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1 **NATIONAL ENERGY SECURITY ASSESSMENT**
2 **IN A GEOPOLITICAL PERSPECTIVE**

3
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5
6 **Abstract**

7 The possibility of ensuring the energy needed by a country is a fundamental requirement for the economic growth and
8 social welfare of that country. The fulfillment of this need is particularly challenging for those countries that are
9 characterized by a low level of energy self-sufficiency. The evaluation of energy security needs to consider different
10 dimensions and is of the utmost importance as a benchmark to conceive and implement different policies. The
11 assessment of the level of security should rely on science-based models that are able to track the rapidly evolving
12 geopolitical scenarios, and to provide detailed information and quantitative indexes to policy decision makers. In this
13 paper, an overarching methodology is outlined to evaluate energy security, in which its external and internal dimensions
14 are considered and integrated: the security of the energy supply from abroad (external) and the security of national
15 energy infrastructures (internal). Attention is then focused on the external dimension, and two indexes are defined, by
16 means of a probabilistic approach, in terms of the expected value of supply and economic impacts. The methodology is
17 then applied to the Italian case, considering different geopolitical scenarios, and conclusions are provided about the
18 energy security of the country.
19

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20 1. INTRODUCTION

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

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

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

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

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

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

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

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

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

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

60 2. LITERATURE REVIEW OF ENERGY SECURITY INDICATORS

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

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

70 Referring to these five indexes, Gupta [2] evaluated an overall oil vulnerability index (OVI) that depends on the
71 combination of seven indicators, related to oil supply and consumption and to the economic level of the receiving
72 country (GDP per capita, oil import dependency, oil consumption per GDP unit). Bollen [3] based his study on a cost-
73 benefit analysis, and this led to the definition of a “Willingness to Pay” function that measures the percentage of GDP
74 that the analysed country is willing to pay in order to decrease its risk. IEA ESI [4] evaluated the effects of the supply
75 market concentration on energy commodity prices, taking into account the geopolitical risk rating of the supply
76 countries. Scheepers et al. [5,6] analysed the Supply-Demand Index, defined on the basis of experts' judgement by
77 means of scoring rules, and focused on the whole energy chain (including conversion, transport, supply and demand of
78 energy in the mid-long term). The Shannon-Wiennier Index (SWI) [7], which quantifies diversification by taking into
79 account the share of each commodity in the fuel mix composition, is also used to evaluate energy security.
80 Martchamadol et al. [8] performed an analysis of the state of the art, in which several indicators were taken into

81 account. Among these indicators, the following can be mentioned: the WEC Assessment Index (AI) [9], which
82 evaluates energy security by means of five indicators (including net energy imports and diversification of the energy
83 supply); the WEC Energy Sustainability Country Index (ESCI) [10], which is based on 22 indicators, including oil
84 reserves, stock and energy security; the APERC study [11], which considers five indicators (such as the net import
85 dependency, the net oil import dependency and the oil import dependency from Middle Eastern countries); the
86 UNDESA Energy Indicators for Sustainable Development [12]; the Global Network on Energy for Sustainable
87 Development (GNESD) indicator [13]. They also developed a new composite index, the Aggregated Energy Security
88 Performance Indicator (AESPI) [8], which ranges between 0 (low security) and 10 (high security), and which is built
89 using 25 indicators. These indicators are evaluated on the basis of the historical data series of the population, the GDP,
90 the energy production, the net import and consumption, the power generation capacity, the transformation and
91 transmission losses, and the coal, crude oil and natural gas emission factor values.

