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Energy interplay in the Mediterranean area in-between ecological transition and geopolitical criticalities

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Abstract

Within the general framework of the transformation of energy systems towards more sustainable solutions at international level, the Mediterranean area plays a particularly important role. The basin has the potential to emerge as a key player in the field of renewable energies, facilitated by innovative technological solutions that unveil new possibilities.

The challenge is to balance the geopolitical criticalities of disruptive phenomena with the need to keep sustainability at the center of the policy framework, while maintaining security and equity.

This study navigates the complex landscape of energy transition in the Mediterranean region, shedding light on the disparities between aspirations and achievements. Initially an overview of renewable energy technologies in the Mediterranean is provided, emphasizing the incongruities in renewable energy capacity between the region's shores. Through a meticulous mapping of installed renewable energy systems across each country, and policies for hydrogen and alternative fuels, the thesis compares the current status, the Business-As-Usual (BAU) scenario at year 2030 and national objectives on renewables, dissecting the economic and social factors contributing to the uneven transition progress.

Subsequently a focus on the natural gas supply system in the Mediterranean is proposed since natural gas can play a transitional role in the shift towards renewables. The analysis encompasses the mapping of pipelines and liquified natural gas terminals and the future development of the infrastructure, studying the physical flows of gas imports for 2021, 2022, and 2023, both onshore and maritime. The evolution of the supply system, the presence of new corridors towards Mediterranean, Russia's role as gas provider, and the impact of the Russo-Ukrainian war on import quotas and storage levels are the main points examined.

Finally, the pivotal role of security and geopolitical risks within the context of energy transition is underscored. An emphasis is placed on how wars and crises in the Mediterranean intersect with energy dynamics. The necessity of assessing geopolitical risks is addressed, developing through the examination of a set of indicators a risk model applied to a case study: evaluate the security and reliability level of gas supply from Algeria to Italy.

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1. Trajectories for possible energy transition in the Mediterranean

1.1 Energy landscape in the Mediterranean area

Over the past few years, there has been a notable shift in global energy systems, primarily motivated by the urgent need to tackle climate change, guarantee energy security, and promote sustainable development. As countries endeavor to move away from reliance on fossil fuels towards cleaner, renewable alternatives, the Mediterranean region stands out as a key area for exploring the complex array of challenges and opportunities associated with this profound transformation.

The Mediterranean region, comprising countries from Southern Europe, North Africa, and the Middle East, is endowed with a diverse array of energy resources, ranging from abundant solar potential and wind resources to conventional fossil fuels. This unique blend of resources presents both challenges and opportunities as the region grapples with the imperative of decarbonization while meeting the growing energy demands of its burgeoning population.[1]

Mediterranean countries can grouped into three main macro areas, showing a certain homogeneity from the macroeconomic, social and energy point of view: the Northern shore (including European and Balkan countries: Spain, Portugal, France, Italy, Malta, Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, Albania, Greece), the Eastern shore (including Middle East countries: Cyprus, Turkey, Syria, Lebanon, Israel) and the Southern shore (including Northern African countries: Egypt, Libya, Tunisia, Algeria, Morocco).

Throughout history, the geographical triangle of the Mediterranean basin has been marked by robust interaction among the countries along its shores. Cultural influences, economic transactions, and conflicts have all played significant roles across both ancient and modern eras in the region. Within this context, the energy dialogue has emerged, centered on the trade of energy commodities. This dialogue has been established since the middle of the last century, involving producing and exporting countries primarily situated on the Southern shore, as well as consuming and importing countries, such as those in Europe.

The objective of this work is to describe the transition from an energy dialogue based on fossil resources towards a new “green dialogue” in which renewable energy systems will be the key players. The need for this shift is stressed by a geopolitical context characterized by wars (e.g. Russia-Ukrainian one) and crisis that bring Mediterranean countries to find an alternative way for their energy supply and commodity mix.

Then a brief description of the energy technologies ready to support this transition is presented, beside which the natural gas, as transitional commodity, plays an important role.

Finally, the importance of the risk assessment for energy security and supply is highlighted with a particular focus on the natural gas provisioning from Algeria to Italy.

1.2 Current RES development in the Mediterranean

Renewable energy sources in the Mediterranean area play a crucial role in addressing the region's energy needs while also promoting environmental sustainability. The Mediterranean area, with its variety of geography, climate, and energy demands, presents opportunities and challenges for harnessing renewable energy.

Additionally, the region's vulnerability to climate change highlights the importance of adopting sustainable and low-carbon energy solutions.

Since this area shows a significant potential for renewable energy development many efforts are underway to enhance regional collaboration, create supportive policies and strategies in order to reach a cleaner, more sustainable energy future for the region.

However, challenges in transitioning to renewable energy sources, including policy and regulatory frameworks, economic considerations, and public acceptance are needed.

At present, RES development and implementation in the Mediterranean region is strongly dependent to the geographic location of the countries. For this reason, the entire area is divided in three macro-areas (northern shore, southern shore, eastern shore) to which each country belongs according to its location, showing different socio-economic, geo-politic and energy features.

To give such a complete overview on the current situation about renewable energy development, in this study data about renewables installed capacity was collected.[2]

With this purpose, the table above reports the current installed capacity (expressed in Gigawatts) of renewables in 2022 in each country.

Table 1 Installed capacity of renewables in 2022 [GW/y]

	Total RES	Solar PV[1]	Onshore wind	Offshore wind	Marine	Hydro	Geothermal	CSP[2]	Bioenergy
Eastern shore	**63,30**	**14,53**	**11,58**	**0,00**	**0,00**	**33,65**	**1,69**	**0,24**	**1,91**
Cyprus	0,60	0,43	0,16	0,00	0,00	0,00	0,00	0,00	0,01
Israel	4,47	4,17	0,03	0,00	0,00	0,31	0,00	0,24	0,03
Lebanon	0,73	0,44	0,00	0,00	0,00	0,28	0,00	0,00	0,01
Syrian AR	1,56	0,06	0,00	0,00	0,00	1,49	0,00	0,00	0,01
Turkiye	55,94	9,43	11,40	0,00	0,00	31,57	1,69	0,00	1,86
Northen shore	**234,64**	**69,99**	**73,30**	**0,54**	**0,22**	**89,23**	**0,83**	**2,32**	**7,81**
Albania	2,54	0,03	0,00	0,00	0,00	2,51	0,00	0,00	0,00
Bosnia Herzegovina	2,09	0,11	0,14	0,00	0,00	2,26	0,00	0,00	0,01
Croatia	3,59	0,18	1,04	0,00	0,00	2,20	0,01	0,00	0,16
France	65,38	17,41	20,64	0,48	0,21	26,29	0,02	0,01	2,05
Greece	13,97	5,56	4,88	0,00	0,00	3,42	0,00	0,00	0,11
Italy	59,89	25,08	11,75	0,03	0,00	22,78	0,77	0,01	3,42
Malta	0,23	0,22	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Montenegro	0,84	0,02	0,12	0,00	0,00	0,70	0,00	0,00	0,00

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[1] Photovoltaic

[2] Concentrated Solar Power

Portugal	16,33	2,54	5,43	0,03	0,00	7,59	0,03	0,00	0,72
Slovenia	1,88	0,63	0,00	0,00	0,00	1,35	0,00	0,00	0,07
Spain	67,91	18,21	29,30	0,01	0,00	20,13	0,00	2,30	1,28
Southern shore	**11,16**	**2,66**	**3,46**	**0,00**	**0,00**	**4,80**	**0,00**	**0,59**	**0,13**
Algeria	0,60	0,44	0,01	0,00	0,00	0,13	0,00	0,03	0,00
Egypt	6,32	1,70	1,64	0,00	0,00	2,83	0,00	0,02	0,12
Libya	0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Morocco	3,72	0,31	1,56	0,00	0,00	1,77	0,00	0,54	0,01
Tunisia	0,51	0,20	0,25	0,00	0,00	0,07	0,00	0,00	0,00

Source:. *Renewable electricity capacity and generation, IRENA, August 2023*

The table shows the shares of renewables currently installed within the Mediterranean countries. As previously anticipated, the three macro-areas display non-homogeneous results due to different economic, political, and social development.

As can be expected, the Northern shore has the highest installed capacity of renewables (almost 235 GW) among the three zones, since it is composed of countries more advanced in the energy sector and in terms of policies and regulations such as Italy, France and Spain.

On the contrary, Southern shore countries despite their great potential of renewable sources, are still in the initial stages of the energy transition process: this is represented by the data that show quite low values especially for Libya, Tunisia, and Algeria. These values are justified also by their geopolitical instabilities which slow down their development process.

Moreover, there are some resources in Southern and Eastern shores (apart from Turkey) that are not developed at all as offshore wind, geothermal and marine energy.

A more comprehensive overview is given in Table 2 in which again data related to year 2022 shows the percentage, source by source, with respect to the total installed RES capacity for each country.[2]

Table 2 Share of different sources on total RES capacity [%]

	Solar PV	Onshore wind	Offshore wind	Marine	Hydro	Geothermal	CSP	Bioenergy
Eastern shore	**47,97%**	**9,51%**	**0,00%**	**0,00%**	**39,41%**	**0,60%**	**1,01%**	**1,49%**
Cyprus	71,64%	26,18%	0,00%	0,00%	0,00%	0,00%	0,00%	2,19%
Israel	87,40%	0,57%	0,00%	0,00%	6,41%	0,00%	5,07%	0,55%
Lebanon	60,10%	0,41%	0,00%	0,00%	38,53%	0,00%	0,00%	0,96%
Syrian AR	3,85%	0,04%	0,00%	0,00%	95,68%	0,00%	0,00%	0,43%
Turkiye	16,85%	20,37%	0,00%	0,00%	56,43%	3,02%	0,00%	3,32%
Northern shore	**26,17%**	**18,84%**	**0,08%**	**0,03%**	**52,11%**	**0,15%**	**0,30%**	**2,32%**
Albania	1,13%	0,00%	0,00%	0,00%	98,82%	0,00%	0,00%	0,06%
Bosnia Herzegovina	4,28%	5,38%	0,00%	0,00%	89,93%	0,00%	0,00%	0,41%
Croatia	5,07%	29,03%	0,00%	0,00%	61,24%	0,28%	0,00%	4,38%
France	25,94%	30,75%	0,72%	0,31%	39,18%	0,02%	0,01%	3,06%
Greece	39,79%	34,93%	0,00%	0,00%	24,51%	0,00%	0,00%	0,78%
Italy	39,29%	18,41%	0,05%	0,00%	35,69%	1,21%	0,01%	5,35%
Malta	97,93%	0,04%	0,00%	0,00%	0,00%	0,00%	0,00%	2,02%
Montenegro	2,65%	14,10%	0,00%	0,00%	83,25%	0,00%	0,00%	0,00%
Portugal	15,53%	33,26%	0,15%	0,00%	46,49%	0,18%	0,00%	4,39%
Slovenia	30,72%	0,16%	0,00%	0,00%	65,80%	0,00%	0,00%	3,32%
Spain	25,57%	41,13%	0,01%	0,01%	28,26%	0,00%	3,23%	1,79%
Southern shore	49,18%	22,61%	0,00%	0,00%	24,31%	0,00%	3,48%	0,43%
Algeria	72,65%	1,67%	0,00%	0,00%	21,51%	0,00%	4,17%	0,00%
Egypt	26,96%	25,98%	0,00%	0,00%	44,80%	0,00%	0,32%	1,95%
Libya	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Morocco	7,50%	37,19%	0,00%	0,00%	42,24%	0,00%	12,89%	0,18%
Tunisia	38,79%	48,22%	0,00%	0,00%	12,99%	0,00%	0,00%	0,00%
Mediterranean	**41,11%**	**16,99%**	**0,03%**	**0,01%**	**38,61%**	**0,25%**	**1,60%**	**1,41%**

The most relevant shares are represented by solar photovoltaic, hydropower and wind energy, being the most developed and regulated technologies. Consequently, other kind of natural sources as Geothermal and Marine energy give only minimum participation to the entire capacity.

As anticipated in the chapter introduction, the resource distribution is obviously non-homogeneous among the different countries due to variety of geographical landscapes and environmental conditions that characterize the Mediterranean zone. Nevertheless, can be noticed that some countries can mostly rely on a single type of source (e.g., solar PV for Libya and Malta or hydropower for Albania and Syria) because of their lower energy consumption but also for the land morphology which makes the development of other kind of resources more challenging.

Table 3 Share of installed RES among the shores [%]

Shore	Total RES	Solar PV	Wind energy	Hydropower	Others[3]
Eastern shore	20,48%	16,66%	13,03%	26,35%	24,44%
Northen shore	75,91%	80,29%	83,08%	69,89%	71,02%
Southern shore	3,61%	3,05%	3,89%	3,76%	4,55%

In order to discuss the current situation in the three shores considered in this study it was reported a table that reports the percentage of RES source by source belonging to each shore of the Mediterranean basin.

This is useful to make a comparison between the different macro-areas in terms of renewables development: from the represented data can be seen that the highest shares belong to northern countries that own almost the total installed capacity for wind energy (83%), but also relevant part of Solar PV (80,3%).

In the eastern area the results are strongly affected by the presence of the Turkish region which shows a quite important share of hydropower, while the other countries belonging to the same shore have almost irrelevant rates.

For what concern the southern shore, these data show the energy paradox of this portion of area that even if possess a significant potential for the exploitation on natural resources, still their development is much more backward with respect to the other countries, probably due to social and economic factors.

1.3 Methodology for trajectories elaboration

This study aims to develop an analysis regarding the energy transition by developing future trajectories, based on a scenario of 100% of renewable energy in the Mediterranean countries.

With this purpose data related to total RES installation from 2010 to 2022 were collected: starting from these informations, a Business-As-Usual scenario (BAU) was build up by observing the yearly annual growth in installed electricity capacity from renewables.

Then the evaluation of the average annual increase of RES installation per country and per source was carried out in order to elaborate the BAU scenario, based on a linear trend up to year 2030.

The objective is to figure out which would be the state of energy transition process in the next years by hypothesizing the same growth level of the last decade and to have useful data about RES development to be compared (in particular for solar photovoltaic and

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[3] Including Bioenergy, CSP, Geothermal and Marine energy

wind energy) to the objectives described in the National Energy and Climate plans to 2030 of the different Mediterranean countries.

Some exceptions were made, for instance on hydropower sector: since it relies on a kind of source that is non-infinite, for the sake of coherence data about year 2022 were kept constant along the trend evolution.

Additionally, in the obtained results only data about solar PV, wind energy and hydropower were explicated since they account for most of the total RES electricity capacity.

Table 4 BAU scenario 2030 (installed capacity [GW])

	Hydropower	**Solar PV**	**Wind**	**Others**
Eastern shore	**33,35**	**24,15**	**18,37**	**6,25**
Cyprus	0,00	0,71	0,21	0,02
Israel	0,01	6,90	0,04	0,44
Lebanon	0,28	0,73	0,01	0,01
Syrian AR	1,49	0,10	0,00	0,01
Turkiye	31,57	15,71	18,11	5,78
Northen shore	**79,63**	**110,74**	**98,02**	**14,66**
Albania	2,51	0,05	0,00	0,00
Bosnia Herzegovina	1,84	0,18	0,23	0,02
Croatia	2,20	0,30	1,69	0,27
France	24,56	28,32	31,26	3,05
Greece	3,42	9,13	7,27	0,15
Italy	18,84	39,40	15,77	5,29
Malta	0,00	0,37	0,00	0,01
Montenegro	0,70	0,04	0,20	0,00
Portugal	7,59	4,14	6,56	0,86
Slovenia	1,17	1,05	0,01	0,08
Spain	16,80	27,77	35,05	4,92
Southern shore	**4,33**	**4,41**	**5,21**	**1,12**
Algeria	0,13	0,73	0,02	0,03
Egypt	2,83	2,83	2,37	0,19
Libya	0,00	0,01	0,00	0,00
Morocco	1,31	0,51	2,45	0,90
Tunisia	0,07	0,33	0,37	0,00
Mediterranean	**117,32**	**139,31**	**121,62**	**22,03**

In Table 4 “others” refers others natural resources including Bioenergy, CSP, Geothermal and Marine energy, that are less relevant in terms of installed capacity.

As previously described, these results are just an extension of the current national trend of RES development up to year 2030, so it is expected that the future development at the same year should go beyond this projection since in the NECPs trends which are better than the linear one are awaited.

The values presented in the table show that despite their great potential for installation of renewable energy, Southern shore countries exhibit in the last decade an historical trend that does not allow them to reach much consistent results in 2030 even though the RES development of recent years in those areas.

On the contrary, Northern shore of the area hold the largest shares for all kind of sources, also due to their higher energy consumption and in particular a significant development of solar PV and wind installation can be predicted.

By analyzing in detail the projection can be seen that the greatest shares of PV technologies are expected to be installed in Italy (39,4 GW), France (28,3 GW) and Spain (27,8 GW), but significant evolution is contemplated also in Turkey (15,7 GW) which contributes to much of the RES capacity among the Eastern shore countries.

Quite same discussion can be made on wind technologies, which are expected to grow beyond 120 GW of installation capacity in the whole area.

Finally, in 2030 hydropower technology still plays an important role in the RES mix of the Mediterranean region, almost on par with solar PV, even though in the trajectory it is not assumed any increase in its installation from 2022 data.

1.4 Electricity demand and generation forecasting

The trajectories elaborated in the previous paragraph are representative of just the electricity capacity regarding renewable energy systems. Above the installed capacity, what is significant to analyze is the expected aggregate electricity demand of each country at year 2030, so as to compare what would be the gap between the awaited electricity generation by RES and the total demand by country.

For this purpose, the expected electricity demand (expressed in GWh) was taken by Med-TSO report[3], which describes the evolution of the Mediterranean according to different scenarios. It provides a platform based on historical data where a rough estimation of the regional demand is proposed: the adopted scenario is the "Mediterranean ambition" [4] one which suggests top-down boost for supra-national cooperation and utility scale developments.

Table 5 Electricity demand forecast at 2030 [TWh]

	Electricity demand [TWh]
Eastern shore	**597,74**
Cyprus	6,21
Israel	85,69
Lebanon	31,36
Syrian AR	43,08
Turkiye	431,41
Northern shore	**1633,46**
Albania	14,96

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[4] In the Mediterranean Ambition scenario, strong RES development is based on utility-scale projects backed by institutional agreements and international cooperation, and through offtake agreements. Complementarities between countries are relevant also in this scenario, emphasized by different individual paths in large project deployment. Mediterranean Ambition favours a centralized low carbon and RES option.

Bosnia Herzegovina	11,75
Croatia	20,70
France	710,17
Greece	81,16
Italy	337,52
Malta	2,04
Montenegro	5,22
Portugal	69,32
Slovenia	25,50
Spain	355,15
Southern shore	**645,38**
Algeria	147,66
Egypt	335,97
Libya	68,70
Morocco	66,54
Tunisia	26,51

Source: Med-TSO digital Masterplan

Obviously, the national demand is strongly related to the size and demography of the countries, so these forecasts reflect the amount of population of each area.

The objective is to understand how the possible trajectory developed in this study, and so how far the electricity generation from RES, could contributes to meet the total demand.

On this basis, a projection to 2030 for the electricity generation from renewables was developed by performing a BAU scenario, as previously done for the electricity capacity: by analyzing historical data from 2010 to 2021 and tracing the linear trajectory to 2030 considering the average annual increase in generation from Solar PV and Wind energy and by keeping as constant the latest value of generation from Hydropower.

Only these sources have been considered in the study, since they account for most of the electricity generation from RES.

