was calculated by means of factor analysis techniques (Marín-Quemada et al. [35,36,37]). During the follow-up phase of the project, these indexes were combined, through an application of the reliability theory, in order to define a single risk index for each corridor; for this purpose, the risk index related to each crossed country was assumed as the probability that a corridor crossing that country would fail (Gerboni et al. [38]). Furthermore, starting from the same risk indexes per country, Doukas et al. [39] developed a web-based tool for the analysis of the natural gas and oil corridors, and they tested it by means of a case study focused on the Greek energy supply. Using the same approach (based on the factor analysis), Muñoz et al. [40] defined the country composite indicator GESRI (Geopolitical Energy Supply Risk Index), which – unlike the one proposed by Marín-Quemada et al. – combines the social and political dimensions in a single risk vector and introduces a new vector that describes the relations between the exporting and transit countries with the EU-27. Finally, in the framework of the REACCESS project, Carpignano et al. [41] proposed a methodological approach to evaluate the technological risk and the loss of production caused by corridor failures, and included these parameters among those used to analyse optimal scenarios for the EU energy supply.

3. INDICATORS FOR NATIONAL ENERGY SECURITY ASSESSMENT

The overall energy security of a country depends on two different "fronts". The first is "internal" and is related to: a) the quantification of the highest or lowest availability of national resources for each considered primary energy commodity (natural gas, oil, coal); b) resilience to possible internal attacks against the infrastructures (distribution networks) or transformation plants (refineries, regasification terminals, etc.).

The second is "external" and includes: a) the geopolitical security of the commodity source country; b) the security of the infrastructures up to the national entry point, taking into consideration the route of the energy corridors (open sea or captive) and the risk indexes associated with each crossed country; c) the possible effects on imports due to the unavailability (at different temporal scales) of the above mentioned infrastructures.

A security index can be conceived for each of these "fronts", and the combination of the two provides the overall assessment of the national security of the Country.

The nomenclature of the main indexes and parameters is given in Table 2. Generally speaking, the internal risk can be expressed as a function of the resilience of the transmission/distribution infrastructure:

$$R_{int} = f(\vartheta_{c,d})$$

Assuming $\vartheta_{c,d}$ as the Resilience index, which is used to quantify the resilience of the internal distribution/transmission network d_d for commodity c_c. This index has been disregarded in this paper and attention has been focused on the external one.

The proposed index for the external risk is a weighted function of the contribution given by the risk indexes associated with the source and crossed countries, and of the energy content of the commodity imported through each corridor.

An index $\varphi_k \in [0,100]$, which is mainly related to the geopolitical situation, has been associated to each country to quantify the criticality of that country; this index is estimated as described in sec. 2 and can continuously be tracked and updated over time.

A corridor i is defined as:

$$\forall i_i \in \mathcal{J} : i_i = \{c_c, l_l, \mathcal{K}_i\} \mid c=l=i,$$

corridor $i_i \in \mathcal{J}$ is defined by a length $l_i \in \mathcal{L}$, a commodity $c_i \in \mathcal{C}_i$, a set of crossed countries $\mathcal{K}^i$ with $\mathcal{k}^i_i \in \mathcal{K}^i$, the country of origin, $dim(\mathcal{K}^i) = K_i$ the number of countries crossed.

A risk index ξ'_i is defined for each corridor i_i and its probability of failure is identified [38]:

$$\xi'_i = 100 \cdot \left[1 - \prod_{\mathcal{k}_i \in \mathcal{K}_i} \left(1 - \frac{\varphi_k}{100}\right)\right] \quad (1)$$

In (1):

$\left(1 - \frac{\varphi_k}{100}\right)$ is the probability of success of crossing country k,

$\prod_{\mathcal{k}_i \in \mathcal{K}_i} \left(1 - \frac{\varphi_k}{100}\right)$ is the probability (of independent events) of success of crossing all the countries involved along the corridor route,

$1 - \prod_{\mathcal{k}_i \in \mathcal{K}_i} \left(1 - \frac{\varphi_k}{100}\right)$ is the probability of failure for the entire corridor, and it is expressed as the complement of the probability of success.