92 Most of the energy risk indicators are assumed steady over time. Apart from the above mentioned AESPI index, only a
93 few other indexes, such as the Supply-Demand Index defined by Scheepers et al. and the Composite Indicator
94 developed by Badea et al. [14], have taken into consideration a forecasted time evolution. These indicators were both
95 based on energy projections from the PRIMES model, and are used by the European Commission to evaluate the EU
96 Trends up to 2030 [15]. The study by Checchi et al. [16] also focused on the long-term evaluation of the security of
97 energy supply, referring to the results of the PRIMES model, but it did not set any index to quantify this evaluation.
98 Among the indicators based on time series analyses, the International Index of Energy Security Risk (IIESR), set up by
99 the U.S. Chamber of Commerce Institute for 21st Century Energy [17], allows the security level of 25 large consuming
100 countries throughout the world to be compared on a yearly basis. This approach refers to the identification of eight
101 index categories (including reserves and the production of oil, natural gas and coal, and energy imports). A set of 29
102 metrics was defined for each of these categories. The 1980-2012 time horizon was taken into account for all of the
103 metrics; moreover, each of these metrics was normalised with reference to the 1980 OECD value. The normalised
104 metrics were then weighted, using the International Weightings Index, which gives the percentage contribution of each
105 category to the total, in order to calculate the overall IIESR value. Sovacool [18] defined an indicator for the evaluation
106 of the energy security of a country, referring to the European Union, the United States, China, India, Japan, South
107 Korea, Australia, New Zealand and ten countries belonging to the Association of Southeast Asian Nations (ASEAN).
108 For this purpose, five fundamental dimensions of energy security were identified (availability, reliability, technological
109 development, sustainability and regulations). In turn, these dimensions were subdivided into 20 components, each of
110 which was related to a metric. Frondel et al. [19,20,21] proposed and implemented a methodology aimed at classifying
111 countries (in particular those belonging to the G7) on the basis of the risk level related to the primary energy commodity
112 supply in the mid-long term; the authors defined, for each commodity, a risk indicator expressed as a function of the
113 probability of commodity flow disruption for the various exporting countries, and of the square value of the percentage
114 contribution given by each exporting country and by the local production to the energy demand fulfilment in the
115 analysed country. In turn, the supply unavailability for a certain country was evaluated on the basis of considerations
116 associated with the geopolitical situation and economic stability, while the share values for the exporting countries were
117 correlated to the Herfindahl index [22], which measures the import concentration for a specific commodity.

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

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

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

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

137 Among the other studies that have focused on the relevance of the geopolitical element in the evaluation of the risk
138 related to the energy supply, those carried out by Correlje and van der Linde [29], Costantini et al. [30], Hedenus [31]
139 and Umbach [32] can be mentioned. The FP-7 European project “Risk of Energy Availability: Common Corridors for
140 Europe Supply Security” (REACCESS) [33] developed tools that can be used to conduct a quantitative assessment of
141 the geopolitical risk for scenario analyses. In this project – characterized by the link between three forecasting TIMES-
142 based [34] optimisation energy models – a risk index (steady over time and ranging between 0 and 100) was defined for

143 all the commodity source countries and for all the countries crossed by the above mentioned corridors. This index is a
 144 function of the socio-political, energetic, political-institutional and economic security level of the country, and it was
 145 calculated by means of factor analysis techniques (Marín-Quemada et al. [35,36,37]). During the follow-up phase of the
 146 project, these indexes were combined, through an application of the reliability theory, in order to define a single risk
 147 index for each corridor; for this purpose, the risk index related to each crossed country was assumed as the probability
 148 that a corridor crossing that country would fail (Gerboni et al. [38]). Furthermore, starting from the same risk indexes
 149 per country, Doukas et al. [39] developed a web-based tool for the analysis of the natural gas and oil corridors, and they
 150 tested it by means of a case study focused on the Greek energy supply. Using the same approach (based on the factor
 151 analysis), Muñoz et al. [40] defined the country composite indicator GESRI (Geopolitical Energy Supply Risk Index),
 152 which – unlike the one proposed by Marín-Quemada et al. – combines the social and political dimensions in a single
 153 risk vector and introduces a new vector that describes the relations between the exporting and transit countries with the
 154 EU-27. Finally, in the framework of the REACCESS project, Carpignano et al. [41] proposed a methodological
 155 approach to evaluate the technological risk and the loss of production caused by corridor failures, and included these
 156 parameters among those used to analyse optimal scenarios for the EU energy supply.