Table 6 Electricity RES generation forecast at 2030 [TWh]

	Hydropower	**Solar PV**	**Wind**	**Total generation**
Eastern shore	**58,61**	**34,72**	**55,51**	**148,84**
Cyprus	0,00	0,85	0,42	1,27
Israel	0,38	8,22	0,32	8,91
Lebanon	0,68	0,20	0,00	0,88
Syrian AR	1,63	0,11	0,00	1,74
Turkiye	55,93	25,34	54,77	136,04
Northern shore	**181,91**	**121,74**	**204,31**	**507,96**
Albania	8,92	0,07	0,00	9,00
Bosnia Herzegovina	6,69	0,13	0,69	7,52
Croatia	7,13	0,27	3,63	11,03
France	59,62	28,10	58,83	146,55
Greece	5,90	9,42	16,84	32,16
Italy	45,39	43,97	30,59	119,94
Malta	0,00	0,46	0,00	0,46

Montenegro	2,01	0,00	0,58	2,60
Portugal	11,91	3,89	16,52	32,32
Slovenia	4,71	0,81	0,01	5,54
Spain	29,63	34,60	76,62	140,84
Southern shore	**16,68**	**10,63**	**18,08**	**45,39**
Algeria	0,15	1,17	0,02	1,34
Egypt	14,77	8,15	8,62	31,54
Libya	0,00	0,01	0,00	0,01
Morocco	1,71	1,01	8,77	11,49
Tunisia	0,05	0,30	0,66	1,01

From Table 6 it can be noticed that consistently with the previous data reported, the highest share of electricity generated from RES comes from Northern shore countries, accounting for almost 508 TWh produced by 2030. Similarly, among the three major natural sources wind energy seems to be the most exploited one across Southern and Northern countries.

The total expected production from RES is apparently not enough to cover the entire demand foreseen by the adopted scenario, so the next step is to assess what should be the additional electricity capacity needed in order to meet the demand by assuming an energy mix of 100% renewables.

Table 7 RES additional capacity to meet the demand [GW]

	Solar PV	**Wind energy**	**Hydropower**
Eastern shore	**112,44**	**37,50**	**130,65**
Cyprus	2,52	0,70	0,00
Israel	52,79	0,07	0,00
Lebanon	36,80	0,00	6,20
Syrian AR	1,16	0,01	60,14
Turkiye	19,17	36,73	64,30
Northern shore	**342,86**	**178,30**	**128,84**
Albania	0,06	0,00	1,66
Bosnia Herzegovina	0,25	0,14	0,89
Croatia	0,60	1,71	1,44
France	169,79	101,27	64,44
Greece	18,09	7,84	4,83
Italy	95,59	22,80	20,99
Malta	1,24	0,00	0,00
Montenegro	0,10	0,19	0,65
Portugal	5,19	4,97	7,88
Slovenia	8,82	0,03	2,42
Spain	43,14	39,34	23,65
Southern shore	**187,71**	**44,59**	**372,86**
Algeria	84,32	2,67	325,29
Egypt	38,20	27,21	20,05
Libya	55,84	0,00	0,00
Morocco	3,09	7,56	22,39
Tunisia	6,26	7,15	5,13

The additional electricity capacity needed to meet the foreseen demand at 2030 is proposed in Table 7. The calculation was made starting from the "delta" between the total demand and the expected generation by source (Solar PV, Wind energy and Hydropower), then by using the historical data the capacity factor of each source was estimated.

Finally, the supplementary capacity of each source was found to underline the difference between the demand forecast and the results of the BAU scenario for the RES generation.

Anyway, the primary objective of this analysis is to show the effort needed in order to reach an energy mix made of 100% renewable systems which could be capable to satisfy the eventual Mediterranean electricity demand.

As evidence of this, the magnitude of the values contained in Table 7 is significantly larger with respect to the current installed capacity (Table 1) but also in comparison to the elaborated trajectory to 2030 (Table 4) for most of the countries.

In particular, these data show how some nations (e.g., Algeria, Egypt, Libya and Israel) need such an important effort in RES installation in order to meet the forecasted demand, meaning that a significant boost in renewable energy technologies in the next years is required.

1.5 Comparison with national objectives

The BAU scenario, as previously anticipated, does not exactly reflect the expected trend in renewable energy development and installation which sees a growth that can be higher than linear, as described within the National Energy and Climate plans.

Focusing on this topic, in Table 8 a comparison between the BAU scenario elaborated and the national objectives at 2030 for Solar PV and Wind energy is carried out with the aim to underline the gap and estimate the number of years needed to reach that objectives by assuming the current trend.

Table 8 Comparison BAU scenario and national objectives for Solar PV and Wind energy [GW]

	PV projection 2030	**PV objective 2030**	**Years to meet PV objective**	**Wind projection 2030**	**Wind objective 2030**	**Years to meet wind objective**
Eastern shore						
Cyprus	0,714	0,8	2	0,208	0,2	/
Israel	6,902	20	38	0,041	/	/
Lebanon	0,733	2,18	40	0,005	1	3980
Syrian AR	0,100	2,5	480	0,001	1,5	9
Turkiye	15,705	38	28	18,114	25	8
Northern shore						
Albania	0,047	0,45	171	0,000	0,2	662
Bosnia Herzegovina	0,179	1,5	148	0,225	0,5	24
Croatia	0,304	0,96	43	1,686	2,562	11

France[5]	28,321	39,55	8	31,259	39,7	7
Greece	9,128	9,7	1	7,267	7,8	2
Italy	39,400	79	22	15,770	28,14	25
Malta	0,368	0,25	/	0,000	/	/
Montenegro	0,037	0,032	/	0,197	0,19	/
Portugal	4,137	20,4	81	6,562	12,4	42
Slovenia	1,046	3,5	47	0,006	0,04	124
Spain	27,774	76	40	35,051	62	38
Southern shore						
Algeria	0,726	13,5	352	0,017	5	5980
Egypt	2,830	23	143	2,368	20,5	200
Libya	0,008	3,35	15231	0,000	0,85	16
Morocco	0,514	4,8	171	2,449	5,7	29
Tunisia	0,327	1,51	73	0,373	1,755	87

For most of the Mediterranean countries the objectives are reported in their own NECPs with exception of Israel[4] and Malta[5] that apparently do not show particular goals for wind energy: as reported in Israel NECP, wind energy development has been the slowest of all renewable energy technologies, despite its enormous potential in the country. This is due to the high cost of wind energy generation and opposition from a variety of groups, including environmental activists and the military lack of approval from authorities who have cited potential harm to bird and bat populations as well as interference with Israel Air Force operations.[4] On the other hand, wind energy projects, both onshore and offshore, cannot be successfully implemented in Malta using mature technologies due to significant restrictions in the local context, including technical, social and environmental constraints. High population density and limited land area inhibit the development of onshore wind power. Planning constraints include the potential interference with the safety of airport operations as well as the significant negative visual impact and proximity to densely inhabited areas. Lack of possible environmental mitigation strategies to reduce impacts on protected bird colonies further contribute to the unfeasibility of onshore wind farms.[5]

Another note regarding these data is related to some countries which do not show any increase in installation capacity in the last decade: this situation refers to Syria, Libya and Albania regarding Wind energy capacity. In such cases the average annual increase of the shore to which they belong has been considered, since in the next years a certain growth is however expected.

It is interesting to note that some countries, assuming the current development trend, will reach their objectives in so many years: this is the case of Algeria, Syria and Libya for PV technology, and Lebanon, Albania, Egypt and Algeria for Wind energy.

This emphasizes the effort that should be made to bridge the gap between the current situation and the future set goals.

However, from the elaborated trajectories there are some nations that are expected to reach their objectives (Malta for PV, Cyprus for wind[6] and Montenegro for both) within year 2030 considering the current trend.

Finally, to complete the overview on this topic, an evaluation of the marginal electricity capacity of Solar PV and Wind technologies has been conducted.

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[5] In France National Energy and Climate plan the objectives are set for year 2028

Table 9 Additional PV & Wind capacity to reach 2030 objectives [GW]

	Solar PV	Wind energy
Eastern shore	**39,33**	**9,38**
Cyprus	0,09	0,00
Israel	13,10	/
Lebanon	1,45	1,00
Syrian AR	2,40	1,50
Turkiye	22,29	6,89
Northern shore	**120,72**	**55,52**
Albania	0,40	0,20
Bosnia Herzegovina	1,32	0,28
Croatia	0,66	0,88
France	11,23	8,44
Greece	0,57	0,53
Italy	39,60	12,37
Malta	0,00	/
Montenegro	0,00	0,00
Portugal	16,26	5,84
Slovenia	2,45	0,03
Spain	48,23	26,95
Southern shore	**41,75**	**28,60**
Algeria	12,77	4,98
Egypt	20,17	18,13
Libya	3,34	0,85
Morocco	4,29	3,25
Tunisia	1,18	1,38

Table 9 describe the quantities needed to reach the 2030 national objectives at that year. These values are indeed obtained by performing a backward analysis starting from the national objectives, from which the results of the 2030 BAU projection have been subtracted.

It is useful to highlight that only few countries are expected to reach on time their own objectives: Malta for PV, Cyprus for wind and Montenegro for both. The empty cells refer to absence of defined objectives in the national plans.

This proves again that the linear trend assumed in the proposed scenario is not enough to reach the goals and so a further effort in RES development and installation is needed in order to keep up with the current plans.

2. Technologies for the Mediterranean energy transition

2.1 Overview of the most relevant technologies

In order to effectively implement the energy transition, the development of new technologies is required, so that processes that are now supplied by fossil fuels may be decarbonized. However, their commercial and technological development at scale to support the energy transition process requires an adequate Technology Readiness Level (TRL)[6]. This section aims to briefly describe the most relevant energy transition-enabling technologies that currently have a TRL larger of equal than 8, i.e., according to IEA's ETP Clean Energy Technology Guide: "First-of-a-kind commercial: commercial demonstration, full-scale deployment in final form".[7]

Only electricity or hydrogen as relevant commodities for the energy transition are considered. This choice was taken because of the pivotal role that they are expected to have in the future, as key enablers of the energy transition.

2.1.1 Electricity-based technologies

In this section are presented and briefly illustrated the main technologies associated to the commodity electricity, organizing them according to the step of the ECC they can relate to.

Table 10 Electricity-based technologies

Electricity generation					
Input	**Technology name**	**TRL**	**Cost [USD/kW]**	**Efficiency**	**Ref**
Solar irradiance	Crystalline Silicon PV	10	810 - 1120	0.174 - 0.227	[8],[9]
	Floating solar PV	8	~ 860	0.174 - 0.227[7]	[9], [10]
	Multi-junction cell PV	9	4850 - 8240	0.392 - 0.471	[11]
Water	Hydraulic turbine (reservoir, run-of-river)	11	2650 - 3900	0.4 - 0.5	[9], [12]
	Tidal stream & tidal range	9	150 - 800	~ 0.8	[13],[14]
Wind	Onshore wind turbines	10	1590 - 1950	0.29 - 0.35	[9], [12]

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[6] The Technology Readiness Level (TRL) is an indicator that measures the maturity of a specific technology; according to the IEA scale, it can range from 1 (initial idea) to 11 (proof of stability reached).

[7] Efficiency value is the same of c-Si PV since same technology is exploited. However an efficiency 2.46 %- 8.81 % higher than ground PV was recorded

	Seabed fixed offshore wind turbines	9	1721 - 4039	0.45 - 0.51	[9], [12]
	Floating offshore wind turbines	8	2936 - 3289	0.45 – 0.51[8]	[15]
Nuclear fuel	Large-scale nuclear power reactor	11	2157 - 6920	~ 0.33	[9], [12]
	Sodium-cooled fast nuclear reactor	10	2467	0.4 - 0.435	[16]
Fossil fuels	Natural gas TPP with CCUS[9]	8	2412 - 2826	~ 0.6	[12],[9]
	Coal TPP with CCUS	9	4490 - 5991	0.3 - 0.33	[9]
Natural Gas + Hydrogen	TPP	9	2412 - 2826	~ 0.608	[17]
Heat	Geothermal power plant	11	3851 - 10959	0.12 - 0.18	[9], [18]
Electricity storage					
Type	**Technology name**	**TRL**	**Cost [USD/kWh][10]**	**Efficiency**	**Ref**
Mechanical	PHS	11	10 - 100	0.7 - 0.84	[19], [20]
	FES	9	1500 - 6000	0.70 - 0.95	[19]
	CAES	8	50 - 80	0.7 - 0.8[11]	[12], [21]
Electro-chemical	Lithium-ion batteries	10	245 - 620	0.92 - 0.96	[19], [22]
	Sodium-based high temperature batteries	9	263 - 735	0.8 - 0.9	[19], [23]
	Redox flow batteries	9	315 - 1680	~ 0.75	[24]
Electricity conversion					
Input	**Technology name**	**TRL**	**Cost [USD/kW]**	**Efficiency**	**Ref**
Hydrogen	SOFC	9	3000 - 4000	0.45 - 0.5	[12], [25]
	MCFC	9	4000 - 6000	0.45 - 0.52	[26],[25]
Electricity transmission & distribution					
Type	**Technology name**	**TRL**	**Cost [MEur/km]**	**Efficiency**	**Ref**
Transmission	HVDC	11	~ 3.5	~ 0.97[12]	[27]
	Ultra-high voltage	11	~ 3.1	0.93 - 0.94	[28]

Source: ETP Clean Energy Technology Guide (IEA, 2023)

Generation – Solar Photovoltaic (PV): PV modules exploit the solar irradiance to produce electric energy.[29] Today, the vast majority of PV modules are based on wafer-based crystalline silicon (c-Si)[30]. Current commercial single-crystalline modules have an higher irradiance-to-electricity conversion efficiency, ranging between 14 % to 20%, [7].

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[8] An increase in efficiency is expected due to the possibility of floating structures to access deeper water and so higher wind charcteristcs

[9] CCUS refers to carbon capture utilization and storage

[10] Refers to energy installation cost

[11] Refers to traditional adiabatic CAES process

[12] Obtained by considering losses over 1000 km distance

Another solar PV technology is represented by multi-junction PV modules whose design involves superposing several cells in a stack[7].
Generally, solar PV installations are characterized by ground-mounted structures, but a further configuration exists, the so-called floating PV systems are mounted on a structure that floats on a water surface[7]

Generation – Wind turbines: wind turbines are devices that exploit the kinetic energy of the wind to produce electricity. The main part of the installation is the rotor that converts the wind energy into rotational energy, which is then used in an electric generator to produce electric energy[7]. Wind turbines can be installed onshore, in specific sites according to some environmental constraints or offshore. The energy capture and power generation technology is fundamentally similar. Offshore turbines are marinised and configured for optimal operation in the offshore environment. In particular there are two different types of design for offshore turbines:

- Offshore wind turbines fixed to the seabed display a variety of foundation types, encompassing monopiles, multi-piles, gravity foundations, and suction caissons. These foundations are often paired with specific support structures, such as tubular towers, jackets, tripods, lattice towers, and hybrid designs [7]

- Floating offshore turbines, in contrast to traditional fixed offshore turbines, lack foundations on the seabed. Instead, they are supported by floating platforms such as barges, semi-submersibles, tension legs, or spars, which are secured in place by various mooring and anchoring systems. This design enables them to operate in water depths exceeding 50-60 meters, surpassing the limitations of the previous configuration[7].

Generation – Hydropower: The basic principle of the hydropower generation is the impulse momentum. Potential energy of the water is converted into the mechanical energy by rotating the turbine and mechanical energy is further converted into the electrical energy by using generator.[31] Hydropower harnesses the perpetual, continually replenishing water cycle to generate electricity, utilizing a resource (water) that remains unaffected or depleted throughout the process. Various types of hydropower facilities exist, all driven by the kinetic energy of flowing water as it progresses downstream. Due to its reliance on water for power generation, these plants are typically situated on or near water sources. The amount of energy derived from moving water is determined by both the volume of water flow and the change in elevation—referred to as the head—between different points. Greater flow rates and higher heads result in increased electricity production potential.[32]

Generation – Tidal stream: Tidal turbines have the option to be either fixed to the seabed or float closer to the surface, secured by moorings attached to the seafloor. Among tidal energy technologies, the horizontal-axis turbine is the most prevalent. In this design, the tidal currents spin the rotors of the turbine, akin to how the blades of a wind turbine are rotated by the wind.
Additional designs include the vertical-axis turbine and the tidal kite. Tidal currents result from the gravitational influences of the sun and the moon, and they tend to be most intense in narrow water bodies like around islands or inlets. [33]

Generation – Tidal range: Tidal range technology, while also utilizing tides for electricity generation, is distinct from tidal stream devices. Unlike tidal stream devices, which capture the energy from tidal currents, tidal range installations generate power from the variance in sea levels between high and low tides.

Tidal range technology operates similarly to hydropower, necessitating the presence of a dam or barrier to contain a substantial volume of water. The contrast in water levels between the impounded area and the surrounding environment prompts the movement of water from one side to the other. This water flow is then directed through turbines housed within the structure, thus generating power. [33]

Conversion – Fuel Cells: Fuel cells are electrochemical devices that generate electricity and heat continuously as long as fuel is provided. Typically, a fuel cell consists of two electrodes—an anode (negative electrode) and a cathode (positive electrode)—encasing an electrolyte. Hydrogen, for example, serves as the fuel and is supplied to the anode, while air is provided to the cathode. A catalyst facilitates the separation of hydrogen atoms into protons and electrons, which then follow separate paths to the cathode. Electrons travel through an external circuit, creating an electric current, while protons migrate through the electrolyte to the cathode. At the cathode, protons combine with oxygen and electrons to produce water and heat. While the fundamental operations of all fuel cells remain consistent, various specialized types have been developed to exploit different electrolytes and fulfill diverse application requirements.[34]. The fuel and the charged species migrating through the electrolyte may be different, but the principle is the same:

- Polymer electrolyte membrane (PEM) fuel cells, also referred to as proton exchange membrane fuel cells, employ a proton-conducting polymer membrane as their electrolyte, commonly utilizing hydrogen as the primary fuel source. These cells are characterized by their operation at relatively low temperatures

- Alkaline fuel cells utilize an alkaline electrolyte such as potassium hydroxide or an alkaline membrane capable of conducting hydroxide ions rather than protons

- Molten carbonate fuel cells utilize a molten carbonate salt confined within a porous matrix to conduct carbonate ions as their electrolyte. Operating at high temperatures (approximately 600°C), they can internally reform fuels such as natural gas and biogas.

- Solid oxide fuel cells utilize a thin ceramic layer as a solid electrolyte, facilitating the conduction of oxide ions. They are currently in development for various stationary power applications and as auxiliary power units for heavy-duty trucks. Operating temperatures range from 700°C to 1000°C with zirconia-based electrolytes, and can go as low as 500°C with ceria-based electrolytes. [34]

Generation – Thermal power plants: Thermal power plants harness the heat energy from primary fuels like coal to generate electricity. Typically, in these plants, the combustion of primary fuels heats water, converting it into steam. This steam then drives steam turbines, ultimately producing electricity. Afterwards, the steam is condensed and recycled within the system. Thermal power stations utilize various heat sources, including fossil fuels, nuclear energy, biomass, and waste.[35]

Geothermal power plants extract fluids from underground reservoirs to the surface to generate steam, which in turn drives turbines to produce electricity. Three primary technologies are employed in geothermal power plants: dry steam, flash steam, and binary cycle.[36]

Fossil-fired TPPs can be equipped with carbon capture utilization & storage (CCUS) systems, to abate the emissions of greenhouse gases (GHG) arising from fuel combustion. To this purpose, hydrogen-rich gas blends can be adopted in some cases[7].

Storage – Mechanical: Mechanical energy storage operates within intricate systems that utilize heat, water, or air along with compressors, turbines, and other machinery, offering sturdy alternatives to electrochemical battery storage. Pumped hydro-storage (PHS) currently stands as the most widely deployed large-scale mechanical energy storage technology. Other notable mechanical energy storage technologies encompass flywheels and compressed air energy storage (CAES).

In pumped hydro-storage (PHS), potential energy is stored by pumping water to an uphill reservoir. When energy is needed, it is retrieved by allowing the water to flow downhill through a hydropower turbine.

Compressed air energy storage (CAES) stores energy in the form of compressed air. In traditional CAES systems, the compressed air is stored in underground caverns due to the large storage volumes required. Typically, fuel is added to the compressed air to power a combustion turbine. However, in adiabatic CAES, heat generated during compression is captured and stored using a thermal storage system.