Corridors are composed of different branches in different countries; each segment has a different length; a "spatial dimension" in the exposure to risk is assumed, in the sense that, given a φ_k index for a country, its contribution to the overall risk of the corridor would be proportional to the length of the segment of the corridor in that country.
The total length l_i of corridor i_i is given by the sum of the length of the branches of the corridor in the crossed countries:

$$l_i = \|B^i\|_1$$

An empirical weighting function γ_k is introduced into (1) in order to incorporate this aspect:

$$\xi_i = 100 \cdot \left[1 - \prod\nolimits_{k_i \in \mathcal{K}_i} \left(1 - \frac{\gamma_k \cdot \varphi_k}{100}\right)\right] \tag{2}$$

The assumed values of γ_k are reported in Tab. 1 as a function of the ratio between the real length of the corridor branch, b_b, and the average length of the corridor branches $\bar{b}_i$ (3).

$$\bar{b}_i = \frac{l_i}{K_i} \tag{3}$$

Open sea routes and submarine pipelines, territorial waters and international waters are all involved in the risk assessment of the corridor. In order to avoid an underestimation of the risk related to maritime routes, in comparison to the one related to terrestrial corridors, a zone of influence is defined for each country, and a portion of the international waters is also covered, to which the same index φ_k as the country is provided.
The risk, R_i, associated to corridor i_i, is defined as the product between the probability of failure ξ_i and the damage, in terms of loss of energy $E_{c,i}$, associated to a commodity c_c:

$$R_i = \sum_{c_i \in \mathcal{C}_i} \frac{\xi_i}{100} \cdot E_{c,i} \tag{4}$$

The overall external risk, for all the corridors supplying the given country, is:

$$R_{ext} = \sum_{i_i \in \mathcal{J}} R_i \tag{5}$$

As far as time granularity is concerned, the analyses can be carried out considering different time scales (year, quarter, months,..). A higher time discretization, such as a monthly analysis, would allow specific criticalities, such as those related to the natural gas supply during winter months, to be highlighted.
The risk in (5) can be converted into equivalent monetary units though the national *energy intensity of the economy Q* (*TJ/G€*), which is defined as the ratio between the gross internal energy consumption (TJ) and the Gross Domestic Product (GDP, G€):

$$R_{int,m} = \frac{R_{int}}{Q} \tag{6}$$

$$R_{ext,m} = \frac{R_{ext}}{Q} \tag{7}$$

This conversion is useful to evaluate the economic impact of the geopolitical energy risk, because a possible loss of energy, due to the unavailability of an energy supply, causes a loss of GDP [42].
The sum of the two indicators, weighted using two coefficients, w_1 and w_2, allows the *National Energy Security Index* R_n to be defined (Fig.1):

$$R_n = w_1 \cdot R_{int} + w_2 \cdot R_{ext} \tag{8}$$

where w_1 and w_2 are defined on the basis of the percentage import dependency χ:

$$w_1 = 1 - \chi \tag{9}$$

$$w_2 = \chi \tag{10}$$

The above described methodology is able to highlight any possible criticalities related to the fulfilment of the national requirement in the case of geopolitical issues that affect the supply and/or the transport/distribution of energy to end-users.
Focusing on the external dimension of security, it is possible to define the “expected supply”. The probability of success (availability) of each corridor is:

$$\omega_i = 100 \cdot \left[\prod_{k_i \in \mathcal{K}_i} \left(1 - \frac{\gamma_k \cdot \varphi_k}{100} \right) \right] \tag{11}$$

The expected supply value S_i for corridor i_i is the product of ω_i and the energy flow $E_{c,i}$ of the commodity c_c carried by the corridor:

$$S_i = \sum_{c_i \in \mathcal{C}_i} \frac{\omega_i}{100} \cdot E_{c,i} \tag{12}$$

The total expected supply S_{ext} (TJ) can be evaluated as:

$$S_{ext} = \sum_{i_i \in \mathcal{J}} S_i \tag{13}$$

The expected supply corresponds to the difference between the total supply, in energy terms *E*, and the overall external risk R_{ext}:

$$S_{ext} = E - R_{ext} \tag{14}$$

The adopted approach assumes that the events are independent, and offers a conservative overestimation of the risk.

Finally, it should be highlighted that the error analysis in the proposed modelling approach on the main parameters (such as energy flows, or corridor branch lengths) is not particularly relevant in comparison with the need to understand whether a certain event could happen or not. The aim of the adopted procedure is to associate a certain probability value to the single countries, which is able to describe the likelihood that a certain supply corridor crossing them fails due to geopolitical reasons, and is not to perform forecasting analyses on unpredictable events. Naturally, disruptive geopolitical events can suddenly occur, and these could significantly modify the probability value of the countries. For this reason, sensitivity analyses on the country risk index parameter are useful to evaluate the effects of such events on the global energy risk. Furthermore, when defining sensitivity scenarios, it could be appropriate to consider that a geopolitical event in a certain country can also affect other countries in the same geographical area, and as a result in some cases the geopolitical risk level should be considered jointly, and in the same way modified for the whole set of countries belonging to the same area. This could be particularly relevant for zones like the Middle-East and North-Africa (some examples are those of the so-called “Arab Spring” and the penetration of terroristic groups in these areas).