158 3. INDICATORS FOR NATIONAL ENERGY SECURITY ASSESSMENT

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

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

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

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

$$171 R_{int} = f(\vartheta_{c,d})$$

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

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

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

180 A corridor i is defined as:

$$181 \forall i \in \mathcal{J} : i_i = \{c_c, l_i, \mathcal{K}_i\} \mid c \neq l = i,$$

182 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 $k_i \in \mathcal{K}^i$, the
 183 country of origin, $\dim(\mathcal{K}^i) = K_i$ the number of countries crossed.

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

$$185 \xi'_i = 100 \cdot \left[1 - \prod_{k_i \in \mathcal{K}_i} \left(1 - \frac{\varphi_k}{100} \right) \right] \quad (1)$$

186 In (1):

187 $\left(1 - \frac{\varphi_k}{100} \right)$ is the probability of success of crossing country k ,

188 $\prod_{k_i \in \mathcal{K}_i} \left(1 - \frac{\varphi_k}{100} \right)$ is the probability (of independent events) of success of crossing all the countries involved along
 189 the corridor route,

190 $1 - \prod_{k_i \in \mathcal{K}_i} \left(1 - \frac{\varphi_k}{100} \right)$ is the probability of failure for the entire corridor, and it is expressed as the complement of
 191 the probability of success.

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

$$201 \quad l_i = \|B^i\|_1$$

202
 203 An empirical weighting function γ_k is introduced into (1) in order to incorporate this aspect:

$$204 \quad \xi_i = 100 \cdot \left[1 - \prod_{k_i \in \mathcal{K}_i} \left(1 - \frac{\gamma_k \cdot \varphi_k}{100} \right) \right] \quad (2)$$

206 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,
 207 b_b , and the average length of the corridor branches \bar{b}_i (3).

$$208 \quad \bar{b}_i = \frac{l_i}{K_i} \quad (3)$$

210 Open sea routes and submarine pipelines, territorial waters and international waters are all involved in the risk
 211 assessment of the corridor. In order to avoid an underestimation of the risk related to maritime routes, in comparison to
 212 the one related to terrestrial corridors, a zone of influence is defined for each country, and a portion of the international
 213 waters is also covered, to which the same index φ_k as the country is provided.

214 The risk, R_i , associated to corridor i , is defined as the product between the probability of failure ξ_i and the damage, in
 215 terms of loss of energy $E_{c,i}$, associated to a commodity c_c :

$$216 \quad R_i = \sum_{c_i \in \mathcal{C}_i} \frac{\xi_i}{100} \cdot E_{c,i} \quad (4)$$

217
 218 The overall external risk, for all the corridors supplying the given country, is:

$$219 \quad R_{ext} = \sum_{i_i \in \mathcal{J}} R_i \quad (5)$$

221 As far as time granularity is concerned, the analyses can be carried out considering different time scales (year, quarter,
 222 months,...). A higher time discretization, such as a monthly analysis, would allow specific criticalities, such as those
 223 related to the natural gas supply during winter months, to be highlighted.

224 The risk in (5) can be converted into equivalent monetary units through the national *energy intensity of the economy* Q
 225 ($TJ/G\text{€}$), which is defined as the ratio between the gross internal energy consumption (TJ) and the Gross Domestic
 226 Product (GDP, G€):

$$227 \quad R_{int,m} = \frac{R_{int}}{Q} \quad (6)$$

$$228 \quad R_{ext,m} = \frac{R_{ext}}{Q} \quad (7)$$

229 This conversion is useful to evaluate the economic impact of the geopolitical energy risk, because a possible loss of
 230 energy, due to the unavailability of an energy supply, causes a loss of GDP [42].

231 The sum of the two indicators, weighted using two coefficients, w_1 and w_2 , allows the *National Energy Security Index*
 232 R_n to be defined (Fig.1):

$$233 \quad R_n = w_1 \cdot R_{int} + w_2 \cdot R_{ext} \quad (8)$$

234
 235 where w_1 and w_2 are defined on the basis of the percentage import dependency χ :

$$236 \quad w_1 = 1 - \chi \quad (9)$$

$$237 \quad w_2 = \chi \quad (10)$$

238

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

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

245
 246 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
 247 the corridor:

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

249
 250 The total expected supply S_{ext} (TJ) can be evaluated as:

$$S_{ext} = \sum_{i_i \in \mathcal{J}} S_i \quad (13)$$

252
 253 The expected supply corresponds to the difference between the total supply, in energy terms E , and the overall external
 254 risk R_{ext} :

$$S_{ext} = E - R_{ext} \quad (14)$$

256
 257 The adopted approach assumes that the events are independent, and offers a conservative overestimation of the risk.