Similarly, liquid air energy storage (LAES) stores energy in the form of liquefied air.

Flywheels, on the other hand, store energy as rotational kinetic energy by spinning a mass around a fixed axis. [37]

Storage – Electro-chemical: Electrochemical energy storage systems represent the most traditional form of energy storage devices for power generation, relying on the storage of chemical energy that can be converted to electrical energy as needed. The most established technologies in this domain are electrochemical batteries, comprised of electrochemical cells that facilitate the conversion of stored chemical energy into electrical energy [38].

A lithium-ion battery consists of several key components: an anode, cathode, separator, electrolyte, and two current collectors (positive and negative). The anode and cathode serve as reservoirs for lithium ions. The electrolyte transports positively charged lithium ions from the anode to the cathode and vice versa, facilitated by the separator. This movement of lithium ions generates free electrons in the anode, leading to the buildup of charge at the positive current collector.[38]

Flow batteries, also known as redox flow batteries (RFB), belong to the category of electrochemical energy storage devices. They typically consist of two liquid electrolyte tanks connected to a cell stack, which is separated by an ion-selective membrane. Electrolytes are drawn from these tanks to the cell stack, where the charging and discharging of the batteries occur through reduction-oxidation reactions of the electrolyte solutions. During the charging process, electrons are provided to recharge the electrolyte, often sourced from photovoltaic (PV) panels, wind turbines, or the grid input. Conversely, in the discharging process, the liquid electrolyte is pumped through electrodes to extract electrons, thereby generating electricity.[39]

Transmission and Distribution: Power transmission involves the movement of electricity on a large scale at extra high voltage levels, transporting it from generation points to substations. Those seeking to connect to the extra high or high voltage transmission network are typically referred to as transmission connections, with connection voltages ranging from above 132kV up to 400kV. This network plays a vital role in transporting electricity across the country, bridging the gap between generation sites and areas of demand. However, it doesn't directly supply electricity to homes and businesses; instead, distribution systems step down voltages to 132kV and below for local consumption.

In contrast, power distribution revolves around converting high-voltage electricity at substations into lower voltages suitable for distribution to private, public, and industrial consumers. Distribution networks typically operate at connection voltages of 132kV and below. Determining limits on megawatt capacity can be more nuanced and subject to variation based on location and network capacity. [40]

2.1.2 Hydrogen-based technologies

Following the previous scheme, below is presented a brief overview of the most technologically mature technologies for the synthesis, storage and transport of hydrogen.

Table 11 Hydrogen-based technologies

H2 generation					
Input	**Technology name**	**TRL**	**Cost [USD/kW]**	**Efficiency**	**Ref**
Electricity	Alkaline electrolyser	9	500 - 1400	0.58 - 0.7	[41], [42]
	PEM electrolyser	9	1100 - 1800	0.5 - 0.83	[42],[43]
	SOEC electrolyser	8	2800 - 5600	up to 0.84[13]	[42]
Fossil fuels	Steam methane reforming with CCUS (low-capture rates)	9	1583	0.69	[24]
	Natural gas pyrolysis (plasma thermal decomposition)	8	90	0.58	[44]
	Coal gasification with CCUS (low-capture rates)	9	2783	0.508	[24]
H2 storage					
Type	**Technology name**	**TRL**	**Cost [USD/kg]**	**Efficiency**	**Ref**
Aboveground physical	Pressure vessel	11	712 - 998	0.91[14]	[45]
	Liquid hydrogen tank	9	1905	0.71	[45],[46]
Undergound physical	Salt cavern	10	0.6	0.98	[12]
H2 transmission & distribution					
	Technology name	**TRL**	**Cost [USD/kg]**	**Efficiency**	**Ref**
	Ammonia tanker ships	11	1.2	0.9	[47]
	New hydrogen pipeline	9	~ 1.28[15]	~1.00	[46], [47]

Source: ETP Clean Energy Technology Guide (IEA, 2023)

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[13] Current highest recorded value by a manufacturing company

[14] Considering standard pressure value for compressed H_2 (200 bar)

[15] Refers to transport unit cost

H2 generation – Electrolysis: An electrolyzer is a device that generates hydrogen through a chemical process known as electrolysis. This process involves the separation of water molecules into hydrogen and oxygen using electricity.[48]

The polymer electrolyte membrane (PEM)-based electrolyzer is widely utilized, with many modern electrolyzers incorporating PEM technology. Similar to PEM fuel cells, PEM electrolyzers employ a thin, solid ion-conducting membrane as the electrolyte, replacing the need for an aqueous solution. This setup ensures the production of highly pure hydrogen.

In contrast, alkaline electrolyzers typically utilize an aqueous potassium hydroxide solution as the electrolyte. Other commonly used electrolytes include sulfuric acid, sodium chloride, and sodium hydroxide. The concentration of the electrolyzing solution typically ranges from 20% to 30% by weight, striking a balance between ionic conductivity and corrosion resistance.

A Solid Oxide Electrolysis Cell (SOEC) essentially functions as the reverse of a Solid Oxide Fuel Cell (SOFC). Operating at relatively high temperatures (700-1000 °C), SOECs exhibit exceptional efficiency, offering significant potential for the efficient and cost-effective production of hydrogen fuel.[49]

Steam-methane reforming represents a well-established production process wherein high-temperature steam (ranging from 700°C to 1000°C) is utilized to generate hydrogen from a methane source, such as natural gas. During steam-methane reforming, methane reacts with steam under pressures ranging from 3 to 25 bar in the presence of a catalyst, yielding hydrogen, carbon monoxide, and a minor quantity of carbon dioxide. This process is endothermic, necessitating the provision of heat for the reaction to progress.

Following steam-methane reforming, the "water-gas shift reaction" takes place, wherein carbon monoxide and steam are reacted with the aid of a catalyst to produce carbon dioxide and additional hydrogen. Subsequently, in the final process step known as "pressure-swing adsorption," carbon dioxide and other impurities are separated from the gas stream, resulting in the production of nearly pure hydrogen.

On the other hand, natural gas pyrolysis offers a hydrogen production method with minimal carbon emissions. Pyrolysis involves the breakdown of molecules in the presence of heat. In the case of natural gas pyrolysis, heat is applied to molecules to decompose them into hydrogen gas and solid carbon.[50]

Gasification is a process that converts coal into a high-temperature synthesis gas, also known as syngas, reaching temperatures of up to 1800°C. This syngas primarily consists of carbon monoxide, hydrogen, and carbon dioxide. Subsequently, the syngas undergoes cooling and purification to eliminate other gases and particles, resulting in a mixture predominantly composed of carbon monoxide, carbon dioxide, and hydrogen.

The purified syngas is then directed to a "shift reactor" where a shift reaction occurs. During this reaction, carbon monoxide is transformed into additional hydrogen and carbon dioxide by reacting it with steam. Following the shift reaction, the syngas is divided into separate streams of hydrogen and carbon dioxide.

The hydrogen stream, once purified, is now suitable for various applications. Meanwhile, the carbon dioxide stream is captured and transported for sequestration.[51]

Storage – physical: Stationary aboveground storage for gaseous hydrogen typically comprises multiple cylindrical pressure vessels. These vessels may be housed within a frame structure and situated on a concrete foundation. Each hydrogen storage cylinder is typically elongated and can be oriented either horizontally or vertically. Pressure and/or thermal relief valves are commonly installed at one or both ends of the cylinders, connected to a vent stack for safe release of excess pressure or thermal buildup.[52]

Liquid hydrogen (LH2) is typically stored in cylindrical tanks, although spherical tanks may be employed for very large volumes. Cryogenic tanks are utilized for storing LH2 and are designed to be vacuum-insulated to minimize evaporation losses. Additionally, these tanks contain redundant pressure relief devices as a safety measure to prevent overpressurization. Liquid hydrogen tanks typically operate at pressures of up to 850 kPa.[53]

Underground salt cavern storage is recognized as one of the most promising geological storage technologies for hydrogen. This is attributed to several factors including their technological maturity, fast cycling flexibility, and large volume storage capacity. Salt caverns are cavities formed through solution mining within suitable salt formations, primarily halite-dominated, using fresh water to dissolve the salt rock. The surrounding salt possesses advantageous properties such as low permeability, high sealing capability, inert chemical behavior with respect to hydrogen, and favorable mechanical properties. These characteristics enable salt caverns to accommodate repeated withdrawal and injection cycles and facilitate secure storage of fluids over extended periods.[54]

2.2 Alternative fuels: policies and regulatory frameworks in the Mediterranean area

2.2.1 EU legislation for alternative fuels

In the next sections an overview on the current development of alternative fuels and hydrogen technologies is displayed as well as their relative policies framework and directives at European and national level, as principal key players for the Mediterranean transition.

Considering the Mediterranean region, the development and diffusion of technologies related to alternative fuels, (that include primary solid biofuels, biogases, biodiesel, biogasoline and other liquid biofuels) is not so established.

At the EU level, a broad policy framework, existing and proposed legislation are presented and specify targets and regulations for alternative fuels. These include the revised Renewable Energy Directive 2018/2001 (REDII) and its proposed update as part of the European Green Deal, the ReFuel EU aviation legislative proposal, and the Renewable Energy Directive Recast.

The Renewable Energy Directive recast - REDII

The Renewable Energy Directive II (RED II) outlines sustainability and greenhouse gas (GHG) emission criteria for bioliquids used in transportation to contribute to the overall 14% target and qualify for financial support from public authorities. While some criteria remain unchanged from the original RED, others are new or revised. Notably, RED II introduces sustainability requirements for forestry feedstocks and GHG criteria for solid and gaseous biomass fuels.

While biofuels play a vital role in helping the EU achieve its greenhouse gas reduction targets, their production often occurs on cropland previously utilized for other agricultural purposes such as food or feed cultivation. This continued agricultural production may lead to the expansion of agricultural land into non-cropland areas, including regions with significant carbon stocks like forests, wetlands, and peatlands.

Within the 14% transport sub-target, there is a specific objective for advanced biofuels derived from feedstocks listed in Part A of Annex IX. The contribution of advanced biofuels and biogas produced from these feedstocks as a percentage of final energy consumption in the transport sector must be at least 0,2% in 2022, 1% in 2025, and 3,5% in 2030.

Member States have the authority to exempt fuel suppliers providing electricity or renewable liquid and gaseous transport fuels of non-biological origin from complying with the minimum share of advanced biofuels and biogas produced from the feedstocks listed in Part A of Annex IX for those fuels.

Moreover, the proportion of biofuels, bioliquids, and biomass fuels utilized in transportation, derived from food and feed crops, should not exceed one percentage point more than their share in the final energy consumption of the road and rail transport sectors in 2020 in a given Member State. This limit is capped at 7% of the final energy consumption in the road and rail transport sectors in that Member State.[55]

The “Fit for 55” REDII revision

In July 2021, the European Commission presented proposed amendments to the Renewable Energy Directive II (RED II) as part of its Fit for 55 legislative package. These amendments are aimed at assisting the European Union in achieving its target of reducing greenhouse gas emissions by 55% by 2030 compared to 1990 levels. The primary adjustment in the proposed amendments involves replacing the 14% target for renewable energy in transport with a new target: a 13% reduction in greenhouse gas (GHG) intensity for transport by 2030, relative to a baseline GHG intensity derived from liquid fossil fuels.

Under these proposed amendments, fuels meeting specific GHG reduction criteria would contribute to the 13% reduction target based on their GHG savings, rather than being counted towards the 14% energy target as outlined in the 2018 RED II. This adjustment incentivizes member states to adopt fuels with higher GHG reductions compared to conventional alternatives. However, the eligibility criteria for GHG reduction remain unchanged for biofuels and certain renewable fuels of non-biological origin (RFNBOs) in the proposed RED II revision. Additionally, a new threshold of 70% GHG reduction has been suggested for renewable carbon fuels (RCFs).

Moreover, the amendments would decrease the advanced biofuels target from 3.5% to 2,2% by 2030 and introduce interim targets of 0.2% in 2022 and 0.5% in 2025. Despite the technically lower target, these revisions are considered more ambitious due to the removal of most multipliers from the 2018 RED II, retaining only the 1,2x multiplier for aviation and maritime fuels.

Additionally, the proposed amendments introduce a new RFNBO target, aiming for 2,6% of all energy supplied to the transport sector to be from RFNBOs. [56]

ReFuelEU - aviation

The primary aim of the ReFuelEU Aviation initiative, an integral aspect of the EU's "Fit for 55" package, is to amplify both the demand and supply of sustainable aviation fuels (SAFs) that yield lower CO2 emissions compared to conventional kerosene. This initiative seeks to ensure fair conditions within the EU aviation market while aligning aviation with the EU's climate objectives for 2030 and 2050, as SAFs are pivotal for reducing the sector's carbon footprint.

The new regulation introduces several significant provisions, including:

- A mandate for aviation fuel suppliers to ensure that all fuel provided to aircraft operators at EU airports contains a minimum share of SAFs from 2025 onwards, progressively increasing until 2050. Suppliers are required to incorporate 2% SAFs by 2025, 6% by 2030, and 70% by 2050. Additionally, starting from 2030, 1,2% of fuels must be synthetic, rising to 35% by 2050.
- An obligation for airlines to ensure that at least 90% of the annual fuel requirement for aviation at a specific EU airport corresponds to the amount of aviation fuel loaded, aimed at discouraging "tankering" practices that result in additional emissions due to increased weight.
- Eligibility criteria for sustainable aviation fuels and synthetic aviation fuels, encompassing certified biofuels, renewable fuels of non-biological origin (including renewable hydrogen), and aviation fuels derived from recycled carbon, meeting sustainability criteria and emission reduction standards specified by the Renewable Energy Directive. However, biofuels derived from food and feed crops are capped at a maximum of 70%. Low-carbon aviation fuels, including low-carbon hydrogen, can also contribute to meeting the minimum quotas stipulated in the regulation.
- Establishment of standards for competent authorities designated by Member States to enforce the regulation, alongside provisions for financial penalties.
- Introduction of a Union labeling system for environmental performance, empowering consumers to make informed choices and incentivizing airlines to embrace greener flights.
  Implementation of data collection and reporting obligations for fuel suppliers and airlines, facilitating monitoring of the regulation's impact on the competitiveness of EU operators and platforms.[58]

For the scope of ReFuelEU aviation, synthetic aviation fuels include:

- renewable hydrogen (produced from renewable electricity or from renewable liquid or gaseous fuels of non-biological origin).
- renewable electricity.
- renewable fuels of non-biological origin (RFNBO)[57].

The Renewable Energy Directive recast – REDIII (2023)

In September 2023, an updated iteration of the Renewable Energy Directive was introduced, incorporating several changes. Under this revision, Member States collectively pledge to elevate the share of energy sourced from renewable sources in the Union's gross final energy consumption to 45% by 2030. Furthermore, within this review, Member States establish an indicative target for innovative renewable energy technology, aiming for it to comprise at least 5% of the new renewable energy capacity installed by 2030.

As written in the recast, to ensure that the utilization of biofuels, bioliquids, and biomass fuels contributes to increased greenhouse gas emissions savings and effectively addresses potential indirect impacts such as deforestation, it is recommended that the Commission reassess the maximum allowable annual expansion rate of global production areas situated on lands with high carbon stocks. This reassessment should be conducted using objective and scientific criteria, while also taking into consideration the climate objectives and commitments of the Union. If deemed necessary, the Commission should propose a new threshold based on the outcomes of this review. Additionally, the Commission should explore the possibility of creating an expedited plan to gradually reduce the reliance on these fuels to meet renewable energy targets, with the aim of maximizing greenhouse gas emissions savings[58]."

The collective share of advanced biofuels and biogas sourced from raw materials listed in Annex IX, Part A, alongside non-biological renewable fuels supplied to the transport sector, is mandated to reach a minimum of 1% by 2025 and 5,5% by 2030. Within this quota, a minimum of 1% should originate from non-biological renewable fuels by 2030. Member States are encouraged to establish tailored targets for advanced biofuels, biogas, and non-biological renewable fuels at the national level to meet this requirement, fostering the development of both types of fuels.

Regarding bio-based components in diesel fuel, the existing reference in Directive 98/70/EC to diesel fuel B7, containing up to 7% methyl ester of fatty acids (FAME), poses limitations on achieving higher biofuel incorporation goals as outlined in Directive (EU) 2018/2001. Since nearly all diesel fuel supply in the Union adheres to the B7 type, the maximum percentage of bio-based components should be raised from 7% to 10%. To facilitate the market adoption of B10, comprising diesel fuel with a FAME content of up to 10%, it is imperative to maintain a protective B7 diesel fuel with a FAME content of up to 7% at the Union level. This is necessary due to the substantial portion of vehicles expected to be incompatible with B10, which is projected to constitute the vehicle fleet by 2030. [58]

2.2.2 Policies and projects in Southern and Eastern shore countries

The policy framework for alternative fuels in Eastern and Southern Mediterranean countries is generally less structured and detailed compared to European nations. However, there are instances of strategic plans, roadmaps, and projects with industrial partners related to the production and utilization of alternative fuels.