4. CASE STUDY: THE EXTERNAL SUPPLY TO ITALY

4.1 Definition of the scenarios

The proposed methodology has been applied to the security analysis of the Italian national energy supply. The contribution to the risk given by the internal component R_{int} has been neglected, and the analysis has only focused on the evaluation of the R_{ext} parameter.
A total of 263 corridors (pipelines, ships, railways, roads, power lines), carrying 6 commodities (coal, crude oil, refined petroleum products, natural gas, LNG, electricity) and accounting for 97.5% of the Italian energy inflows in 2014 have been considered [43,44]. Country risk indexes have been assumed on the basis of the FP-7 REACCESS ([35], [36], [37], [38]) project (Fig. 2, Tab. 3).

Italian energy security has been assessed against five possible adverse scenarios. The scenarios are characterized by two different types of situation; in the first, the criticality of the country is increased due to a deterioration of the geopolitical situation in the area (modelled by an increase in the geopolitical country index), while in the second the situation, the country causes actions that provide the actual failure of a corridor.
Five scenarios (*S1*-*S5*) have been taken into account (Tab. 4):
S1) Increased activity of terroristic groups in North Africa (Algeria, Egypt, Libya and Tunisia);
S2) Deterioration of the Italian/Qatari diplomatic relations, with cuts in gas/oil exports to Italy;
S3) Antagonistic actions in Libya with disruption of the Greenstream gas pipeline;

S4) Increase in the contrast between Russia and the Ukraine, with a country risk increase and disruption of the NG and oil corridors from Russia across the Ukraine;
S5) The simultaneous occurrence of S1 and S4.

4.2 Energy security analysis for different scenarios

The impact of the considered scenarios has been assessed, considering the energy risk R_{ee} and economic risk R_{em} values (Tab. 5) and they have been compared with the values related to the year 2014 (Reference situation, *REF*: corresponding to the actual configuration of flows, corridors and suppliers) with the Country indexes reported in Tab. 3. In Tab. 6, the indexes have been computed considering only the natural gas supply, which accounts for 33% of the Italian energy inflows in 2014.

S1 shows an increase, of about 3%, in both R_{ee} and R_{em}, mostly due to the large number of corridors (79, 30% of the total) that are affected by the increase in geopolitical risk in the four countries; their average risk index for corridor ξ increases by 17.6%, in comparison with the Reference, while the overall value of ξ increases by 5.4%.
In Tab. 7, the analysis is undertaken on a monthly time basis; both risk indexes, in this case, have a peak increase in September, due to an increase in the flow exported by the countries involved in *S1,* in comparison with the one exported by countries that do not undergo changes. An increase in the risk can be observed for *S1* but, due to the absence of actual disruptions, the inflows are still there.

S2 shows a criticality related to the LNG supply (the LNG supply from Qatar in 2014 was equal to 172.8 PJ/y). By setting the corridor risk to 100% (i.e. full unavailability and expected supply = 0) for all the Qatari corridors, the overall risk increases by 2.46%: this variation is due to the natural gas corridors (whose contribution to the total risk increases by 5.79%, in comparison with the reference case).

S3 shows an increase of 3.52% in the overall risk caused by the disruption of the Greenstream NG corridor (ξ = 100%). This unavailability has a relevant effect on the NG risk, which increases by 8.27%. Furthermore, the amount of energy lost in the case of a disruption of the Greenstream pipeline cannot be replaced by the same amount imported as LNG from the same supplier, because the only Libyan LNG terminal (i.e. the one located in Marsa al-Brega) is presently out of service and has been since 2011, as it was damaged during the civil war.

S4 involves the whole Italian natural gas import from Russia (corresponding to 48.82% of the total natural gas import) and 3% of the crude oil import (one corridor). This situation has a particular impact on the overall risk, as it causes an increase of 8.68% (which reaches 16.33% for the risk contribution only related to the natural gas supply). This effect is prevalently due to the high level of import dependency on Russia: as a consequence, this can be a significant example of the importance of supply diversification (in terms of energy sources, supply countries and corridors), in order to avoid such criticalities and enhance the security level of a Country.