258
 259 Finally, it should be highlighted that the error analysis in the proposed modelling approach on the main parameters
 260 (such as energy flows, or corridor branch lengths) is not particularly relevant in comparison with the need to
 261 understand whether a certain event could happen or not. The aim of the adopted procedure is to associate a certain
 262 probability value to the single countries, which is able to describe the likelihood that a certain supply corridor crossing
 263 them fails due to geopolitical reasons, and is not to perform forecasting analyses on unpredictable events. Naturally,
 264 disruptive geopolitical events can suddenly occur, and these could significantly modify the probability value of the
 265 countries. For this reason, sensitivity analyses on the country risk index parameter are useful to evaluate the effects of
 266 such events on the global energy risk. Furthermore, when defining sensitivity scenarios, it could be appropriate to
 267 consider that a geopolitical event in a certain country can also affect other countries in the same geographical area, and
 268 as a result in some cases the geopolitical risk level should be considered jointly, and in the same way modified for the
 269 whole set of countries belonging to the same area. This could be particularly relevant for zones like the Middle-East and
 270 North-Africa (some examples are those of the so-called “Arab Spring” and the penetration of terroristic groups in these
 271 areas).

273 4. CASE STUDY: THE EXTERNAL SUPPLY TO ITALY

274 4.1 Definition of the scenarios

275 The proposed methodology has been applied to the security analysis of the Italian national energy supply. The
 276 contribution to the risk given by the internal component R_{int} has been neglected, and the analysis has only focused on
 277 the evaluation of the R_{ext} parameter.

278 A total of 263 corridors (pipelines, ships, railways, roads, power lines), carrying 6 commodities (coal, crude oil, refined
 279 petroleum products, natural gas, LNG, electricity) and accounting for 97.5% of the Italian energy inflows in 2014 have
 280 been considered [43,44]. Country risk indexes have been assumed on the basis of the FP-7 REACCESS ([35], [36],
 281 [37], [38]) project (Fig. 2, Tab. 3).

282
 283 Italian energy security has been assessed against five possible adverse scenarios. The scenarios are characterized by two
 284 different types of situation; in the first, the criticality of the country is increased due to a deterioration of the geopolitical
 285 situation in the area (modelled by an increase in the geopolitical country index), while in the second the situation, the
 286 country causes actions that provide the actual failure of a corridor.

287 Five scenarios (S1-S5) have been taken into account (Tab. 4):

- 288 S1) Increased activity of terroristic groups in North Africa (Algeria, Egypt, Libya and Tunisia);
- 289 S2) Deterioration of the Italian/Qatari diplomatic relations, with cuts in gas/oil exports to Italy;
- 290 S3) Antagonistic actions in Libya with disruption of the Greenstream gas pipeline;

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

294
295

4.2 Energy security analysis for different scenarios

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

301

302 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
303 total) that are affected by the increase in geopolitical risk in the four countries; their average risk index for corridor ξ
304 increases by 17.6%, in comparison with the Reference, while the overall value of ξ increases by 5.4%.

305 In Tab. 7, the analysis is undertaken on a monthly time basis; both risk indexes, in this case, have a peak increase in
306 September, due to an increase in the flow exported by the countries involved in S1, in comparison with the one exported
307 by countries that do not undergo changes. An increase in the risk can be observed for S1 but, due to the absence of
308 actual disruptions, the inflows are still there.