In Morocco, as part of a broader policy aimed at substantially boosting investment in renewable energy, efforts are underway to green the transport sector through pilot projects involving waste-based biodiesel and green hydrogen. The initiative aims to harness underutilized resources for energy production, particularly biomass and waste, while simultaneously prohibiting the use of cropland for biofuel feedstocks due to apprehensions about food security.[59]

Furthermore, Morocco has initiated the BIORESOL project, which aims to valorize the solid residues generated from the crushing of olives in the country. This project seeks to examine

various stages of the process, including fuel preparation through drying and densification, as well as its utilization through combustion, gasification, or hydrothermal carbonization. The project is supported by the IRESEN (Research Institute in Solar Energy and New Energies).[60]
Moreover, in Morocco, a pre-feasibility study was initiated in 2021 to assess the viability of sustainable biogas production in three Moroccan cities. The study revealed a potential to generate approximately 100 GWh of biogas annually, which could satisfy the fuel requirements for around 300 buses, although the actual potential is believed to be much greater. The investigation focused on substrate analysis in the cities of Kénitra, Tangier, and Rabat, with an emphasis on waste streams from industries to avoid any competition with food production. Slaughterhouse waste accounted for 72% of the potential, while 19% originated from manure and sewage sludge, and the remainder was derived from the fish and food industry. The study proposed biogas production to fuel the local bus fleet, offering a clean and economically viable mass-transport solution for future smart cities.[61]

In Algeria, there has been exploration into the use of certain non-edible oilseeds, as well as recycled cooking oils, for biodiesel production. These include Jatropha, Moringa, Citrullus, and Castor oil seeds. These oilseeds are being evaluated for their suitability to local climates and their potential yields in biodiesel production. While biodiesel production from these plants has been explored, it has mostly been at the experimental scale. Some cultivation trials have been conducted to assess their viability as raw material sources for biodiesel production. However, large-scale biodiesel production from these plants in Algeria is still at an early stage. Jatropha was introduced in Algeria as part of the European project JATROMED, and research and pilot projects have been undertaken to evaluate its potential for biodiesel production, with a specific emphasis on its oil yield and overall feasibility as a sustainable feedstock.[62]

In Tunisia, on December 4, 2019, Eni and the SNDP (Societé National de Distribution des Petroles AGIL SpA) signed a Memorandum of Understanding at the Tunisian Ministry of Industry, in the presence of the Tunisian Minister of Industry, Selim Feriani. This memorandum outlined a joint collaboration aimed at establishing a joint company to cultivate castor at a semi-industrial level. The purpose of this cultivation is to produce sustainable biofuels. Eni has already initiated trials in the Gafsa area to test the viability of this project.[63]

In its second updated NDC, Egypt has outlined several objectives. Firstly, it aims to produce alternative green fuels, including extracting 350,000 tons of algae oil annually for use in biofuel production and generating 100,000 tons of bioethanol annually. Additionally, Egypt plans to green its civil aviation sector by introducing 2% biofuels for airplanes, converting passenger buses and other vehicles to operate on cleaner fuels, installing photovoltaic (PV) systems in airports, and enhancing the energy efficiency of its facilities. Furthermore, Egypt aims to increase the contribution of waste-to-energy in solid waste management to 20% of collected waste by 2026. This will be achieved through utilizing waste as alternative fuel in the cement sector, converting waste to biofuels, and installing 300 MW of power generation capacity through incineration, pyrolysis, and other modern technologies.[64].
In Lebanon, on July 16, 2018, the IPT Energy Center (IPTEC) and the Holy Spirit University of Kaslik (USEK), with support from the United Nations Development Programme (UNDP) in Lebanon, entered into a Memorandum of Understanding (MOU). The purpose of this MOU was to establish a pilot plant for the production of biodiesel from Waste Cooking Oil (WCO) at the USEK campus in Kaslik. The President of USEK emphasized the significance of

converting used cooking oil into clean energy, particularly given the escalating waste crisis in Lebanon. He expressed hope that this initiative would lay the groundwork for a fruitful collaboration between the university and the private sector, underscoring the educational benefits for youth in environmental preservation for the well-being of future generations and the planet.[65]

In Syria, a town called Armanaz, located in the northwestern part of Idlib province, has adopted a unique approach to heating homes during the winter. Instead of traditional fuels, such as wood or coal, residents utilize a fuel known as 'birin', which is made from olive waste. This waste, derived from the seeds of olives leftover from the olive oil-making process, is commonly referred to as pomace. During olive oil production, significant amounts of pomace are left unused. To utilize this waste, it undergoes a process where it is pressed using a specialized machine and then dried in the sun. Once dried, the waste is transformed into cylindrical pellets, effectively converting it into biomass fuel. This innovative approach not only promotes environmental sustainability but also offers a cost-effective solution, as the production of birin is essentially free.[66]

In Israel, the Fuel Choices Initiative, sanctioned by the Cabinet of the Government of Israel in January 2013, represents a 10-year governmental endeavor managed within the Prime Minister’s Office. This initiative is committed to diminishing global reliance on oil for transportation while championing alternative fuels in the sector. Israel aims to position itself as a hub of expertise and industry in alternative fuel technologies by fostering the development and adoption of the next generation of such technologies. The initiative operates in collaboration with various vehicle manufacturers, advocating for the increased integration of alternative fuel technologies in Israel’s transportation sector. The Fuel Choices Initiative is motivated by the imperative to reduce dependence on crude oil for transportation, driven by concerns regarding energy security, economic stability, and environmental sustainability. Ambitious targets have been set: Israel aims to slash its use of oil for transportation by 30% by 2020 and by 60% by 2025, in contrast to the projected “business as usual” oil consumption levels. These targets have been established through meticulous bottom-up analysis of Israel’s diverse transportation market segments, with the understanding that any proposed solution must be economically feasible for end-users and the economy at large. The initiative promotes several alternative fuels, including compressed natural gas (CNG) for heavy-duty trucks and buses, methanol blends for cars (commencing with a 15% blend and gradually advancing to higher blends), and electric mobility solutions for buses, mass transit, and specialized fleet applications. Furthermore, the Fuel Choices Initiative envisions the implementation of projects in the longer term that utilize biofuels derived from second- and third-generation nonedible crops developed in Israel, as well as waste-to-energy conversion processes.[67]

As outlined in Turkey's National Renewable Energy Action Plan, the incorporation of bioethanol content in gasoline derived from domestic agricultural sources for road fuel distributed in the market is projected to reach a minimum of 2% effective January 1, 2013, followed by an increase to 3% by January 1, 2014.[68]

As a tangible demonstration of the integration of alternative fuels in the transportation sector, Turkish Airlines took a significant step forward by endorsing the Global SAF Declaration in 2022, signaling their commitment to advocating for the adoption of Sustainable Aviation Fuels (SAF). Initiating concrete actions, Turkish Airlines commenced the utilization of SAF on specific flight routes, notably between Istanbul Airport and Paris Charles De Gaulle Airport. Subsequently, they expanded the implementation of SAF to encompass routes connecting to various cities including Paris, Oslo, Gothenburg, Copenhagen, London, and Stockholm, with a dedicated day each week allocated for the utilization of these sustainable fuels.[68]

Table 12 Share of biofuels in TFC & TPES in 2019 [%]

	Biofuels in TFC (%)	**Biofuels in TPES (%)**
Northern Shore	**11,60%**	**10,00%**
Albania	13,08%	11,89%
Bosnia and Herzegovina	27,06%	17,42%
Croatia	15,20%	16,61%
France	7,90%	6,13%
Greece	6,37%	5,11%
Italy	6,80%	8,53%
Malta	2,48%	1,98%
Montenegro	18,13%	13,42%
Portugal	12,53%	13,33%
Slovenia	11,56%	9,78%
Spain	6,50%	5,77%
Southern Shore	**3,67%**	**4,31%**
Algeria	0,02%	0,02%
Egypt	0,92%	3,71%
Libya	1,96%	2,69%
Morocco	6,98%	5,46%
Tunisia	8,47%	9,70%
Eastern Shore	**1,26%**	**1,14%**
Cyprus	2,54%	2,27%
Israel	0,03%	0,12%
Lebanon	2,13%	1,48%
Syria	0,03%	0,08%
Turkiye	1,60%	1,74%
Mediterranean	**4,13%**	**3,86%**

The table provides the share of biofuels in Total Final Consumption (TFC) and Total Primary Energy Supply (TPES) for the year 2019.

These data underline once again the difference between the three shores, where, although displaying minimal percentages, the northern shore stands out as the most advanced in the field of biofuels. Conversely, countries on the eastern shore show extremely low shares, indicative of limited policies and initiatives in this sector.

2.3 Hydrogen policies and regulatory frameworks in the Mediterranean area

2.3.1 EU hydrogen policies

The EU's hydrogen strategy and REPowerEU plan present a comprehensive framework aimed at promoting the adoption of renewable and low-carbon hydrogen to facilitate the decarbonization of the EU and reduce reliance on imported fossil fuels.

A primary focus for the EU is the development of renewable hydrogen, with targets set to produce 10 million tonnes domestically and import an additional 10 million tonnes by 2030.

The EU's hydrogen strategy, adopted in 2020, outlines policy action points across five key areas: investment support, production and demand stimulation, market and infrastructure development, research and cooperation, and international collaboration. Hydrogen is also integral to the EU's strategy for energy system integration.

To support these objectives, the EU has launched various industrial, funding, research, and innovation initiatives. The Clean Hydrogen Partnership, spanning from 2021 to 2027, is a public-private partnership under Horizon Europe aimed at advancing hydrogen technologies. It includes the Hydrogen Valleys Platform, focused on renewable hydrogen research and innovation.

The European Clean Hydrogen Alliance, initiated in 2020, brings together industry, authorities, civil society, and stakeholders to drive the ambitious deployment of hydrogen technologies by 2030. It coordinates efforts across hydrogen production, transportation, and usage through thematic roundtables and project pipelines.

The Electrolyser Partnership, hosted by the Alliance, aims to boost electrolyser manufacturing capacity in Europe to 17,5 GW annually by 2025 by fostering collaboration among manufacturers and component suppliers.

Furthermore, the Hydrogen Public Funding Compass serves as an online guide for stakeholders, providing information on relevant EU programmes and funds (2021-2027) to support hydrogen projects.[69]

The Fuel Quality Directive 98/70/EC indirectly encourages the adoption of hydrogen by stipulating that fuel suppliers must decrease the life cycle greenhouse gas (GHG) emissions per unit of energy by 6% by December 31, 2020. Supporting this directive, Council Directive (EU) 2015/652 outlines calculation methods and reporting requirements, setting the efficiency factor of hydrogen fuel cell electric powertrains at 40% and establishing the GHG intensity of clean and fossil-based hydrogen, along with hydrogen-derived methane.

Furthermore, the HyLaw project identified over 50 EU legislative acts spanning various regulatory domains such as health and safety, environment, labor, and transport, all of which indirectly influence hydrogen technology development and must be taken into account.

The EU actively promotes research and innovation in hydrogen through its research framework programs, including Horizon 2020 and Horizon Europe (2021-2027). These initiatives are managed by the Fuel Cells and Hydrogen Joint Undertaking, a public-private partnership supported by the European Commission. Over the past decade, these programs have attracted more than €1 billion in investment for hydrogen projects. The second phase of the FCH JU (2014-2024) is projected to receive €665 million in EU support, which, combined with private funding, is expected to exceed €1,3 billion in total investments.[70]

The European Hydrogen Valleys Partnership initiative, part of the Commission's Smart Specialisation Platform, aims to foster collaboration among European regions interested in developing hydrogen production and utilization. Member States can jointly support specific innovation projects designated as important projects of common European interest (IPCEI), subject to criteria set by the European Commission. In December 2020, 22 EU Member States and Norway endorsed a manifesto to establish an IPCEI on hydrogen, following similar initiatives for microelectronics and batteries.

The European Commission's communication on a hydrogen strategy for a climate-neutral Europe, adopted on 8 July 2020, aims to expedite the development of clean hydrogen and position it as a cornerstone of a climate-neutral energy system by 2050. The strategy outlines a gradual trajectory, starting with blue hydrogen projects. Key actions will be implemented over three strategic phases between 2020 and 2050.

The strategy acknowledges the current limited role of hydrogen, particularly renewable hydrogen, in the overall energy supply, citing challenges related to cost competitiveness, production scale, infrastructure requirements, and safety perceptions. The Commission emphasizes the importance of collaboration across the entire supply chain and between the public and private sectors to establish an enabling regulatory framework and drive investments in hydrogen research and deployment. These efforts are deemed crucial for achieving the necessary scale-up of hydrogen technologies.[70]

With the establishment of the European Clean Hydrogen Alliance, a collaborative forum has been created to coordinate investments and scale up clean hydrogen production and demand. The strategy emphasizes the need for prioritized financing for clean hydrogen projects, ensuring coherence across EU funds and European Investment Bank (EIB) financing. The alliance aims to develop an investment pipeline and enhance policy coordination.

Policy measures include providing clarity on policy direction and investment needs. The Commission plans to propose a low-carbon threshold/standard and a certification scheme by June 2021, likely based on Emissions Trading System (ETS) benchmarks and the CertifHy project.

The strategy outlines three strategic phases. The initial phase, towards 2024, focuses on deploying infrastructure near demand centers, such as industry or refueling stations, to minimize infrastructure requirements. This phase emphasizes scaling up electrolyzer manufacturing, decarbonizing existing hydrogen installations, and promoting hydrogen adoption in end-use applications.

In the second phase (2024-2030), infrastructure deployment expands, starting with local networks in islands, remote areas, or hydrogen clusters. Hydrogen usage broadens to include renewable energy balancing, industry, transport, and residential and commercial heating. This phase also involves developing EU-wide logistical infrastructure, including refueling stations networks and storage facilities, and planning a pan-European hydrogen network.

Research and innovation funding will be crucial in the next decade to improve efficiency, scale up electrolysers to gigawatt capacity, and achieve cost competitiveness of renewable hydrogen by 2030.[70]

Beyond 2030, renewable hydrogen technologies are anticipated to reach maturity, with large-scale deployment and demand expected to increase. The strategic objective for installed production capacity is ambitious, aiming for at least 6 GW of renewable hydrogen electrolysers producing 1 million tonnes of renewable hydrogen by 2024. This capacity is projected to grow significantly to 40 GW by 2030, with 10 million tonnes of renewable hydrogen production.

On 11 December 2020, the Council adopted conclusions titled 'Towards a hydrogen market for Europe', urging the Commission to further develop and operationalize the EU hydrogen strategy. The Council emphasizes the importance of renewable hydrogen for decarbonization, recovery, and competitiveness. It calls on the Commission to explore the EU's potential for hydrogen production from cost-effective renewable electricity sources while prioritizing energy efficiency and direct electrification options. Additionally, the Council seeks approaches to ensure a smooth transition, avoiding lock-in and sunk investment costs.

Furthermore, the Council identifies an opportunity to enhance the EU's energy security by reducing import dependency and diversifying import opportunities. This aligns with the 2x40 GW initiative proposed by the industry association Hydrogen Europe, which aims to install 40 GW of renewable hydrogen capacity in the EU and an additional 40 GW across Ukraine and North Africa.[70]

2.3.2 Hydrogen policies in Eastern and Southern shore

The Middle East and North Africa (MENA) countries have historically played a crucial role in the global energy sector, primarily due to their substantial exports to Europe. With half of the world's confirmed oil reserves and around 45% of global proven natural gas reserves as of 2021, the MENA region has wielded significant influence throughout the 20th century. However, in recent years, the MENA region has reached a critical juncture in its energy transition towards renewable and sustainable sources, positioning itself to regain a prominent role in the global energy landscape.[1]

Given its abundant renewable energy resources, expansive land availability, and close proximity to the European market, North Africa is poised to become a major producer and exporter of green hydrogen. The region boasts significant potential for green hydrogen production, with ample sunlight and land suitable for renewable energy infrastructure. Furthermore, existing pipelines between North Africa and Europe offer a cost-effective means of transporting hydrogen to European markets. In recent years, North African countries have entered into agreements with various nations and private entities to explore green hydrogen production and launch pilot projects, many of which are geared towards export opportunities.

Eni and Snam have recently concluded an agreement for the transfer of a 49,9% stake (comprising both direct and indirect holdings) in specific entities managing two sets of international gas pipelines connecting Algeria to Italy. This transaction covers the onshore gas pipelines extending from the borders of Algeria and Tunisia to the Tunisian coast (TTPC), as well as the offshore gas pipelines linking the Tunisian coast to Italy. According to the terms of the deal, Eni will transfer its complete ownership interests in these pipelines to a newly formed Italian company (NewCo), in which Eni will retain a 50,1% ownership share. Snam will acquire the remaining 49,9% stake in NewCo for a total consideration of 385 million euros.[71].

Snam will finance the acquisition using its internal financial reserves. The deal is expected to generate synergies by leveraging the expertise of both companies in gas transportation along a critical route for ensuring Italy's natural gas supply security. Additionally, it opens up opportunities for potential collaborative initiatives in developing the hydrogen value chain originating from North Africa.[71]

In Tunisia, the GIZ, in collaboration with the Tunisian Ministry of Industry, Mines, and Energy (MIME), initiated the "Green Hydrogen for Sustainable Growth and a Low-Carbon Economy in Tunisia" (H2Vert.TUN) project in June 2022. The primary objective of this project is to assist MIME in coordinating the development of renewable hydrogen and Power-to-X (PtX) technologies in Tunisia, thereby fostering the growth of a hydrogen market. The project operates on three core pillars:

- Development of a National Hydrogen Strategy 2050: This involves formulating a comprehensive national hydrogen strategy for the year 2050. It includes identifying key stakeholders, fostering synergies with international partners for specific activities, and facilitating the participatory preparation of three sectoral strategies for green hydrogen and PtX. Additionally, action plans and roadmaps will be crafted to guide implementation.
- Facilitating Cooperation between Local and International Companies: The project facilitates collaboration between local and international companies interested in green hydrogen and PtX initiatives. It also provides advisory support to the national observatory for green hydrogen/PtX value chains, enhancing its role in monitoring and facilitating industry developments.
- Enhancing Professional Capacities: Capacity-building efforts target individuals with political and scientific responsibilities. Through training and knowledge-sharing activities, the project aims to equip stakeholders with the expertise needed to effectively navigate and contribute to the development of green hydrogen and PtX sectors in Tunisia.[72]

Some North African countries have incorporated hydrogen into their national energy strategies, with Morocco leading the charge by releasing a National Strategy on Green Hydrogen in August 2021, following the establishment of a National Hydrogen Commission in 2019. The Moroccan Ministry of Energy, Mines, and the Environment anticipates that the country could fulfill up to 4% of the global green hydrogen demand by 2030.

In 2021, Morocco initiated a tender for a 100 MW green hydrogen electrolyser project slated for 2022. Additionally, plans were unveiled for a project to produce 183000 tonnes of green ammonia by 2026, with an annual production capacity of 31000 tonnes of green hydrogen.

Egypt has also intensified its focus on hydrogen development. In 2021, the country announced the formulation of an integrated strategy for hydrogen production and the revision of its Energy Strategy 2030 to encompass green hydrogen. Furthermore, in March 2022, the Egyptian Ministry of Electricity and Renewable Energy, in conjunction with the Ministry of Petroleum and Mineral Resources, inked a memorandum of understanding with the European Bank for Reconstruction and Development. This accord aims to evaluate the potential of low-carbon hydrogen supply chains, guiding the establishment of guidelines for the national low-carbon hydrogen strategy.

In another notable development, Egypt's Sovereign Fund, partnering with the Norwegian company Scatec and Fertiglobe, signed an agreement to produce green hydrogen, ranging from 50 to 100 MW, to serve as a feedstock for green ammonia production.

However, the advancement of hydrogen in the southern shore countries encounters challenges, particularly pertaining to water management. The risk of unsustainable water withdrawal and groundwater depletion looms large, given the region's acute water stress, exacerbated by climate change impacts. Realizing sustainable green hydrogen production demands an effective policy framework that mandates sound water management practices, both within and beyond the hydrogen sector. This entails initiatives such as appropriate water pricing, adoption of water-saving technologies, and systematic investments in desalination infrastructure.[73]

2.3.3 Current and future hydrogen production

Table 13 Hydrogen production by process in 2022 [kT/y]

	Production capacity	**Output**
France	**822,71**	**552,82**
By-product	107,82	72,69
Reforming	700,52	469,74
Reforming (carbon capture)	13,39	9,73
Water electrolysis	0,98	0,67
Greece	359,74	326,56
By-product	0,28	0,19
Reforming	359,30	326,25
Water electrolysis	0,17	0,11
Italy	**829,24**	**607,91**
By-product	42,59	30,86
Reforming	785,02	575,83
Reforming (carbon capture)	1,18	0,92
Water electrolysis	0,45	0,30
Portugal	**110,88**	**106,28**
By-product	11,93	9,83
Reforming	98,95	96,45
Slovenia	**2,42**	**1,85**
By-product	0,45	0,31
Reforming	1,97	1,54
Spain	**797,03**	**614,47**
By-product	48,21	38,02
Reforming	744,68	573,64
Water electrolysis	4,13	2,81

Table 13[74] summarizes the yearly production capacity and actual output (in Ktonnes) of hydrogen for the main EU countries in the reference year 2019. The main processes for H2 production are: steam reforming, steam reforming by using carbon capture, H2 as by-product of other processes, and water splitting (electrolysis). It is important to specify that only processes that rely on renewable energy input can be defined as “green” H2 production.

As can be seen, there are still some countries (Portugal and Slovenia) which do not show any capacity for renewable hydrogen since water electrolysis technologies, that are the principal ways to obtain green H2, are not yet developed.

Then a brief scheme of planned projects from 2023 to 2030 about green hydrogen production for the main Mediterranean countries is presented, in terms of aggregated announced size (MWel):

- Italy: 13 projects with a total capacity of 1094 MWel
- Cyprus: 1 project with a total capacity of 25 MWel
- France: 25 projects with a total capacity of 3923 MWel

- Spain: 32 projects with a total capacity of 10091 MWel
- Greece: 4 projects with a total capacity of 1553 MWel
- Portugal: 10 projects with a total capacity 2935 MWel
- Slovenia: 1 project with a total capacity 34 MWel
- Egypt: 2 projects with a total capacity 1154 MWel
- France-Spain: 2 projects with a total capacity 72772 MWel

Source: International Energy Agency hydrogen projects database (2022)

The list above summarizes the main projects (planned, under construction and demos) in the European countries (including also Egypt) of Mediterranean area until year 2030[75]. For each project the announced size is displayed.

Spain and France seem to be the main countries seriously committed to investing in green hydrogen projects, with initiatives primarily scheduled in the upcoming years, as well as Italy.