S5 combines the effects of *S1* and *S4*. This situation is extremely risky because it affects 46.1% of the total Italian energy supply, and it leads to a critical situation, especially for natural gas supply, as more than 70% of the imported flux is involved; the percentage of oil, RPP and coal imports involved is lower, but is significant, as it ranges between 20% and 50%. The overall energy risk increases by 11.7%, above all due to the specific risk contribution of natural gas (+20.4%). This relevant growth is justified by the fact that seven suppliers (Russia, the Ukraine, Algeria, Libya, Egypt, Tunisia and Nigeria) and 98 corridors undergo changes. In particular, the average ξ increases by 17.5%, in comparison with the Reference case.

4.3 Mitigation actions

If a scenario leads to a loss of energy flow (*S2-S5*), specific countermeasures have to be planned and implemented to ensure the needed supply. Some of the possible mitigation options have been tested using the here presented model, their feasibility has been analysed and their effects have been compared in terms of risk reduction, in comparison with the related scenario. For *S2*, the following options were considered:

MA1-S2) *Replacement of the Qatari LNG flow with a flow from Algeria (50%, Transmed pipeline;) and Russia (50%, TAG pipeline).*
This configuration – which is coherent with the maximum capacities at the national entry points – allows the needed annual quantity of natural gas to be ensured with a risk reduction of 1.21%, in comparison with *S2*.

MA2-S2) *Replacement of the Qatari LNG flow with a flow from Norway (25%, Transitgas pipeline), the Netherlands (25%, Transitgas pipeline) and Russia (50%, TAG pipeline).*
In this case, the reduction in the overall risk is lower than the one obtained from *MA1-S2* (and equal to 2.10%), due to the low risk level of the two European countries.

MA3-S2) *Replacement of the Qatari LNG flow with a flow from the UAE (100%, LNG to regasification terminals located near Panigaglia and Porto Levante).*
The resulting overall risk reduction is close to the one obtained for *MA2-S2* (-2.39% vs. – 2.10%). The obtained configuration is similar to the reference one, due to the fact that the country indexes for Qatar (38.5) and the UAE (39.4), and the ship route to deliver LNG to Italy, are comparable.
The effects of the mitigation actions are reported in Tab. 8.

For *S3*, two mitigation actions were identified:

MA1-S3) Replacement of the Libyan NG flow with a flow from Algeria (50%, Transmed pipeline) and Nigeria (50%: 25% Transmed pipeline; 25% LNG).
The risk reduces by 1.56%, in comparison with the *S3* scenario. It should be noticed that the ξ associated to these corridors is higher that the Greenstream one: this is not due to the source country indexes (as they are similar to the Libyan one for both Algeria and Nigeria), but – and particularly for Nigeria – to the high number of countries that are crossed.

MA2-S3) Replacement of the Libyan NG flow with a flow from the UAE (50%, LNG) and Qatar (50%, LNG).
The resulting risk reduces by 3.49%. This option allows only maritime routes, which are more flexible and therefore more effective from the security point of view, to be used.

The missing flow cannot be replaced entirely by European Countries (Norway and the Netherlands) as the required capacity is higher than the maximum one for the Transitgas corridor, which should be involved in this case.
The effects of the mitigation actions are reported in Tab. 9.

For *S4*, two mitigation options are defined:

MA1-S4) Replacement of the Russian crude oil flow with a flow from Kazakhstan (50%) and Azerbaijan (50%); replacement of the Russian NG flow with a flow from Algeria (30%), Nigeria (30%), the Netherlands (10%), Norway (10%), Libya (7%), Qatar (7%) and the UAE (6%), i.e. from all the other countries that supply Italy, according to the maximum capacity of the pipelines.
In this way, the overall risk decreases by 9.88%: this is mostly due to the decrease in the risk related to natural gas (-21%).

MA2-S4) Replacement of the Russian crude oil flow with a flow from the Russian corridors that do not cross the Ukraine; replacement of the Russian NG flows as in MA1-S4.
The results show a reduction in the overall risk index of -10.08%, which is comparable with the one obtained in *MA2-S3*. As in *MA2-S3*, this reduction is mostly related to the diversification of the NG supply.