309

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

314

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

320

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

327

328 S5 combines the effects of S1 and S4. This situation is extremely risky because it affects 46.1% of the total Italian
329 energy supply, and it leads to a critical situation, especially for natural gas supply, as more than 70% of the imported
330 flux is involved; the percentage of oil, RPP and coal imports involved is lower, but is significant, as it ranges between
331 20% and 50%. The overall energy risk increases by 11.7%, above all due to the specific risk contribution of natural gas
332 (+20.4%). This relevant growth is justified by the fact that seven suppliers (Russia, the Ukraine, Algeria, Libya, Egypt,
333 Tunisia and Nigeria) and 98 corridors undergo changes. In particular, the average ξ increases by 17.5%, in comparison
334 with the Reference case.

335

4.3 Mitigation actions

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

341

342 MA1-S2) Replacement of the Qatari LNG flow with a flow from Algeria (50%, Transmed pipeline;) and Russia (50%,
343 TAG pipeline).

344 This configuration – which is coherent with the maximum capacities at the national entry points – allows the needed
345 annual quantity of natural gas to be ensured with a risk reduction of 1.21%, in comparison with S2.

346 MA2-S2) Replacement of the Qatari LNG flow with a flow from Norway (25%, Transitgas pipeline), the Netherlands
347 (25%, Transitgas pipeline) and Russia (50%, TAG pipeline).

348 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
349 the low risk level of the two European countries.

350 *MA3-S2) Replacement of the Qatari LNG flow with a flow from the UAE (100%, LNG to regasification terminals*
351 *located near Panigaglia and Porto Levante).*

352 The resulting overall risk reduction is close to the one obtained for MA2-S2 (-2.39% vs. - 2.10%). The obtained
353 configuration is similar to the reference one, due to the fact that the country indexes for Qatar (38.5) and the UAE
354 (39.4), and the ship route to deliver LNG to Italy, are comparable.

355 The effects of the mitigation actions are reported in Tab. 8.

356

357 For S3, two mitigation actions were identified:

358

359 *MA1-S3) Replacement of the Libyan NG flow with a flow from Algeria (50%, Transmed pipeline) and Nigeria (50%:*
360 *25% Transmed pipeline; 25% LNG).*

361 The risk reduces by 1.56%, in comparison with the S3 scenario. It should be noticed that the ξ associated to these
362 corridors is higher than the Greenstream one: this is not due to the source country indexes (as they are similar to the
363 Libyan one for both Algeria and Nigeria), but – and particularly for Nigeria – to the high number of countries that are
364 crossed.

365 *MA2-S3) Replacement of the Libyan NG flow with a flow from the UAE (50%, LNG) and Qatar (50%, LNG).*

366 The resulting risk reduces by 3.49%. This option allows only maritime routes, which are more flexible and therefore
367 more effective from the security point of view, to be used.

368 The missing flow cannot be replaced entirely by European Countries (Norway and the Netherlands) as the required
369 capacity is higher than the maximum one for the Transigas corridor, which should be involved in this case.

370 The effects of the mitigation actions are reported in Tab. 9.

371

372 For S4, two mitigation options are defined:

373

374 *MA1-S4) Replacement of the Russian crude oil flow with a flow from Kazakhstan (50%) and Azerbaijan (50%;*
375 *replacement of the Russian NG flow with a flow from Algeria (30%), Nigeria (30%), the Netherlands (10%), Norway*
376 *(10%), Libya (7%), Qatar (7%) and the UAE (6%), i.e. from all the other countries that supply Italy, according to the*
377 *maximum capacity of the pipelines.*

378 In this way, the overall risk decreases by 9.88%: this is mostly due to the decrease in the risk related to natural gas (-
379 21%).

380 *MA2-S4) Replacement of the Russian crude oil flow with a flow from the Russian corridors that do not cross the*
381 *Ukraine; replacement of the Russian NG flows as in MA1-S4.*

382 The results show a reduction in the overall risk index of -10.08%, which is comparable with the one obtained in MA2-
383 S3. As in MA2-S3, this reduction is mostly related to the diversification of the NG supply.