In any case, according to the supportive policies and government incentives the production capacity of green H2 is expected to grow during the next years in order to meet the escalating demand for clean and sustainable energy.

2.4 National objectives for electrolysis capacity

As described within EU and National policies, a strong increase in green hydrogen production is expected for contributing to the decarbonization of the energy sector.

With this aim, several Mediterranean countries developed an Hydrogen Strategy which proposes pathways and objectives for electrolysis technologies development. On the contrary, other countries set these objectives in their own NECPs.

For instance, Turkey has set the objective to reach 5 GW of electrolysis capacity whitin 2035. Morocco instead has a goal of 1 GW to be reached in 2030-2040.[76]

For what concern the Northern shore countries, most of them show an objective for the installation of electrolysers: Croatia has a target value of 70 MW within 2030[77], for Greece is around 750 MW[78], 5,5 GW for Portugal[79] and 11 GW for Spain.

The Italian Hydrogen Strategy, which set itself as a very challenging objective, 2 % penetration of the hydrogen carrier in final energy demand, expects the installation of 5 GW of electrolysers in 2030.[80]

Also France has a very challenging target of 38 GW in 2030-2035 (considering periods during which some marginal renewable or nuclear power is unused), while with operating modes in which only baseload electricity or solar self-generation is used, the total capacity expected is much lower, either 3.7 GW (mode 2, baseload excluding times when supply is tight) or 9 GW (mode 3, coupled with solar self-generation).[81]

Finally, Slovenia has set the goal of 34 kToe of hydrogen produced in final energy consumption.[82]

Unfortunately some nations do not show precise goals in their energy plans: this is the case of Tunisia which has however the ambitious target of manufacturing 8.3 million tonnes of green H2 per year by 2050[82], and Malta.

In Algeria the hydrogen strategy is still under development since late 2021: pilot projects are expected from 2023 to 2030[83]. Similarly, Egypt is still awaited to launch national strategy for green hydrogen production.

Also for the Libyan National Oil Corporation (NOC), green electricity can be converted into hydrogen and then shipped to Europe. This, however, requires infrastructure for production and shipping which is not yet in place. This may be an area for the NOC to develop within the framework of a more comprehensive decarbonization strategy[84].

Finally, as reported in Cyprus NECP emerging technologies like hydrogen and carbon capture and storage have not been considered in the scenario due to the lack of available data[85].

Other countries, including Bosnia Herzegovina, Montenegro, Lebanon and Syria do not mention at all strategies related to hydrogen production in their official documents.

3. Role of the natural gas within geopolitical dynamics

3.1 Natural gas as “transitional” energy commodity

Natural gas plays a pivotal role in the ongoing global energy transition, acting as a versatile energy commodity that contributes to the shift towards more sustainable and cleaner energy sources.

Natural gas indeed has the potential to serve as a crucial complement to renewable energy development and facilitate the transition to a low-carbon energy system. Its compatibility with renewable energy sources allows for a smoother transition, leveraging the benefits of both energy sources. With its high efficiency due to the relatively high atomic hydrogen-to-carbon ratio, natural gas can be effectively utilized alongside renewables to meet energy demands while minimizing carbon emissions. Additionally, its abundance, relatively low development costs, and utility make it a valuable asset in the transition towards a sustainable energy future[86].

Natural gas also contributes to global energy security by diversifying the energy mix and reducing dependence on a single energy source. It provides a reliable and stable source of energy, especially in regions where access to other energy resources may be limited.

Indeed, governments worldwide are incorporating natural gas into their energy transition strategies through supportive policies and regulatory frameworks. These measures encourage investment in cleaner technologies, incentivize the reduction of greenhouse gas emissions, and promote the responsible extraction and use of natural gas.

The role of natural gas in the energy transition is multifaceted, as it acts as both a bridge and a complement to the broader shift towards cleaner and more sustainable energy sources. Its combustion produces fewer greenhouse gas emissions compared to coal and oil, making it a relatively cleaner option during the initial stages of the transition. By looking at carbon footprint, natural gas owns the lowest emission factor among the main fossil fuels (0,205 $kgCO_2/kWh$), if compared to electricity (0,482 $kgCO_2/kWh$), coal (0,341) or diesel (0,264).[87]

3.2 Evolution of natural gas supply in the Mediterranean

The geopolitical uncertainties surrounding the Russian-Ukrainian conflict forced the Mediterranean countries to reassess their energy strategies. In particular, the reliability and stability of natural gas supplies became a pressing issue and consequently considerable variations on gas imports as primary energy commodity have been registered.

The main effect regards the change in imports by country showing the presence of "new" gas suppliers and alternative corridors to the Russian ones.

Another significant change concerns the diversification of gas supply methods. For instance, the increasing shares of transportation by ships (in liquified form) to regasification terminals has proven itself as a major alternative to transportation by pipeline.

Table 14 Gas transmission pipelines entering Mediterranean area (2023)

Name	Physical border	Main pipeline	Country source	Status	Length [km]	Diameter [mm]	Design capacity [Gm3/y]
Greenstream	Libya	Greenstream	Libya	In operation	516	812,8	11
MedGaz	Algeria	MedGaz	Algeria	In operation	210	609,6	8
Transmed	Tunisia	Transmed	Algeria	In operation	1538	1219,2	33,5
Bluestream	Russia	Bluestream	Russia	In operation	1213	1400	16
Turkstream	Russia	Turkstream	Russia	In operation	930	810	31,5
TAP	Albania	TANAP	Azerbaijan	In operation	877	1219,2	10
Franpipe	Norway	Franpipe	Norway	In operation	840	1066,8	20
South Caucasus pipeline (SCPX)	Georgia	South Caucasus pipeline (SCPX)	Azerbaijan	In operation	691	1219,2	24
Maghreb - Europe	Morocco	Maghreb - Europe	Algeria	Susp.	1620	1219,2	12
TAG	Austria	Soyuz / Brotherhood (UPU)	Russia	In operation	1140	1066,8	30
Transitgas	Switzerland	Franpipe	Norway	In operation	293	1219,2	18
Tabriz–Ankara	Iran	Tabriz-Ankara	Iran	In operation	2577	1168,4	20
MEGAL	Germany	/	Russia	In operation	1162	1219,2	32

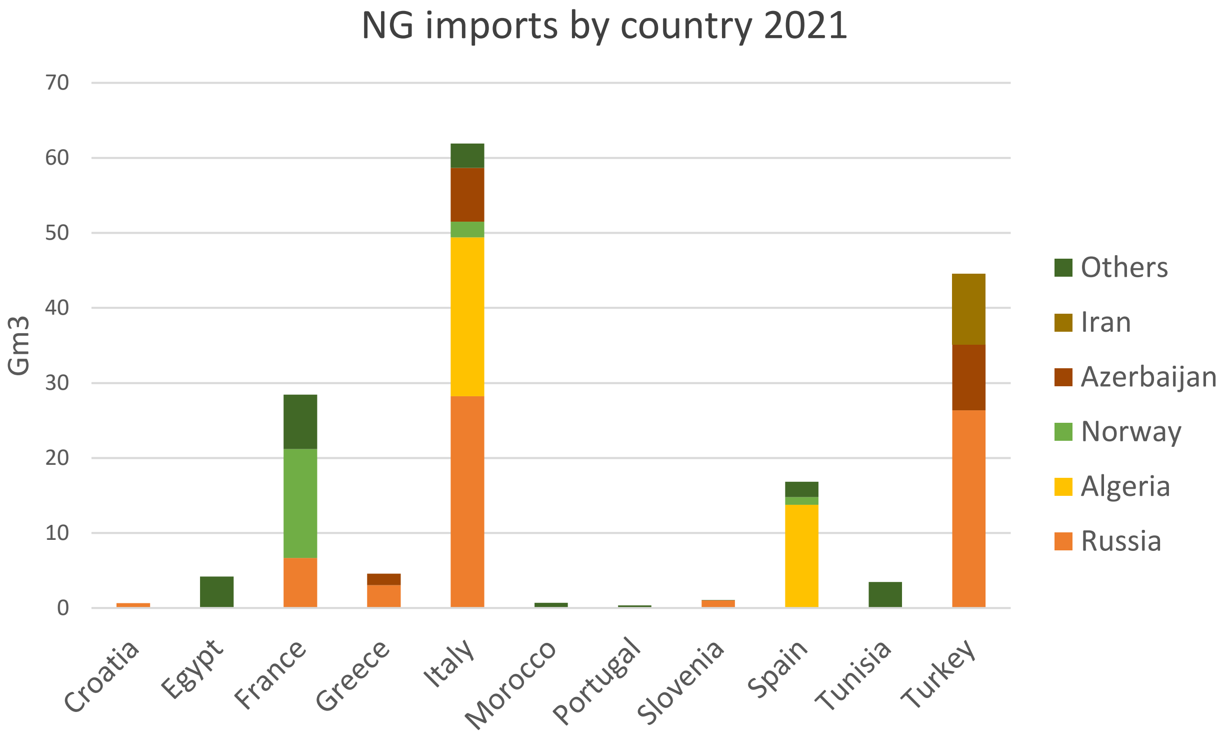
The table above lists the cross-border pipelines transporting natural gas towards the Mediterranean countries, according to their main technical specifications as pipe length, diameter and designed annual capacity.

The main country source is represented from Russia, from which many pipelines towards Mediterranean basin originate.

As reported the Maghreb-Europe pipeline is currently suspended form its operations due to geopolitical frictions between Algeria and Morocco[88]. However, there are active connections with North Africa and North European countries together with Eastern corridors. In particular the major natural gas exporters towards Mediterranean via pipelines are: Russia, Azerbaijan, Norway, Algeria and Libya.

Then the volumes of natural gas imported by pipeline from Mediterranean countries during the last three years are displayed and analyzed[16]

Figure 1 Volumes of NG imported by supplying country (2021) [Gm3/y][17]



This graphical representation shows the amount of gas imported via pipeline from each supplying country during 2021. Italy has the highest imported volume (61,9 Gm3) among all the Mediterranean countries, followed by Turkey (44,6), France (28,4) and Spain (16,8).

For what concern the others, due to lower demographics and so smaller consumption countries like Croatia, Greece and Slovenia exhibit not significant amounts of imports.

What is important to underline is the dependence from the major suppliers, in particular in 2021 the leading NG supplier was Russia with almost 66 Gm3 (39,58% of the total) delivered to the Mediterranean countries. Proof of this is the fact that the two primary importers (Italy and Turkey) rely on Russian gas respectively for 45,64% and 59,07% of the total imports.

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[16] References: Italy: Snam[105], Croatia: Plinacro[106], France: GRTgaz[107], Greece: Desfa[108], Portugal: REN[109], Spain: Enagas[110] and Eurostat[111], Slovenia: Agen-rs[112] Turkey: Botas[113], Egypt Morocco and Tunisia: JODI[114]

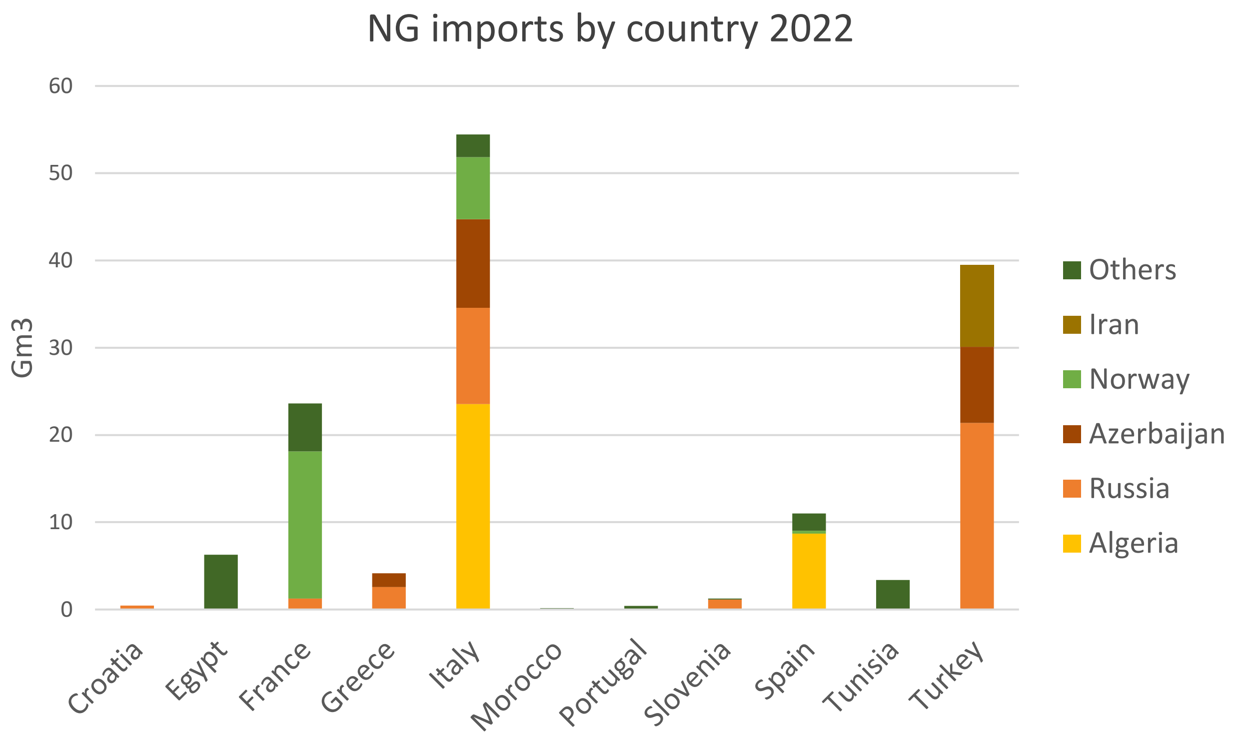
[17] Others includes: Belgium, Croatia, France, Italy, Libya, Portugal, Spain, Switzerland and other undetermined countries

Other countries relying on NG coming from Russia are Croatia, Greece, Slovenia and partly France.

Algeria also plays an important role in the NG furnishing thanks to its connections with Italy and Spain through which almost 35 Gm3 of natural gas were transported during 2021.

The remaining shares belong to Norway, which exports gas through connection with France (17,64 Gm3), and Azerbaijan (17,5 Gm3) thanks to its route through the Eastern area.

Figure 2 Volumes of NG imported by supplying country (2022) [Gm3/y]



In 2022 the major suppliers are still the same of the previous year but with a consistent difference: the share of imports from Russia undergoes a critical reduction (42,9% less with respect to 2021) with a value of 37,7 Gm3 of gas transported via pipeline. However, countries like Turkey still rely on Russian gas (54,1% of the total imports) as well as Croatia, Greece and Slovenia.

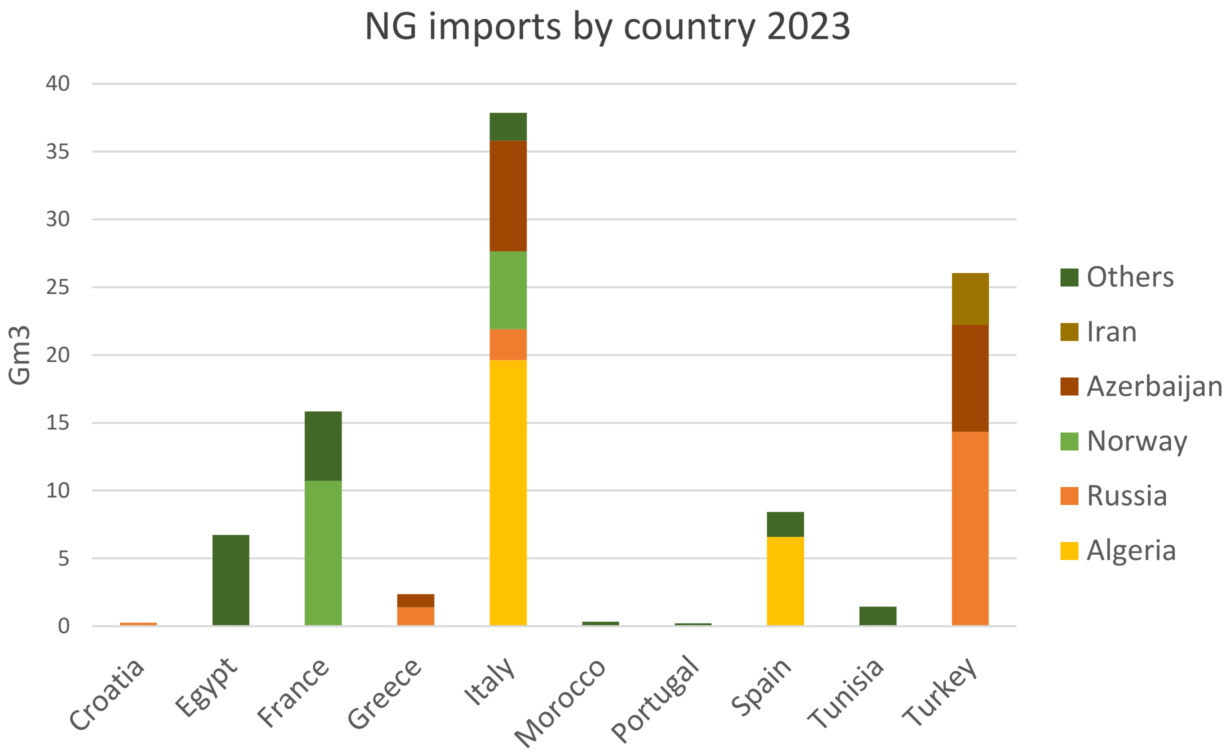
The main author of this drop is Italy, that in 2022 reduced its amount of NG imported from Russia to 11 Gm3 (more than 60% less with respect to 28,25 Gm3 in 2021), showing a reshaping process of its supply routes. Same observation can be made for France, that in 2022 lowers its dependance from Russia by decreasing imports to 5,25% of the total.

Consequently, a growth in NG coming from other corridors has been registered: Italy singed new contracts[89] with its new main supplier Algeria which also becomes the second one (behind Russia) in the Mediterranean. During this period Italy also starts importing NG from Norway and so adding a new supplier to its mix contributing to the

Russian dependance reduction. This reshape made Norway to become the third major supplier for the Mediterranean region with 24,3 Gm3 delivered during 2022.

Also imports from Azerbaijan have seen a slight increase to 20,5 Gm3 (17% higher than 2021) establishing itself as one of the main suppliers for Italy, Turkey and Greece.

Figure 3 Volumes of NG imported by supplying country (2023)[18] [Gm3/y][19]



During 2023 the decreasing trend regarding Russian imports persist since they represent only 18,39% of the total imported volumes by pipeline.

it is important to notice that France stopped their pipeline imports from Russia. On the contrary, beyond Croatia (that has 100% imports from), the main countries that still strongly rely on Russian gas are Turkey with 55% and Greece with 59,1% of their total imports.

Instead, imports from Algeria and Azerbaijan (mainly across Italy, Spain and Turkey) show a slightly growing trend as main suppliers in the Mediterranean.

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[18] 2023 data are until October

[19] Slovenia is not present due to lack of data in 2023

Table 15 Synoptic view on NG source of imports (2021-2023)

	2021		2022		2023	
Supplying country	**Quantity [Gm3]**	**Share [%]**	**Quantity [Gm3]**	**Share [%]**	**Quantity [Gm3]**	**Share [%]**
Russia	65,99	39,58	37,72	26,07	18,30	18,39
Algeria	34,92	20,94	32,32	22,34	26,19	26,31
Norway	17,64	10,58	24,31	16,81	16,43	16,51
Azerbaijan	17,50	10,50	20,47	14,15	17,02	17,11
Iran	9,43	5,66	9,40	6,50	3,81	3,83
Others	21,26	12,75	20,43	14,12	17,76	17,85

These aggregated data just briefly describe the evolution analyzed within the paragraph.

As can be seen the most relevant aspect regards supplies from Russia, that in 2022 (starting year of the conflict against Ukraine) are almost halved with respect to 2021 in favour of Algeria, Norway and Azerbaijan. The trend keeps on also in 2023 confirming the reshaping process of the gas market.