The possible evolution of the corridors can provide additional possibilities, in terms of mitigation effects. The supply from Russia through different corridors (whose routes do not cross the Ukraine), mainly depends on future strategies related to the possible new pipelines that could be built. One of these alternatives could be represented by the South Stream project, even though this solution does not currently seem feasible. In fact, the South Stream project (a pipeline of a total length of about 2380 km, of which 931 will be offshore through the Black Sea, from Russia to Bulgaria, with a capacity of 63 bcm/y) was declared, at the end of 2013, not to be compliant with the EU Third Energy Package regulations [45], which introduced incompatibility between producers and TSOs (thus affecting the role played by the Russian natural gas production and distribution company Gazprom); furthermore, this decision has to be contextualized in a more general framework of geopolitical tensions between the EU and Russia, caused by the economic sanctions imposed after the Crimea crisis. After the declared abandon of the South Stream project by Russia, the alternative Turkish Stream (or TurkStream) project was proposed. This pipeline – originally expected to have the same capacity as the South Stream one – should run from Russia to Turkey and cross the Black Sea (with a subsea branch of about 900 km) and to deliver 31.5 bcm/y; the construction is planned to start in 2017 and to be completed by 2019. According to the most recent information available, Russia could build an additional line to connect Turkey to Greece, thus allowing Europe to be supplied (15.75 bcm/y to Turkey, 15.75 bcm/y to Europe). Among all the possible options, an interconnection between the Turkish Stream and the Trans Adriatic Pipeline (TAP) can be mentioned. The TAP pipeline infrastructure is presently under construction (with a length of 878 km, an initial capacity equal to 10 bcm/y and a planned maximum capacity of 20 bcm/y). It runs from Greece to Italy and will be connected to the Trans Anatolian Pipeline (TANAP) – as part of the Southern Gas Corridor (SGC) – in order to carry natural gas from the Azeri field of Shah Deniz to Europe. The construction of the TAP pipeline, and in particular the possibility of linking it to the Turkish Stream, could be relevant for Italy, as this situation could allow it to become a European hub for natural gas imported from Azerbaijan and Russia. As far as the security point of view is concerned, in 2014 (the reference year of the case study), Italy's overall natural gas import was equal to 55.78 bcm, of which 26.15 bcm came from Russia (46.9%). In the long term, hypothesising that the TAP pipeline could reach its maximum capacity, if the gas import remains constant, this corridor could impact on the supply for about 36%. By considering the latest data made available by the Italian Ministry of Economic Development and referring to 2015 [46], an increase in the overall imports can be

observed of up to 61.20 bcm; furthermore, if the historical trends are analysed, it can be noticed that the 2014 gas import value is significantly lower than the average import related to the last 12 years (69.27 bcm, with a peak of 77.40 bcm in 2006). These observations, coupled with the constantly decreasing trend of local gas production (which accounted for 11.5% of the Gross Inland Consumption in 2014), have lead us to suppose that the import of natural gas in 2020 (the planned year for starting the TAP pipeline) could be higher than the present one. However, it can reasonably be expected that it will be lower than 80 bcm/y: in this case, the contribution of the TAP will range from 12.5% (starting capacity = 10 bcm/y) to 25% (expansion up to the maximum capacity = 20 bcm/y). Focusing on the risk indexes (Tab. 3), it is possible to notice that the country risk index related to Azerbaijan is higher than that of Russia (43.9 vs. 34.0), and that the corridor route of the TAP pipeline (which crosses Azerbaijan, Armenia, Turkey, Greece and Albania) cannot be considered "safer" than the TAG pipeline one (which crosses Russia, the Ukraine, Slovak and Austria). For these reasons, it is possible to conclude that the TAP corridor would probably not reduce the absolute value of the supply risk, but it could be useful to increase diversification of the supply, and it could also offer a relevant alternative that could help in the case of geopolitical tensions between Russia and the Ukraine.
Other options, such as the use of the Yamal pipeline, cannot be considered, because of the constraint on the maximum capacity at the entry point, which is located in Passo Gries.
The effects of the mitigation actions are reported in Tab. 10.

For *S5*, flows from Russia and crossing the Ukraine (3 gas corridors and 1 oil corridor) have to be supplied in another way (as in S4), while this is not compulsory for those from North Africa (but could be recommended because of the high risk in comparison with the Reference scenario, due to hypothesised increase in the activity of terroristic groups). If the Russian flows are replaced in such a way as to avoid the North African corridors, it can be seen that several alternative options are available for oil import: ship transportation could be used (with the oil still coming from Russia) or the supplier could be changed (Caucasian countries, North and South America). As far as natural gas is concerned, if the supply from North African countries is avoided, only 60% of the flow that has to be replaced can be provided without overcoming the maximum capacity of the national entry points. As a consequence, with the current configuration of infrastructures, suppliers and corridors, the problem cannot be solved. In order to overcome this issue, some important changes have to be considered, including improvements of the infrastructures (new regasification plants or new pipelines) and the increase in the diversification of suppliers.