384 The possible evolution of the corridors can provide additional possibilities, in terms of mitigation effects. The supply
385 from Russia through different corridors (whose routes do not cross the Ukraine), mainly depends on future strategies
386 related to the possible new pipelines that could be built. One of these alternatives could be represented by the South
387 Stream project, even though this solution does not currently seem feasible. In fact, the South Stream project (a pipeline
388 of a total length of about 2380 km, of which 931 will be offshore through the Black Sea, from Russia to Bulgaria, with a
389 capacity of 63 bcm/y) was declared, at the end of 2013, not to be compliant with the EU Third Energy Package
390 regulations [45], which introduced incompatibility between producers and TSOs (thus affecting the role played by the
391 Russian natural gas production and distribution company Gazprom); furthermore, this decision has to be contextualized
392 in a more general framework of geopolitical tensions between the EU and Russia, caused by the economic sanctions
393 imposed after the Crimea crisis. After the declared abandon of the South Stream project by Russia, the alternative
394 Turkish Stream (or TurkStream) project was proposed. This pipeline – originally expected to have the same capacity as
395 the South Stream one – should run from Russia to Turkey and cross the Black Sea (with a subsea branch of about 900
396 km) and to deliver 31.5 bcm/y; the construction is planned to start in 2017 and to be completed by 2019. According to
397 the most recent information available, Russia could build an additional line to connect Turkey to Greece, thus allowing
398 Europe to be supplied (15.75 bcm/y to Turkey, 15.75 bcm/y to Europe). Among all the possible options, an
399 interconnection between the Turkish Stream and the Trans Adriatic Pipeline (TAP) can be mentioned. The TAP
400 pipeline infrastructure is presently under construction (with a length of 878 km, an initial capacity equal to 10 bcm/y
401 and a planned maximum capacity of 20 bcm/y). It runs from Greece to Italy and will be connected to the Trans
402 Anatolian Pipeline (TANAP) – as part of the Southern Gas Corridor (SGC) – in order to carry natural gas from the
403 Azeri field of Shah Deniz to Europe. The construction of the TAP pipeline, and in particular the possibility of linking it
404 to the Turkish Stream, could be relevant for Italy, as this situation could allow it to become a European hub for natural
405 gas imported from Azerbaijan and Russia. As far as the security point of view is concerned, in 2014 (the reference year
406 of the case study), Italy's overall natural gas import was equal to 55.78 bcm, of which 26.15 bcm came from Russia
407 (46.9%). In the long term, hypothesising that the TAP pipeline could reach its maximum capacity, if the gas import
408 remains constant, this corridor could impact on the supply for about 36%. By considering the latest data made available
409 by the Italian Ministry of Economic Development and referring to 2015 [46], an increase in the overall imports can be

410 observed of up to 61.20 bcm; furthermore, if the historical trends are analysed, it can be noticed that the 2014 gas
411 import value is significantly lower than the average import related to the last 12 years (69.27 bcm, with a peak of 77.40
412 bcm in 2006). These observations, coupled with the constantly decreasing trend of local gas production (which
413 accounted for 11.5% of the Gross Inland Consumption in 2014), have lead us to suppose that the import of natural gas
414 in 2020 (the planned year for starting the TAP pipeline) could be higher than the present one. However, it can
415 reasonably be expected that it will be lower than 80 bcm/y: in this case, the contribution of the TAP will range from
416 12.5% (starting capacity = 10 bcm/y) to 25% (expansion up to the maximum capacity = 20 bcm/y). Focusing on the risk
417 indexes (Tab. 3), it is possible to notice that the country risk index related to Azerbaijan is higher than that of Russia
418 (43.9 vs. 34.0), and that the corridor route of the TAP pipeline (which crosses Azerbaijan, Armenia, Turkey, Greece and
419 Albania) cannot be considered “safer” than the TAG pipeline one (which crosses Russia, the Ukraine, Slovak and
420 Austria). For these reasons, it is possible to conclude that the TAP corridor would probably not reduce the absolute
421 value of the supply risk, but it could be useful to increase diversification of the supply, and it could also offer a relevant
422 alternative that could help in the case of geopolitical tensions between Russia and the Ukraine.

423 Other options, such as the use of the Yamal pipeline, cannot be considered, because of the constraint on the maximum
424 capacity at the entry point, which is located in Passo Gries.