3.2.1 Liquified natural gas as emerging supply chain

Beyond the transport by pipeline, natural gas transport by ship in liquified form also plays an important role, mainly thanks to its flexibility and with the only requirement of performing the transformation from gaseous to liquid state.

The most obvious advantage of maritime transport is the possibility of reducing the importance of the geographical component in international gas trade, which can be freed of the rigidity of pipelines where production and consumption points are exclusively fixed. The development of maritime gas transmission has also benefited the countries increasing their energy security by expanding and diversifying their import sources.

Currently there are more than 20 operating LNG regasification terminals across the Mediterranean countries with an annual total capacity of nearly 200 Gm3.[90]

Table 16 Operating LNG regasification terminals in the Mediterranean basin (2023)

Country	**Terminal**	**Nominal annual capacity [Gm3/y]**	**Type**	**Coast**
Croatia	Krk Island	2,60	FSRU[20]	Mediterranean
Egypt	Sumed	7,80	FSRU	Mediterranean
France	Le Havre	5,00	FSRU	Atlantic
France	Montoir de Bretagne	10,00	onshore facility	Atlantic
France	Fos Tonkin	1,50	onshore facility	Mediterranean
France	Dunkerque	13,00	onshore facility	Atlantic
Greece	Revithoussa (Agia Triada)	7,00	onshore facility	Mediterranean
Israel	Hadera	2,50	FSRU	Mediterranean
Italy	Rovigo	9,00	offshore GBS[21]	Mediterranean
Italy	Panigaglia	3,40	onshore facility	Mediterranean
Italy	OLT Offshore Toscana	5,00	FSRU	Mediterranean
Italy	Piombino	5,00	FSRU	Mediterranean
Malta	Delimara	0,70	FSU + OR[22]	Mediterranean
Portugal	Sines	7,60	onshore facility	Atlantic
Spain	Mugardos	3,60	onshore facility	Atlantic
Spain	Sagunto	8,80	onshore facility	Mediterranean
Spain	Huelva	11,80	onshore facility	Atlantic
Spain	Gijón (Musel)	7,00	onshore facility	Atlantic
Spain	Cartagena	11,80	onshore facility	Mediterranean
Spain	Bilbao	7,00	onshore facility	Atlantic
Spain	Barcelona	17,10	onshore facility	Mediterranean
Turkey	Gulf of Saros	9,70	FSRU	Mediterranean
Turkey	Marmara Ereglisi	12,80	onshore facility	Mediterranean
Turkey	Dörtyol	9,70	FSRU	Mediterranean
Turkey	Aliaga Izmir	13,80	onshore facility	Mediterranean
Turkey	Aliaga Etki	7,30	FSRU	Mediterranean

Source: GIE LNG map 2022

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[20] Floating Storage and Regasification Unit

[21] Gravity Based Structure

[22] Onshore Regasification

There is a summarized list of the LNG terminals currently in operation. Spain is the country with the highest regasification capacity with a value of 67,1 Gm3/y, followed by Turkey (53,3). Also Italy and France show a relevant number of regasification facilities.

Some of the regasification terminals belonging to Mediterranean countries overlook on the Atlantic Ocean since LNG is traded almost worldwide reducing geographical restrictions.

Table 17 Synoptic view on LNG source of imports (2021-2023)

	2021		2022		2023	
Supplying country	**Quantity [Gm3/y]**	**Share [%]**	**Quantity [Gm3/y]**	**Share [%]**	**Quantity [Gm3/y]**	**Share [%]**
USA	17,46	25,59	39,34	39,74	25,66	34,67
Algeria	13,59	19,92	12,72	12,85	11,45	15,41
Nigeria	11,78	17,26	10,34	10,44	6,91	9,30
Qatar	10,79	15,82	10,98	11,09	7,71	10,38
Russia	7,40	10,84	13,87	14,01	11,32	15,24
Trinidad	2,76	4,04	2,60	2,62	1,88	2,54
Egypt	2,13	3,12	5,03	5,09	2,19	2,95
Others	2,32	3,40	4,12	4,16	7,17	9,52

This table gives an overview on the amount of LNG imported during the last years according to the major suppliers for the Mediterranean countries. In 2021 the total imported LNG amounted to 68,22 Gm3 almost equally distributed between USA, Algeria, Nigeria and Qatar as primary sources.

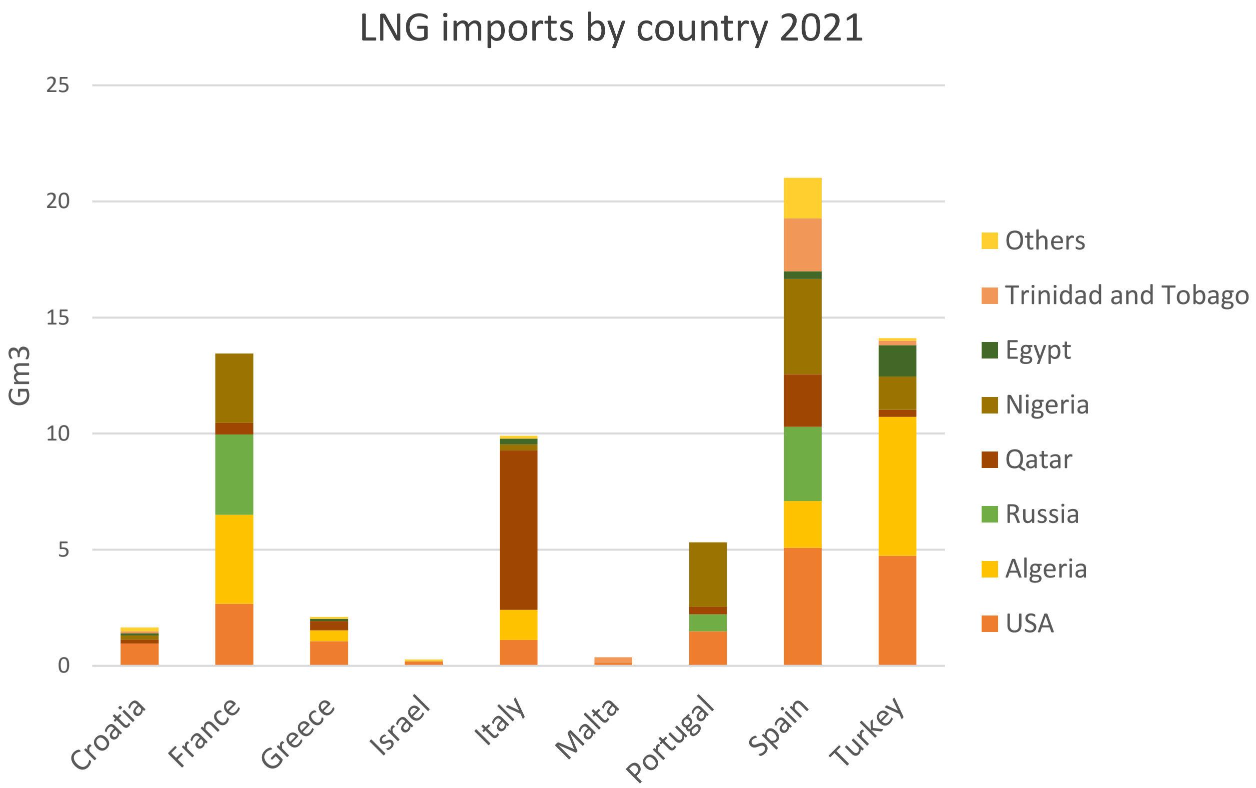
At the end of 2022 a significant growth has been registered in LNG imports with a total volume nearly 100 Gm3. The main increase regards USA that by doubling their exports reached 39,74% of the total LNG imported in the Mediterranean basin. This huge increase is at the cost of Algeria, Nigeria and Qatar which all registered a slight reduction (between 4% and 7%) in the share of LNG coming from their ships.

In contrast, Russian LNG exports have doubled with respect to 2021, contrary to what registered about NG via pipeline.

The growing trend is expected to extend also for 2023 since imported volumes at October 2023 are already higher than 2021, and sees USA still as the main LNG supplier currently accounting for 34,67% of the total Mediterranean imports.

Following, a quantitative analysis of the evolution of LNG imports across the Mediterranean is presented[23].

Figure 4 Volumes of LNG imports by supplying country (2021)[24] [Gm3/y]



A more detailed view on the shares of imports by country source in 2021 is given in the figure above. As anticipated, maritime trade of LNG allows the importing countries to have a really diversified mix of sources.

Spain is evidently the country with the highest volume of LNG imported in 2021 exceeding 21 Gm3, followed by Turkey and France, and also shows the most diversified mixture of sources. As can be seen almost all the countries rely on imports from USA, in particular the major importers in terms of volume are Spain and Turkey with 5,08 and 4,74 Gm3 respectively. However, even though lower amounts, significant data can be registered for Croatia and Israel since they rely on LNG from USA for 58,24% and 68,74% of their gross imports respectively.

Qatar is by far the leading supplier of Italy with 69,24% of the total imports and also has significant shares in the Spanish mix (10,73%).

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[23] References: italy and croatia: Eurostat[111], France: Ministère de la transition énergétique[115], Greece: Desfa[108], Portugal: REN[109], Spain: Enagas[110], Turkey: Botas[113], Malta and Israel: Alphatanker[102]

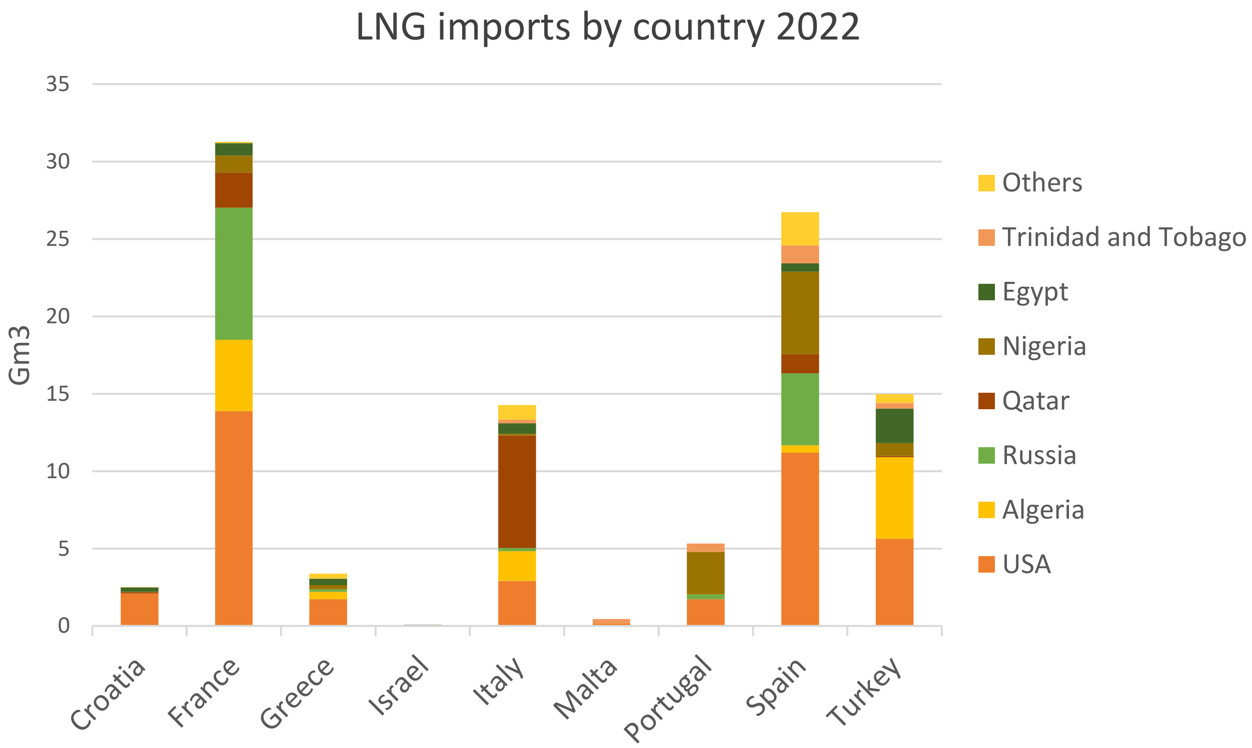
[24] Others includes: Angola, Australia, Belgium, Cameroon, Cyprus, Equatorial Guinea, France, Indonesia, Mozambique, Netherlands, Norway, Oman, Papua New Guinea, Peru, Portugal, South Korea, Spain and United Kingdom

Nigeria also plays in important role as LNG exporter in the Mediterranean basin, having relevant shares of transport mainly towards France, Spain, Portugal and Turkey.

Moreover, France and Turkey strongly rely on LNG coming from Algeria that is their main source accounting for 28,47% and 42,44% of the total maritime imports in 2021.

Finally, in this context Russia plays a secondary role since it accounts for only 10,84% of the entire LNG amount imported from Mediterranean countries in 2021, underlying the difference of dependance level in comparison with NG transported via pipeline.

Figure 5 Volumes of LNG imports by supplying country (2022) [Gm3/y]

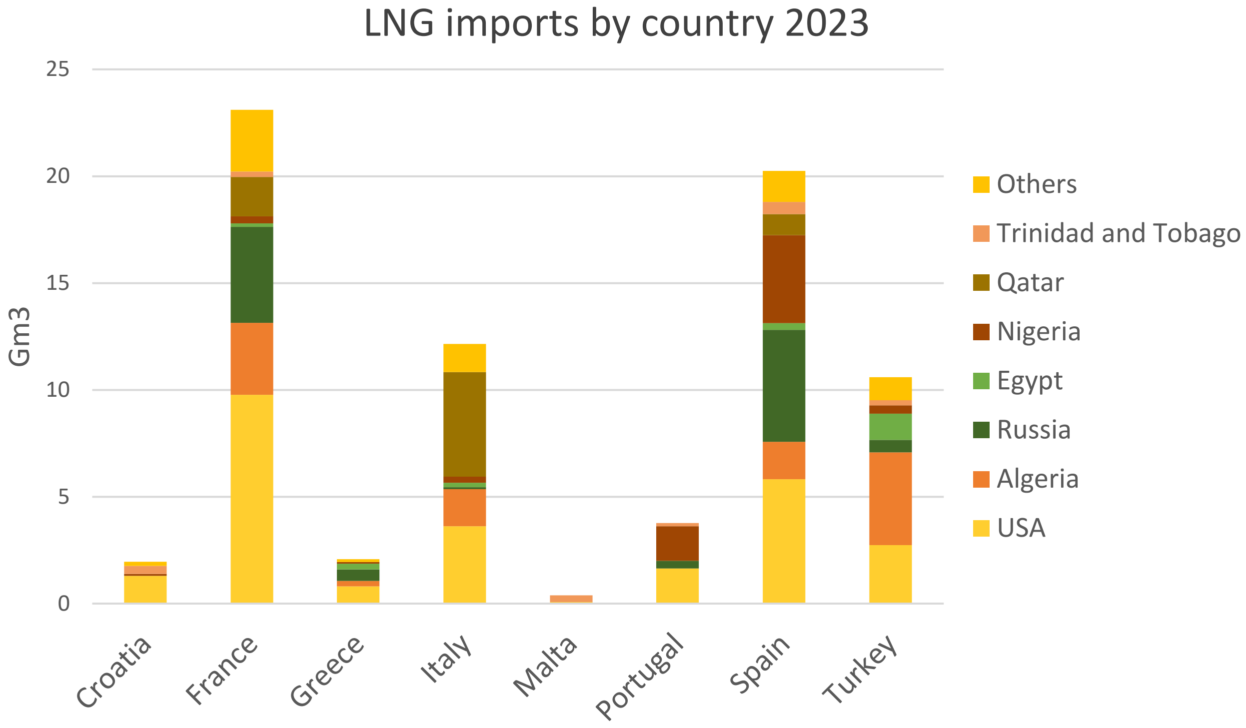


As previously anticipated, 2022 sees a boost in LNG imports across the Mediterranean. Main authors of this rise are France that more than doubled its LNG imports reaching 31,28 Gm3 at the end of the year and also Italy (44% higher than 2021) and Spain (27,16% higher).

The most important aspect of 2022 data is the establishment of USA as leading supplying country with a recorded value of 39,74% of the total imports coming from the United States. It is indeed the main supplier for the majority of the Mediterranean countries.

It's interesting to notice that shares related to Russian exports towards Mediterranean are almost doubled with respect to 2021, with France as main importer where 61,54% of Russian LNG was delivered during the year.

Figure 6 Volumes of LNG imports by supplying country (2023)[25] [Gm3/y]



Data about 2023 confirm the trend of the previous year by showing a great level of source diversification but still seeing USA as main exporter towards Mediterranean with relevant shares in almost all the countries.

Furthermore, several countries still rely on maritime imports from Russia which established its sensible role as LNG provider, in particular towards Spain (25,86% of total LNG imports) and France (19,45%).

For what concern the other sources no significant variation has been registered, with shares that stand at those of the previous year.

Currently across the Mediterranean there is only one LNG terminal under construction, that should be operational in Greece from the beginning of 2024[91].

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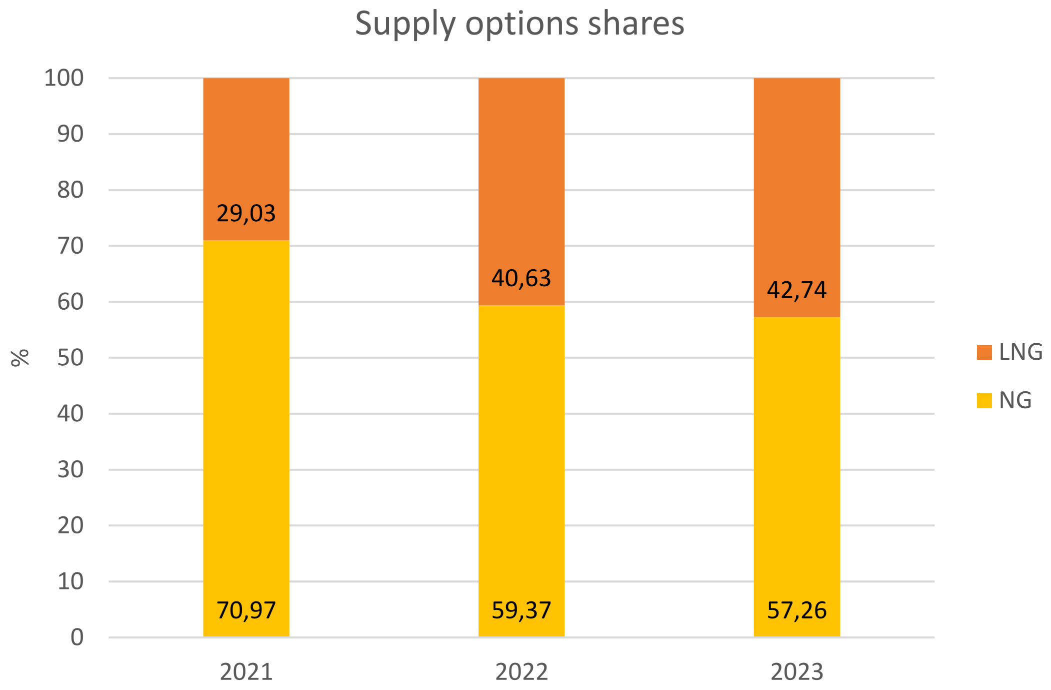
[25] Data about 2023 are until October

Table 18 Planned and under construction LNG regasification terminals

Country	Terminal	Status	Nominal annual capacity [Gm3/y]	Type
Greece	Alexandroupolis LNG terminal	Under construction	5,50	FSRU
Albania	Vlora	Planned	-	FSRU
Greece	Argo	Planned	5,20	FSRU
Greece	Dioriga Gas (Corynth)	Planned	3,00	FSRU
Greece	Thrace LNG Terminal	Planned	5,50	FSRU
Italy	FSRU 1 - SNAM	Planned	5,00	FSRU
Italy	FSRU 2 - SNAM	Planned	5,00	FSRU
Italy	Porto Empedocle	Planned	8,00	Onshore facility
Morocco	Jorf Lasfa	Planned	5,00	Onshore facility
Morocco	Morocco FSRU	Planned	3,00	FSRU

However, several projects are planned to be completed during the next years[90]: the most active countries in this field are Italy, Morocco and Greece itself, making the total regasification capacity in the Mediterranean basin expected to grow to almost 250 Gm3 per year. This scenario strongly confirms the trend seen during the last years in which the development of LNG seems to be dynamic, driven by geopolitical shifts that cause a need for higher source diversification and so greater energy security.