The approach described in sec. 3 and the case study analysed in sec. 4 are proposed from a single country perspective. However, the methodology could be applied at different scales (country, region, macro-areas). In fact, it could be useful to explore the energy security issues, especially for developing countries like China or India (for example, mention can be made to the studies performed by Jiang-Bo et al. [47] – which focus on the historical evolution of Chinese energy supply security, considering four dimensions and seven indexes – and the one carried out by Bambawale et al. [48], which was based on the analysis of Indian energy security from different perspectives), which are characterised by a relevant energy consumption growth rate, and for countries that show a relevant import dependency.
As far as the latter ones are concerned, Asian countries, like Japan and South Korea, can be mentioned. The overall Japanese energy import dependency in 2014 was equal to 93.5%, with relevant values for natural gas (97.6%) and crude oil (99.7%), while for South Korea, the import dependency in 2014 was equal to 82.8% (99.3% for natural gas and 99.5% for crude oil) [49]. Some European Countries are also affected to a great extent by this issue [50]: among the most populated ones, the dependency level of Italy is significantly high, but the situation of smaller countries, such as the Baltic ones, should also be highlighted, due to the fact that, since their independence and up to recent years, they have depended completely on a single supplier (Russia) [51].

5. CONCLUSIONS

The proposed methodology (and the implemented tool) can provide a quantitative assessment of the energy security of a country in a geopolitical perspective. The methodology, implemented and tested with reference to the Italian case, has proved to be effective in supporting policy decision making in the short, mid and long term.
This methodology allows a comprehensive representation of the inflow of a country, the assessment of its geopolitical risk and a cost benefit analysis, which is useful to compare different strategic options, to be obtained; a) in the short-mid-term, to allocate efforts with the aim of protecting a given corridor b) in the mid/long term, to plan and activate new supply options and corridors.
In addition, this methodology provides an effective way of designing mitigation countermeasures in the presence of an increase in the geopolitical risk or of adverse events, which could causing a certain percentage of the needed supply to become unavailable; it allows their effectiveness to be compared, and the related economic impacts to be assessed in terms of reduction in GDP loss.
With reference to the case of the Italian external supply, the analysis of the considered scenarios has highlighted the relevant role played by diversification in reducing the overall external risk. In a low self-sufficient country, the spatial dimension of energy corridors (the routes, lengths and the geopolitical security of the crossed countries) significantly affects the risk value. Moreover, in a strategic perspective, as natural gas is the most "risky" commodity, investments in

new LNG connections and terminals, or to increase the capacity of existing ones, could be beneficial from the security point of view.

Investments in preventive actions against terroristic attacks against sensitive targets, such as pipelines, for example, the Greenstream corridor, could also lead to significant benefits from an economic point of view, as they could prevent the loss of a relevant amount of the GDP as the consequence of the sudden unavailability of an energy supply.

The examined scenarios are related to the current energy system. From a more general perspective, the need to take into account climate changes, and to introduce adequate policies and countermeasures could have an effect on energy security [52] and lead to a new paradigm, based on a strong decarbonisation of the energy system and on the relevant role that renewables could play. According to this approach, among the future energy scenarios, the one that considers electrical UHV super-grids at a global scale, which would be able to transport electricity generated from renewable sources, such as wind and solar, from large production areas (the North Pole and African desert zones, respectively) to large consumption areas (such as the U.S.A., Asia and Europe), thus shifting the end-use energy consumptions from fossil fuels to cleanly produced electricity, can be mentioned [53]. Such a configuration could lead to an evolution in energy security, and could radically change the overall situation. The methodological approach described in this paper to evaluate supply security could also be adopted in future works to analyse these possible future scenarios and to compare them with other more traditional ones.

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TABLES

Table 1: Weighting function γ_k

$b_b/\bar{b}_i$	γ_k
0-0.2	0.90
0.2-0.5	0.93
0.5-0.9	0.96
0.9-1.1	1.00
1.1-1.5	1.04
1.5-2.0	1.07
>2.0	1.10