425 The effects of the mitigation actions are reported in Tab. 10.

426

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

438

439 The approach described in sec. 3 and the case study analysed in sec. 4 are proposed from a single country perspective.
440 However, the methodology could be applied at different scales (country, region, macro-areas). In fact, it could be useful
441 to explore the energy security issues, especially for developing countries like China or India (for example, mention can
442 be made to the studies performed by Jiang-Bo et al. [47] – which focus on the historical evolution of Chinese energy
443 supply security, considering four dimensions and seven indexes – and the one carried out by Bambawale et al. [48],
444 which was based on the analysis of Indian energy security from different perspectives), which are characterised by a
445 relevant energy consumption growth rate, and for countries that show a relevant import dependency.

446 As far as the latter ones are concerned, Asian countries, like Japan and South Korea, can be mentioned. The overall
447 Japanese energy import dependency in 2014 was equal to 93.5%, with relevant values for natural gas (97.6%) and
448 crude oil (99.7%), while for South Korea, the import dependency in 2014 was equal to 82.8% (99.3% for natural gas
449 and 99.5% for crude oil) [49]. Some European Countries are also affected to a great extent by this issue [50]: among
450 the most populated ones, the dependency level of Italy is significantly high, but the situation of smaller countries, such
451 as the Baltic ones, should also be highlighted, due to the fact that, since their independence and up to recent years, they
452 have depended completely on a single supplier (Russia) [51].

453

454 5. CONCLUSIONS

455 The proposed methodology (and the implemented tool) can provide a quantitative assessment of the energy security of a
456 country in a geopolitical perspective. The methodology, implemented and tested with reference to the Italian case, has
457 proved to be effective in supporting policy decision making in the short, mid and long term.

458 This methodology allows a comprehensive representation of the inflow of a country, the assessment of its geopolitical
459 risk and a cost benefit analysis, which is useful to compare different strategic options, to be obtained; a) in the short-
460 mid-term, to allocate efforts with the aim of protecting a given corridor b) in the mid/long term, to plan and activate
461 new supply options and corridors.

462 In addition, this methodology provides an effective way of designing mitigation countermeasures in the presence of an
463 increase in the geopolitical risk or of adverse events, which could causing a certain percentage of the needed supply to
464 become unavailable; it allows their effectiveness to be compared, and the related economic impacts to be assessed in
465 terms of reduction in GDP loss.

466 With reference to the case of the Italian external supply, the analysis of the considered scenarios has highlighted the
467 relevant role played by diversification in reducing the overall external risk. In a low self-sufficient country, the spatial
468 dimension of energy corridors (the routes, lengths and the geopolitical security of the crossed countries) significantly
469 affects the risk value. Moreover, in a strategic perspective, as natural gas is the most “risky” commodity, investments in

470 new LNG connections and terminals, or to increase the capacity of existing ones, could be beneficial from the security
471 point of view.
472 Investments in preventive actions against terroristic attacks against sensitive targets, such as pipelines, for example, the
473 Greenstream corridor, could also lead to significant benefits from an economic point of view, as they could prevent the
474 loss of a relevant amount of the GDP as the consequence of the sudden unavailability of an energy supply.
475 The examined scenarios are related to the current energy system. From a more general perspective, the need to take into
476 account climate changes, and to introduce adequate policies and countermeasures could have an effect on energy
477 security [52] and lead to a new paradigm, based on a strong decarbonisation of the energy system and on the relevant
478 role that renewables could play. According to this approach, among the future energy scenarios, the one that considers
479 electrical UHV super-grids at a global scale, which would be able to transport electricity generated from renewable
480 sources, such as wind and solar, from large production areas (the North Pole and African desert zones, respectively) to
481 large consumption areas (such as the U.S.A., Asia and Europe), thus shifting the end-use energy consumptions from
482 fossil fuels to cleanly produced electricity, can be mentioned [53]. Such a configuration could lead to an evolution in
483 energy security, and could radically change the overall situation. The methodological approach described in this paper
484 to evaluate supply security could also be adopted in future works to analyse these possible future scenarios and to
485 compare them with other more traditional ones.