Figure 7 Evolution of gas supply option (2021-2023)



This graphical representation gives a comprehensive overview on the evolution of shares of about the two import types in the entire Mediterranean basin. As previously reported, in 2022 almost all countries have experienced a consistent growth in maritime imports, at the cost of transportation by pipeline that consequently reduced its shares.

By examining the aggregated data, it is remarkable to observe the evolution that the market has undergone: in 2021 70,97% of natural gas was imported by pipeline and 29,03% by ship, while in 2022 values are respectively of 59,37 and 40,63% resulting in a balancing process of the technologies. Also during the 2023 the trend continued, with current registered shares of 57,26% of pipeline imports and 42,74% of LNG by ship.

3.2.2 The role of gas storage

Natural gas storage is essential in upholding the equilibrium between supply and demand, and in safeguarding a continuous and dependable provision of natural gas.

The concept of storage transforms into a strategic reservoir management tool. During periods of surplus production or low demand, this unified reservoir-storage system allows for the accumulation of excess gas. Conversely, during peak demand or supply disruptions, the stored natural gas becomes an immediate and flexible resource, ensuring a continuous and stable supply.

But most of all natural gas reserves are crucial for ensuring a nation's energy security since storage facilities play a pivotal role in smoothing out fluctuations in natural gas availability and in balancing the energy mix, reducing reliance on a single energy source and minimizing susceptibility to geopolitical tensions that may cause unexpected disruptions in production or supply.

In summary, geopolitical unbalances also had a remarkable impact on gas stock management since it represents a "lifeline" during periods of uncertainty.

The following table gives a measure of the storage reserves exploitation of the EU Mediterranean countries: in particular the withdrawal season period (from 1 November to 31 March) of time has been considered during which the NG reserves are used in order to cover the demand[92].

Table 19 Storage filling level by country [%]

Country	**01/11/2020**	**31/03/2021**	**01/11/2021**	**31/03/2022**	**01/11/2022**	**31/03/2023**
Croatia	94	19,92	81,88	16,68	97,03	75,75
France	101,13	19,63	94,55	23,66	100,04	27,66
Italy	98,84	36,59	87,57	29,92	95,45	59,32
Portugal	92,87	58,4	68,22	79,75	109,25	106,12
Spain	94,8	59,91	82,58	58,18	94,75	78,27

Source: GIE storage database - 2023

A comparison between storage filling percentage in the first and last day of the withdrawal season has been done in order to evaluate how the level of exploitation has changed during the last years.

As demonstrated by the high filling levels at the end of the last season, 2022-2023 period sees a lower exploitation of the internal reserve, probably in consequence of the Russian-Ukrainian conflict that by causing uncertainties in natural gas supply, prompted the Mediterranean countries to increase their security in case of energy crisis.

4. Risk assessment for energy security: case study of natural gas supply from Algeria to Italy

4.1 The importance of geopolitical risk assessment in the energy sector

Energy security is a multidimensional concept comprising technical, economic, social, political, environmental and geopolitical aspects that are mutually interdependent[93].

Presently, it stands as one of the paramount geopolitical concerns globally, intricately intertwined with the economic downturn, and conversely influenced by it. The issue of energy security has been notably intensified by the rise of emerging nations transitioning into significant energy consumers. Consequently, substantial shifts have taken place and are poised to persist on the geopolitical stage. Correspondingly, notable adjustments are unfolding within macroeconomic strategies and financial stability, particularly within nations and regions identified as substantial energy consumers.[94].

The challenges surrounding the approach and comprehension of energy security persist, rendering the definition of an effective energy security management methodology an ongoing area of study. The study of energy security is inherently intricate, given that access to energy sources in the twenty-first century relies on a multifaceted system encompassing global markets, extensive cross-border infrastructure networks, a limited number of primary energy suppliers, and interconnections with financial markets and technology. Consequently, energy security is influenced by numerous factors that are often difficult to precisely quantify. Furthermore, the relationships between these factors can be ambiguous, subject to variation in their direction and intensity, and exhibit diverse manifestations across different countries, regions, and time periods.

Energy security entails the assurance of a stable and dependable supply of energy resources to fulfill a nation's economic and societal requirements. Within this framework, evaluating geopolitical risks assumes a critical role in comprehending and addressing energy security challenges. The nexus between energy security and geopolitical risks constitutes a pivotal domain necessitating thorough analysis and strategic management to mitigate potential disruptions stemming from unexpected events. This assessment is essential for devising effective strategies to uphold supply security.

In recent years, nations have become increasingly interconnected through complex energy networks, fostering interdependence wherein political decisions in one country can directly impact the energy security of others. For example, geopolitical tensions within an exporting region can reverberate throughout global energy markets. Energy supply chains, spanning across nations and continents, form intricate networks susceptible to geopolitical influences. The intricacies of these supply chains render them vulnerable to disruptions arising from political developments, conflicts, or policy shifts. Hence, comprehending and addressing these complexities are vital for enhancing the resilience of energy systems.

However, most geopolitical risk factors cannot be expressed as probabilities due to the unavailability of objective data. This complicates the construction of quantitative scenarios regarding the geopolitical context or the integration of geopolitical data with quantitative scenarios.

Currently, 11 most commonly used approaches to measuring geopolitical risk of energy supply have been defined, all of which can be divided into two major groups: measurement based on security of supply and measurement based on aggregation of different indicators[94]. Each of these methodologies possesses its own set of advantages and disadvantages, rendering them more or less suitable for application in this domain. Nonetheless, given the prevailing trends, it is imperative to adopt the stance that measurement methods should be continually reassessed and adjusted in line with the evolving dynamics on the global stage. The transformation of geopolitical relations is a fluid process occurring at a much swifter pace in the contemporary world compared to the past.

Primary or causal energy risks encompass a combination of geopolitical, technical, and economic parameters. Managing primary energy risks originating within the importing country is generally perceived as relatively straightforward for national authorities. Consequently, geopolitical energy risks are perceived to stem from exporting and transit countries that constitute the energy corridors towards the importing country. Conversely, technical energy risks involve threats to the physical infrastructure of these corridors.[94]

Geopolitical energy risks can generally be categorized into three aspects of human activity: economic, political, and social. In addition, since this analysis is applied to the energy sector, some technical-related variables, mainly related to the energy physical infrastructure, must be taken into account. These four risk vectors, collectively determine the geopolitical reliability of exporting and importing countries forming the energy corridors. These vectors are objective indicators, relying on country-level data from reputable institutions or scholars[94].

4.2 Case study: developing a risk model to evaluate energy security level of Algerian gas supply to Italy

4.2.1 Methodology for risk assessment

Within the framework of the current European and Mediterranean geopolitical scenario, that has a huge impact on the energy infrastructure and in particular on the gas trade and supply, a focus on the Algerian-Italian connection has been made, since during the last few years Algeria became the main Italian gas provider.

This connection has been chosen as case study with the aim to evaluate the security level in-between geopolitical, economic and infrastructure-based aspects which involve assessing various factors that could impact the reliability and stability of the supply chain.

For this scope, the analysis has been conducted by dividing the supply chain into: supplier (Algeria), connection (pipeline and maritime route) and receiver (Italy) and by assigning a set of indicators that contribute to the overall assessment of the security level.

The table below summarizes the setup of the analysis.

Table 20 Setup scheme of the analysis

Italy	Connection	Algeria
Availability of LNG regasification terminals	Reliability of pipeline	Political Stability and Absence of Violence/Terrorism
Reliability of pipeline entry point	Availability of LNG carriers	Government Effectiveness
	Volatility of transport costs	Regulatory Quality
		Rule of Law
		Security level of gas reserves
		Security level of gas production
		Volatility of natural gas price

Socio-Political indicators

The indicators representing the geopolitical stability level of the country have been chosen from Worldwide Governance Indicators[95], that also provides their definition:

- *Government Effectiveness* captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies.

- *Political Stability and Absence of Violence/Terrorism* measures perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism
- *Regulatory quality* captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development
- *Rule of law* captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence

Supply Infrastructure indicators

- *Security level of gas production* describes the historical trend of gas production within Algerian fields
- *Security level of gas reserves* describes the historical trend of gas reserves within the Algerian storage facilities
- *Reliability of pipeline* measures the ability of the pipeline to provide service at its technical capacity
- *Availability of ships* captures the availability of LNG vessels to undertake this route
- *Availability of LNG terminals* captures the residual capacity of Italian terminals as measure of flexibility

Economic indicators

- *Volatility of natural gas price* measures the dispersion of contracted prices between Algeria and Italy during the last years and sea freight costs for liquified natural gas
- *Volatility of transport costs* measures the dispersion of the gas transport costs via pipeline from Algeria to Italy during the last years

4.2.2 Gas supply security by pipeline

Focusing on the onshore gas supply chain, several indicators related to the supplying country and the transmission infrastructure has been considered.

The socio-political indicators are grouped in Table 22 that shows an historical assessment of the Algerian governance level.

Table 21 Algerian score of socio-political indicators (2010-2022)

Governance score (-2,5 to 2,5)				
Year	**Political Stability and Absence of Violence/Terrorism**	**Government Effectiveness**	**Rule of Law**	**Regulatory Quality**
2010	-1,26	-0,40	-0,82	-1,10
2011	-1,36	-0,52	-0,85	-1,21
2012	-1,33	-0,45	-0,81	-1,32
2013	-1,20	-0,43	-0,69	-1,14
2014	-1,19	-0,34	-0,80	-1,30
2015	-1,09	-0,41	-0,94	-1,26
2016	-1,10	-0,46	-0,92	-1,24
2017	-0,92	-0,54	-0,93	-1,28
2018	-0,84	-0,49	-0,81	-1,35
2019	-1,06	-0,57	-0,86	-1,39
2020	-0,85	-0,57	-0,80	-1,36
2021	-0,99	-0,65	-0,83	-1,18
2022	-0,74	-0,51	-0,83	-1,06

Source: Worldwide Governance Indicators - World Bank

Governance score refers to an estimation that measures the quality of governance measured on a scale approximately from -2,5 to 2,5. Higher scores correspond to better governance and vice versa.

As reported, Algeria does not display an overall optimal governance score, that may suggest challenges related to various aspects, including security, risk, economy, and markets.

In order to obtain a better understanding of these indicators, a normalization process has been carried out by using Python® environment. The scaling procedure has been performed to get the new data in an interval between 0 and 1, always representing the governance score. Then a weighted average of the four indicators has been calculated over each year with the purpose of give an aggregated value that reflects the overall level of security and stability regarding socio-political aspects in the Algerian region.

Additionally, the normalization process allows also to evaluate, on yearly basis, the impact (share) of each indicator on the weighted average.

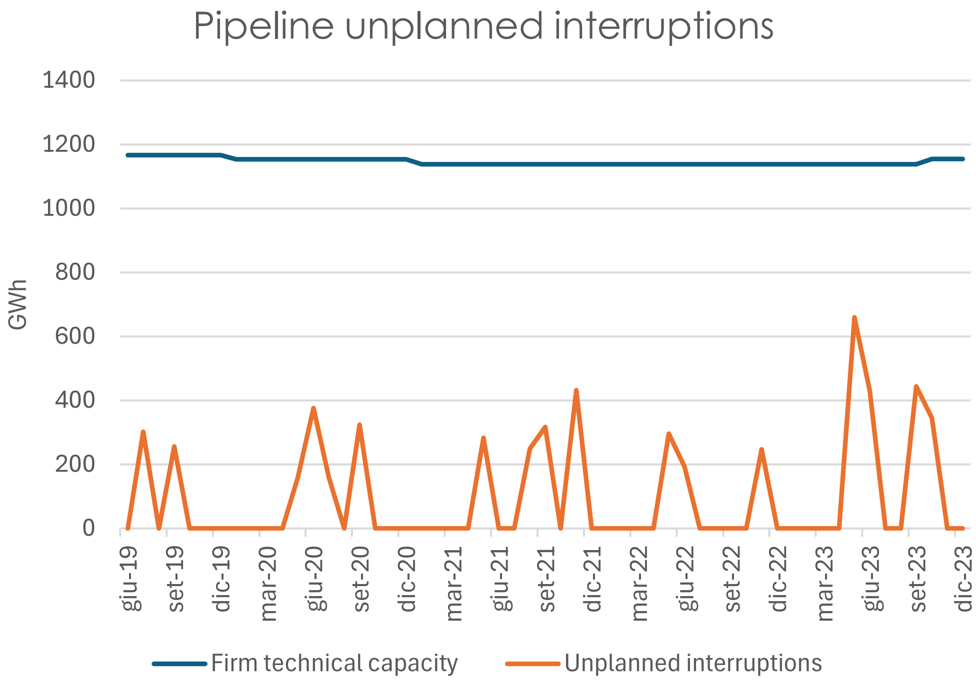
Table 22 Normalized and aggregated socio-political indicators

Year	PS & AV/T_scaled	GE_scaled	RL_scaled	RQ_scaled	PS & AV/T_share	GE_share	RL_share	RQ_share	Weighted avg
2010	0,25	0,42	0,34	0,28	0,19	0,33	0,26	0,22	0,33
2011	0,23	0,40	0,33	0,26	0,19	0,33	0,27	0,21	0,32
2012	0,23	0,41	0,34	0,24	0,19	0,34	0,28	0,19	0,32
2013	0,26	0,41	0,36	0,27	0,20	0,32	0,28	0,21	0,34
2014	0,26	0,43	0,34	0,24	0,21	0,34	0,27	0,19	0,34
2015	0,28	0,42	0,31	0,25	0,22	0,33	0,25	0,20	0,33
2016	0,28	0,41	0,32	0,25	0,22	0,32	0,25	0,20	0,32
2017	0,32	0,39	0,31	0,24	0,25	0,31	0,25	0,19	0,33
2018	0,33	0,40	0,34	0,23	0,25	0,31	0,26	0,18	0,34
2019	0,29	0,39	0,33	0,22	0,24	0,32	0,27	0,18	0,32
2020	0,33	0,39	0,34	0,23	0,26	0,30	0,26	0,18	0,33
2021	0,30	0,37	0,33	0,26	0,24	0,29	0,26	0,21	0,32
2022	0,35	0,40	0,33	0,29	0,26	0,29	0,24	0,21	0,35

Historically, the aggregated value has remained quite stable during the years, between 0,3 and 0,35, evidencing levels of political and social stability below the average. This can have various implications for trade agreements, influencing decisions and economic dynamics, in particular may be perceived as a risk for foreign investors and for transportation infrastructure.

This trend suggests the possibility of continuity in the future, at least until significant changes are introduced into the Algerian government context.

Figure 8 Pipeline unplanned interruptions on technical capacity (2019-2023)



Source: ENTSOG Transparency platform

Above there is an historical graphical representation of the unplanned interruptions of gas pipeline at interconnection point between Algeria and Italy (Mazara del Vallo entry point) with respect to the firm technical capacity (that describes the maximum amount of transportable natural gas)[96]. Unplanned interruptions or disruptions in gas pipelines can occur for various reasons and are often referred to as incidents or outages as equipment failure, gas leakages, sabotages, natural disasters etc.

These interruptions lead to partial (or complete in extreme circumstances) reduction of pipeline technical capacity in terms of transportable energy that can pose a risk to the gas supply.

Table 23 Effect of pipeline interruptions

Year	**Interrupted firm capacity (%)**	**Interruption time (%)**
2019	23,91	2,74
2020	21,59	10,96
2021	26,55	16,44
2022	22,42	18,36
2023	33,01	6,58

The rate of interrupted firm capacity gives a measure of reliability of the connection on the basis of failure magnitude helping to assess the safety and operational continuity of the gas transportation system.

This index allows system operators and regulatory bodies to monitor the performance of the gas pipeline, identify areas for improvement, and ensure a safe and reliable supply.

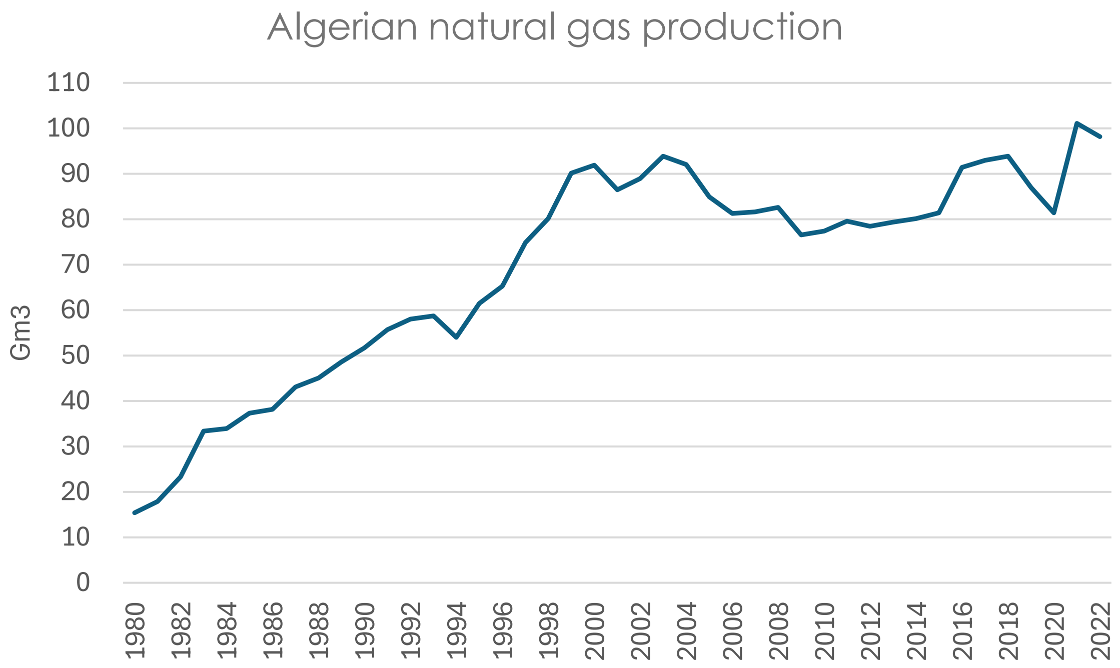
The nearly constant trend indicates that the system has consistently demonstrated a certain level of dependability. Minimal or negligible fluctuations in the reliability metric suggest a quite stable performance with no particular and noteworthy failures, with only marginal variations detected during the last year.

By expressing this data in temporal terms allows to show the availability of pipeline to be correctly operational over a specific time frame. The historical trend shows a significant reduction of temporal unavailability of the system especially during 2023 (only 6,58% of interruption time) with respect to the higher values of the previous years, indicating a greater operational availability of the connection.

This trend may persist in the future since commercial agreements between Algeria and Italy continue to intensify during the last periods and the need for a secure and available transmission infrastructure becomes crucial.

Algeria has been a significant global player in natural gas production, leveraging its extensive reserves and advanced infrastructure to extract, process, and export substantial volumes of natural gas.

Figure 9 Algerian dry natural gas production (2010-2022)



Source: U.S. Energy Information Administration

The trend in Algerian gas production from 1980 to 2022 has generally been characterized by significant growth and strategic developments in response to domestic and international demand.

As can be seen the major boost in gas production occurred during the decades before 2000s during which rapidly moved from around 15 up to 90 Gm3. Then the trend remains almost constant with little fluctuations: in particular the 2020s are influenced by a combination of market dynamics, technological advancements, and geopolitical factors.