Table 2: Nomenclature

Set / Parameter	Description
$\mathcal{C} = \{\ldots, c_{c,} \ldots\}, dim(\mathcal{C}) = C$	Set of energy commodities
$\mathcal{J} = \{\ldots, i_{i,} \ldots\}, dim(\mathcal{J}) = I$	Set of energy corridors
$\mathcal{C}_i \subseteq \mathcal{C} \mid c_i \in \mathcal{C}_i$	Commodity delivered by corridor i_i
$\mathcal{K} = \{\ldots, k_{k,} \ldots\}, dim(\mathcal{K}) = K$	Set of countries (both source and corridor)
$\mathcal{K}^i \subseteq \mathcal{K} \mid \mathscr{k}^i_h \in \mathcal{K}^i$	Country crossed by corridor i_i
$\mathcal{L} = \{\ldots, l_{l,,} \ldots\}, dim(\mathcal{L}) = L = I$	Set of corridor lengths (km)
$\mathrm{B}^i = \{\ldots, b_{b,,} \ldots\}, dim(\mathrm{B}) = B^i,$	Set of the lengths of branches of corridor i_i
$\mathcal{D} = \{\ldots, d_{d,} \ldots\}, dim(\mathcal{D}) = D$	Set of distribution / transmission infrastructures
γ_k	Geopolitical country index weight for Country *k*, depending on the length of each corridor branch
$\vartheta_{c,d}$	Resilience index for the internal distribution network *d* carrying commodity *c*
ξ_i	Risk index of corridor *i*
φ_k	Geopolitical country index for country *k*
χ	Import dependency (%)
ω_i	Probability of success of corridor *i*
Q	Energy Intensity of the Economy
w_1	Weight coefficient for the internal risk
w_2	Weight coefficient for the external risk
R_i	Risk of corridor *i*
$R_{int\ (ext)}$	Overall internal (external) risk value
$R_{int\ (ext),m}$	Overall internal (external) risk, monetary units
S_i	Expected supply of corridor *i*
$S_{int\ (ext)}$	Overall internal (external) expected supply
E	Total energy supply
$E_{c,i}$	Energy flow of commodity *c* carried by corridor *i*
R_n	National Energy Security Index

Table 3: Geopolitical country index φ_k

Source Country	φ	Source Country	φ
Algeria	44.7	Mexico	31.7
Angola	61.7	the Netherlands	10.5
Australia	12.5	Nigeria	48.0
Austria	22.0	Norway	0.4
Azerbaijan	43.9	Qatar	44.2
Belgium	25.8	Russia	34.0
Canada	9.9	Saudi Arabia	47.9
China	44.1	Slovenia	28.7
Colombia	39.9	South Africa	36.1
Congo	55.0	Spain	24.1
Egypt	47.0	Switzerland	22.8
France	23.0	Syria	52.5
Gabon	44.5	Thailand	40.1
Germany	12.3	Tunisia	44.7
Ghana	52.7	Turkey	41.8
Greece	30.2	Turkmenistan	52.3
India	38.3	the Ukraine	35.9
Indonesia	46.0	the UAE	43.1
Iran	50.4	the USA	5.9
Iraq	67.9	Venezuela	39.9
Kazakhstan	38.3		
Kuwait	38.5		
Libya	47.5		

Table 4: Scenarios for the energy security analysis

S	Description	Country risk φ_k	Corridor disruption
S1	Increased activity of terroristic groups in NA	+15% Algeria, Egypt, Libya, Tunisia	-
S2	Deterioration of the Italian/Qatari relations	-	Unavailability of all the Qatari LNG corridors (4)
S3	Antagonistic actions in Libya	-	Disruption of the NG Greenstream corridor (1)
S4	Increase in contrast between Russia and the Ukraine	+10% Russia, Ukraine	Closure of the NG/Oil pipelines in the Ukraine (3 +1)
S5	Simultaneous Scenarios 1 + 4	+15% Algeria, Egypt, Libya, Tunisia; +10% Russia, Ukraine	Closure of NG/Oil pipelines in the Ukraine (3 +1)

Table 5: Impact analysis for various scenarios, all commodities (reference 2014)

	Total Supply		
	Energy risk [TJ/y]	Economic risk [G€/y]	Percentage variation
REF	3320988,0	848,9	-
S1	3421496,4	874,6	+ 3,03%
S2	3402748,3	869,8	+ 2,46%
S3	3437896,7	878,7	+ 3,52%
S4	3609261,2	922,6	+ 8,68%
S5	3709769,6	948,2	+ 11,70%

Table 6: Impact analysis for various scenarios - only NG (reference 2014)

	Natural Gas Supply		
	Energy risk [TJ/y]	Economic risk [G€/y]	Percentage variation
REF	1412834,3	361,1	-
S1	1470743,8	375,9	+ 4,10%
S2	1494594,5	382,0	+ 5,79%
S3	1529742,9	391,0	+ 8,27%
S4	1643575,4	420,1	+ 16,33%
S5	1701484,9	434,9	+ 20,40%