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604 TABLES
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Table 1: Weighting function γ_k

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

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Table 2: Nomenclature

Set / Parameter	Description
$\mathcal{C} = \{\dots, c_c, \dots\}, \dim(\mathcal{C}) = C$	Set of energy commodities
$\mathcal{J} = \{\dots, i_i, \dots\}, \dim(\mathcal{J}) = I$	Set of energy corridors
$\mathcal{C}_i \subseteq \mathcal{C} \mid c_i \in \mathcal{C}_i$	Commodity delivered by corridor i_i
$\mathcal{K} = \{\dots, k_k, \dots\}, \dim(\mathcal{K}) = K$	Set of countries (both source and corridor)
$\mathcal{K}^i \subseteq \mathcal{K} \mid k_h \in \mathcal{K}^i$	Country crossed by corridor i_i
$\mathcal{L} = \{\dots, l_i, \dots\}, \dim(\mathcal{L}) = L=I$	Set of corridor lengths (km)
$\mathcal{B}^i = \{\dots, b_{b_i}, \dots\}, \dim(\mathcal{B}) = B^i$	Set of the lengths of branches of corridor i_i
$\mathcal{D} = \{\dots, d_d, \dots\}, \dim(\mathcal{D}) = D$	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
λ	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

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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		

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628**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)

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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%

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

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

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

	Energy risk [TJ/month]		Economic risk [G€/month]		% variation
	REF	<i>S1</i>	REF	<i>S1</i>	
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%

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

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

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

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

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

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

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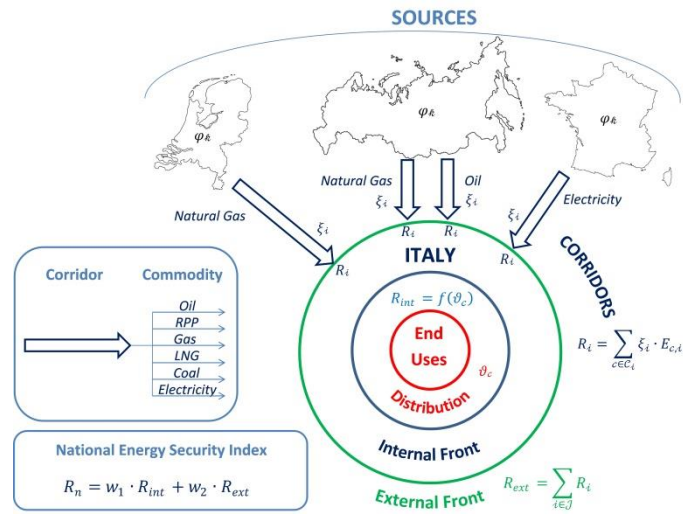


Fig. 1 – “Fronts” and risk indexes in a national energy security assessment

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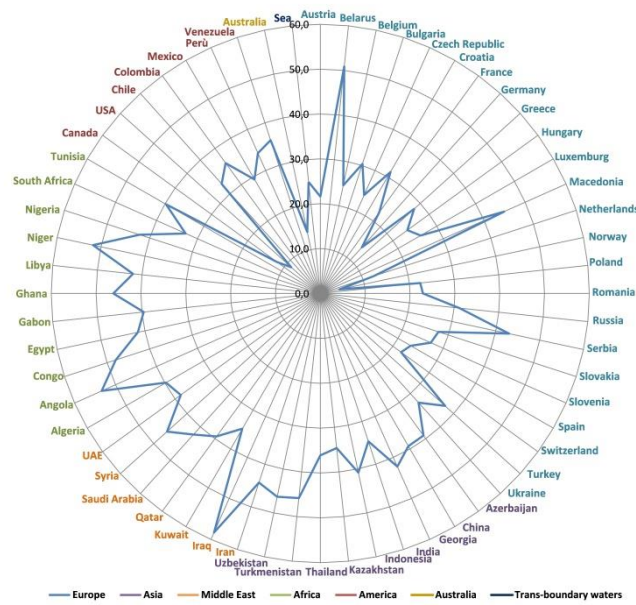


Fig. 2 – Polar representation of the geopolitical country index ϕ_k

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