Table 7: Monthly energy and economic risk variation for *S1*

	Energy risk [TJ\month]		Economic risk [G€\month]		% variation
	REF	S1	REF	S1	
January	326301,9	335475,6	83,4	85,7	+ 2,8%
February	266461,9	275681,2	68,1	70,5	+ 3,5%
March	285720,8	292396,6	73,0	74,7	+ 2,3%
April	271453,4	280431,3	69,4	71,7	+ 3,3%
May	303996,6	313961,8	77,7	80,3	+ 3,3%
June	260970,7	267085,1	66,7	68,3	+ 2,3%
July	290410,6	297436,9	74,2	76,0	+ 2,4%
August	259432,6	268039,6	66,3	68,5	+ 3,3%
September	246424,2	255304,8	63,0	65,3	+ 3,6%
October	264644,3	271567,0	67,6	69,4	+ 2,6%
November	266992,5	276374,6	68,2	70,6	+ 3,5%
December	278178,6	287741,8	71,1	73,5	+ 3,4%

Table 8: Energy and economic risk variation for mitigation actions to *S2*

	Energy risk [TJ/y]	Economic risk [G€/y]	Percentage variation
S2	3353434,3	857,2	-
MA1-S2	3360660,8	859,0	-1,21%
MA2-S2	3329944,1	851,2	-2,10%
MA3-S2	3319985,2	848,6	-2,39%

Table 9: Energy and economic risk variation for mitigation actions to *S3*

	Energy risk [TJ/y]	Economic risk [G€/y]	Percentage variation
S3	3387423,0	865,8	-
MA1-S3	3334651,4	852,4	-1,56%
MA2-S3	3269333,4	835,7	-3,49%

Table 10: Energy and economic risk variation for the *S4* mitigation actions

	Energy risk [TJ/y]	Economic risk [G€/y]	Percentage variation
S4	3555031,6	908,7	-
MA1-S4	3203725,9	818,9	-9,88%
MA2-S4	3196688,0	817,1	-10,08%

FIGURES

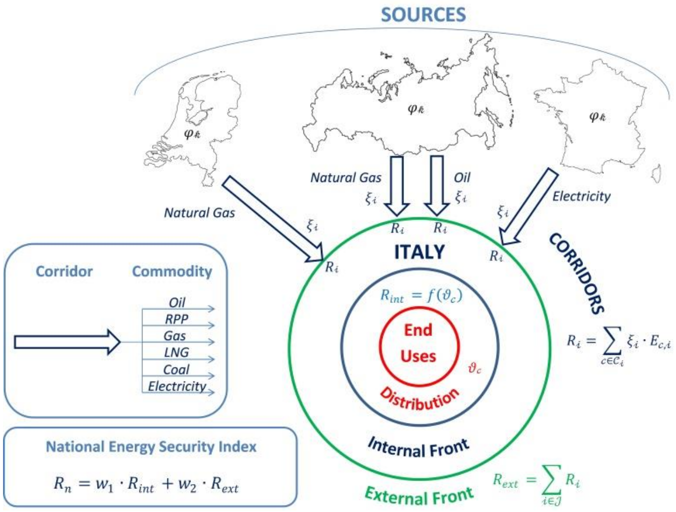

Fig. 1 – "Fronts" and risk indexes in a national energy security assessment

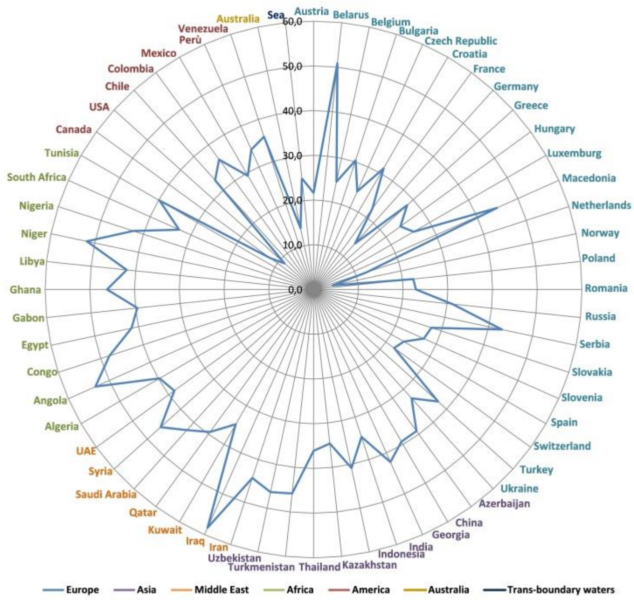

Fig. 2 – Polar representation of the geopolitical country index φ_k