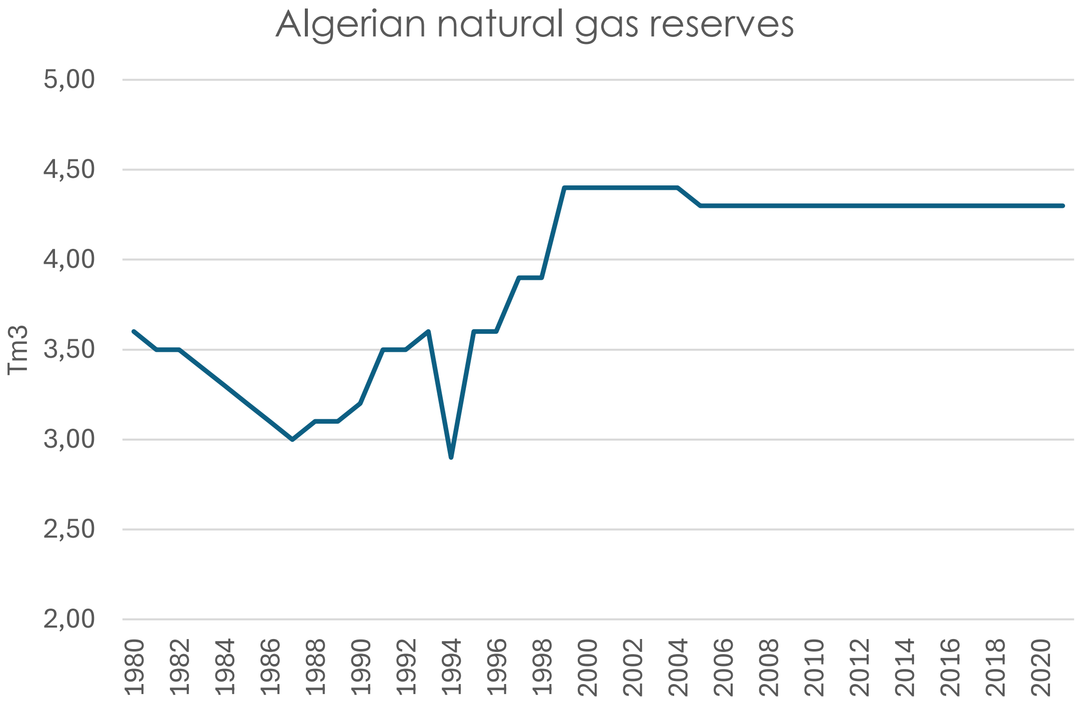
Overall, the upward trend highlighted by the diagram suggests steady and sustained growth and consequently an adequate level of availability.

Algeria also possesses significant natural gas reserves, making it a prominent player in the global energy market. The country is renowned for its abundant and high-quality natural gas resources, primarily found in the vast Sahara Desert. These reserves have played a crucial role in Algeria's economic development and its status as one of the leading gas exporters.

The country has been actively involved in international energy trade, with natural gas being a key export commodity. Algeria's strategic location, coupled with its extensive pipeline infrastructure allows it to supply gas to Europe and other global markets.

However, the management of information regarding gas reserves may be a matter of strategic policy: maintaining secrecy about gas reserves could be a strategic precaution to prevent other nations from gaining a detailed understanding of the country's energy capabilities, but also from commercial negotiations point of view: the lack of information may be used as leverage in international trade negotiations in order to influence prices and gain advantages in negotiations.

Figure 10 Algerian natural gas reserves (1980-2021)



Source: U.S. Energy Information Administration

In this context, the almost constant trend in Algerian gas reserves across the last years may be justified by the reasons mentioned above, so not significant fluctuation are expected to be recorded also during next years.

Table 24 Natural gas import price contracted between Algeria and Italy (2020-2022)

Period	Price (EUR/MWh)	Yearly variation (%)	Coefficient of variation (%)
Q1 2020	20,30		75,94
Q2 2020	14,00	-31,03	
Q3 2020	11,40	-18,57	
Q4 2020	13,20	15,79	
Q1 2021	13,40	1,52	
Q2 2021	15,80	17,91	
Q3 2021	18,50	17,09	
Q4 2021	20,00	8,11	
Q1 2022	29,00	45,00	
Q2 2022	41,10	41,72	
Q3 2022	79,50	93,43	

In table 25 contracted import price between Algeria and Italy are displayed[97].

The Coefficient of Variation (CV) is a statistical measure that is used to assess the level of variation in a data set. It is commonly used to compare the degree of variability in data sets that differ in scale or units of measurement. CV is often used in fields such as finance, engineering, and science to evaluate the risk associated with a particular investment or process. The CV is calculated by dividing the standard deviation by the mean and expressing the result as a percentage[98]. It provides standardized measure of variability that can be used to compare different data sets. The CV in this case is used to understand the volatility level of the costs and can help to determine the risk level: the higher the CV the greater will be the risk.

The data presents quarterly variations in prices in EUR/MWh, showcasing notable dynamics over time.

The CV calculation (nearly 76%) shows quite significant risk associated with the import price, that can be affected by several social, political and economic factors.

The table shows a clearly growing trend quarter by quarter during which the prices have experienced an almost constant surge until the beginning of 2022. From Q2 2022 the trend reached significantly higher levels leading the contracted prices to nearly double within a few months.

This noteworthy price increase could be attributed to several factors as fluctuations in commodity prices and dynamics in the global energy market. Changes in energy policies and geopolitical relations could also have influenced this upward trend: in fact the most significant surge in prices coincides with the onset of the Russo-Ukrainian conflict, highlighting the strong correlation between economic and geopolitical patterns.

Table 25 Average transport cost for gas pipeline connection between Algeria and Italy (2018-2022)

Year	Cost (EUR/tonne)	Yearly variation (%)	Coefficient of variation (%)
2018	33,80		31,17
2019	30,40	-10,06	
2020	22,50	-25,99	
2021	14,70	-34,67	
2022	17,10	16,33	

Beyond the contracted price for the commodity, for the sake of completeness also the costs for transportation of natural gas (from Algeria to Italy[99]) should be analyzed.

Onshore transport costs include the maintenance and regulatory compliance of transport infrastructure, tariffs and fees and others ancillary services. These kinds of costs can be related to market conditions, regulatory changes, and technological advancements.

In this case the value associated with the CV suggests not so significant risk level and the historical data show a quite descending trend, maybe related to the technological advancement of the transmission infrastructure.

4.2.3 Liquified natural gas supply chain

From the perspective of supply security, LNG trade appears entirely advantageous as it enhances the diversification of supply sources. The option to import liquefied natural gas instead of compressed gas can be seen as a solution to implement continuously or in the case of a crisis, such as a pipeline flow interruption. In the former case, long-term contracts should be pursued, while in the latter, turning to the spot market would be necessary. In both scenarios, it is essential not to forget that the LNG chain to Europe is more expensive than the pipeline route, and, especially in times of scarcity, prices tend to rise and become volatile.[100]

Liquefied natural gas vessels embark on a strategic journey from the North African shores of Algeria to the heart of Southern Europe, weaving a significant chapter in the evolving narrative of sustainable energy, since Algeria, as seen in the previous paragraphs, has positioned itself as a key supplier in the LNG market.

In this context, the Mediterranean Sea plays host to modern vessels carrying the promise of cleaner and more efficient energy solutions. This maritime passage represents the convergence of economic interests, geopolitical dynamics, and environmental aspirations as LNG becomes the pivot connecting Algeria's abundant natural gas reserves to Italy's growing demand for cleaner energy alternatives. So these vessels not only ferry fuel but also carry with them the potential to reshape the energy landscape of both nations and influence the broader contours of the global energy transition.

In Italy there are 4 regasification terminals and a small-scale LNG depot currently operating with a total annual capacity of almost 22 Gm3[101].

Table 26 Technical data on Italian LNG terminals (2023)

Location/Name of installation	**Type**	**Nominal annual capacity (Gm3/y)**	**LNG storage capacity (m^3)**	**Max send out pressure (bar)**	**Max ship class size receivable (m^3)**
Livorno - OLT Offshore LNG Toscana FSRU	FSRU[26]	5,00[27]	137500	80,00	180000
Panigaglia LNG terminal (La Spezia)	Large onshore	3,40	100000	70,00	70000
Adriatic LNG (Porto Levante)	Offshore GBS[28]	9,00	250000	70,00	217000
Piombino LNG terminal	FSRU	5,00	170000	/	/
Ravenna LNG small-scale	Small-scale LNG depot	0,91	20000	/	/

Source: GIE LNG database

Two of them started quite recently their operations: Ravenna small-scale LNG has been operational since 2021 while the Piombino LNG terminal only during the middle of 2023.

Nominal annual capacity refers to the regasification potential, representing the maximum amount of LNG that a regasification facility can convert back into its gaseous state for distribution, while for small-sale depot it describes the handling capacity.

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[26] Floating storage and regasification unit

[27] Until 2022 nominal capacity was of 3,75 Gm^3

[28] Gravity based structure

The following table shows the list of all the vessels transporting LNG from Algeria to the Italian regasification terminals[102].

Table 27 LNG carriers from Algeria to Italy (Aggregated 2017-2023)

Vessel name	Vessel deadweight tonnage (kt)	Discharge port	Average voyage duration (days)
BERGE ARZEW	77,47	Livorno (FSRU)	7,03
BW PAVILION ARANDA	95,88	Livorno (FSRU)	26,39
CHEIKH BOUAMAMA	39,52	La Spezia (Panigaglia)	6,34
CHEIKH EL MOKRANI	39,52	La Spezia (Panigaglia)	5,87
COOL EXPLORER	81,89	Livorno (FSRU)	6,77
DAPENG PRINCESS	45,46	La Spezia (Panigaglia)	17,81
ENERGY SPIRIT	36,95	La Spezia (Panigaglia)	6,10
GRACE DAHLIA	86,51	Livorno (FSRU)	26,26
KOOL ICE	81,53	Livorno (FSRU)	9,41
LALLA FADHMA N SOUMER	80,92	Livorno (FSRU)	7,27
OUGARTA	94,58	Piombino	5,43
SEAPEAK CATALUNYA	77,20	Piombino	29,41
VIVIRT CITY LNG	92,86	Livorno (FSRU)	7,60

Source: Alphatanker database

These data refer to the period from 2017 to 2023 highlighting the main features of the 13 different LNG vessels that embarked this maritime route during the last years. As can be seen, the main maritime routes undertaken by Algerian LNG vessels are the ones towards La Spezia and Livorno seaports.

Vessel DWT is a measure of the weight that a vessel can carry, and so representing its capacity, while the duration of loading, voyage and discharging phases are expressed in number if days.

In particular, these parameters help to give a measure of efficiency and reliability of each vessel.

Table 28 LNG transported from Algeria to Italy (2017-2023)

Year	Vessels #	Voyages #	Total LNG shipped (Gm^3)
2017	4	17	0,7961
2018	3	18	0,7595
2019	7	63	2,9430
2020	5	63	2,8044
2021	4	27	1,2170
2022	3	34	1,4160
2023	10	46	2,3123

Source: Alphatanker database

By looking at the total amount of LNG imported from Algeria during the last years[102] a significant increase in 2023 has been registered (63,29% higher than the previous year) confirming the increasing strength of this maritime trading.

Same observation can be made for the number of vessels that embarked this route: after a quite constant trend during the previous years, in 2023 it has reached 10 units suggesting a further increase in the future.

Table 29 Average import rates for chemical products sea freight (2018-2022)

Year	Cost (Eur/ton)	Yearly variation (%)	Coefficient of variation (%)
2018	85,2	/	11,83
2019	92	7,98	
2020	82,5	-10,33	
2021	84,7	2,67	
2022	111,9	32,11	

The table above shows the price evolution of sea freight costs regarding chemical products imported by Italy, in whose class also LNG is included[99].

Historically, these rates remained almost constant, suggesting quite low risk level also demonstrated by the modest value of CV.

Anyway, in the most recent period, the remarkable price growth (+32,11% in 2022) could be linked to geopolitical shifts, such as changes in energy policies, increased demand for chemicals, or disruptions in supply chains due to geopolitical tensions.

In order to provide a measure of the operational availability of each regasification unit, two different parameters have been evaluated:

1. $\frac{\text{LNG received}}{\text{Annual regasification capacity}}$

2. $\frac{\text{Send}-\text{out amount}}{\text{Send}-\text{out firm capacity}}$

The first parameter is a crucial metric in evaluating the residual capacity. It is related to the exploitation of the terminal and is represented by the ratio between amount of LNG received by a single installation and its annual regasification capacity with the exception of the Ravenna small-scale for which an equivalent factor (annual LNG handling capacity) has been considered. This ratio provides insights into how effectively the terminal is utilizing its available capacity over a specific timeframe.

Table 30 Share of LNG received over nominal regasification capacity (2017-2023) [%]

Terminal	2017	2018	2019	2020	2021	2022	2023
Livorno - FSRU Toscana	23,45	29,02	83,16	76,82	36,02	85,29	73,61
La Spezia (Panigaglia)	18,46	22,34	69,07	74,75	30,81	61,09	62,06
Adriatic LNG	71,13	71,03	81,61	68,15	77,62	94,99	90,59
Piombino							23,80
Ravenna					1,83	12,82	18,23

A high LNG utilization ratio indicates that the regasification terminal is operating close to its maximum capacity, optimizing its resources and efficiently meeting the demands for natural gas. However, a lower ratio may suggest underutilization, indicating greater flexibility that is a crucial point in assessing the availability of the infrastructure.

Over the years, especially during 2022 and 2023, the utilization ratios have undergone a quite significant increase due to the development of the LNG market, suggesting both an higher exploitation level but simultaneously a noteworthy surge in the expansion of LNG terminals capacity in the future, spurred by a confluence of factors: the escalating global demand for natural gas, coupled with advancements in technology and a heightened emphasis on sustainable energy sources. Additionally, recognizing the importance of diversifying import channels in order to enhance the energy security.

Table 31 Share of send-out amount over nominal capacity (2018-2023) [%]

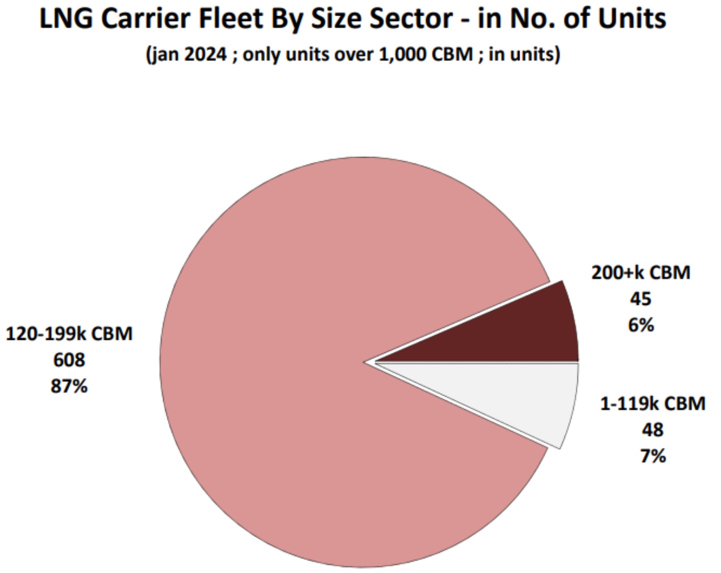
Terminal	Average 2018-2021	01-04-2021 to 23-02-2022	24-02-2022 to 31-05-2022	01-06-2022 to 30-09-2022	01-10-2022 to 31-08-2023
Livorno - FSRU Toscana	41%	33%	38%	82%	66%
La Spezia (Panigaglia)	42%	23%	28%	63%	80%
Adriatic LNG	91%	94%	95%	71%	89%
Piombino					13%

Source: European Union Agency for the Cooperation of Energy Regulators

The send-out utilization ratio elucidates the correlation between the actual volume of liquefied natural gas dispatched from the terminal and its committed firm capacity – the maximum quantity the terminal has contractually pledged to deliver[103].

Also here the focus of the analysis is centered on the operational availability of the terminal, in particular towards the gas network infrastructure. The network is designed to accommodate fluctuations in demand, so a better level of flexibility, represented by an higher residual capacity, ensures that natural gas can be efficiently supplied to meet varying consumer needs, responding dynamically to changes in usage patterns. A heightened send-out utilization ratio signifies that the terminal is operating efficiently, fulfilling its contractual obligations. However, a lower ratio may indicate that the terminal is not fully leveraging its firm capacity, and so it is available to adapt to reassessment of market dynamics and to increase its operations. For all these reasons the historical data shows a substantial fluctuation in values without revealing a precise trend, since they are influenced by several factors.

Figure 11 LNG carrier fleet by size (2024)[29]



Source: LNG carrier market outlook 2024 – Banchero Costa research

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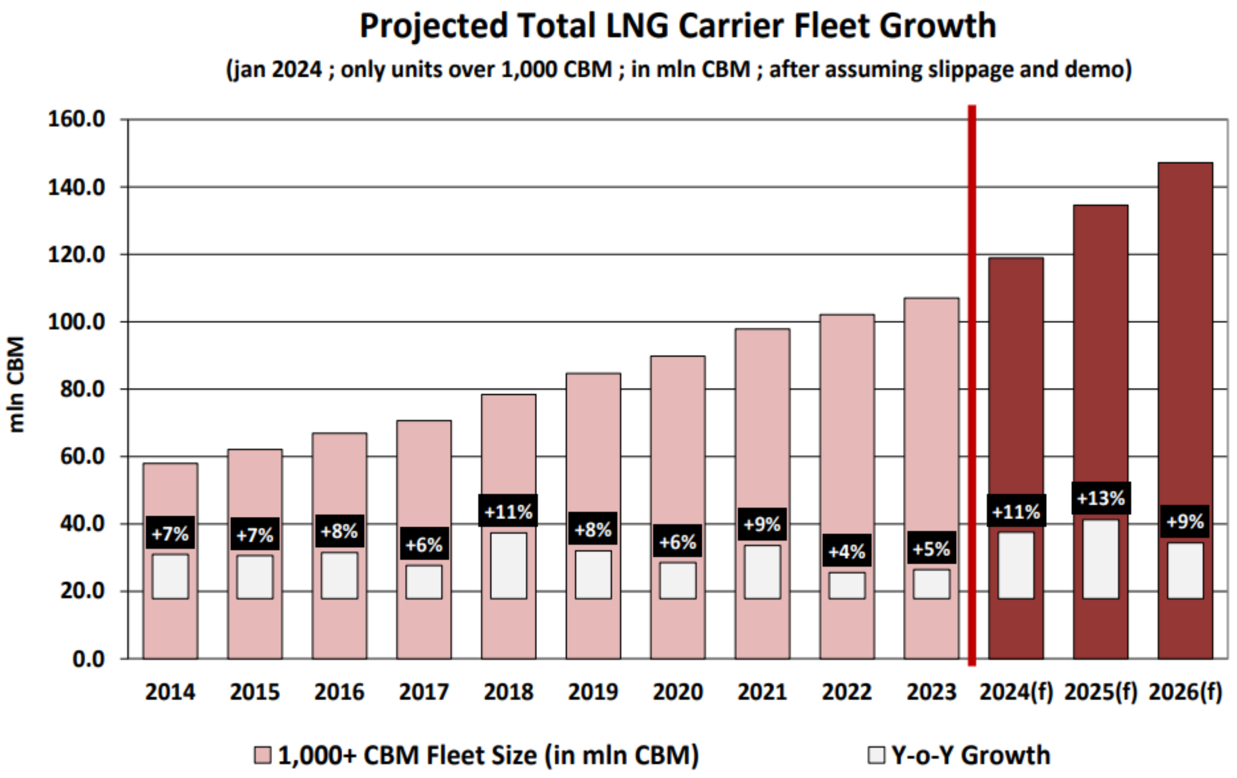
[29] CBM = cubic meters

The trading LNG Carrier fleet currently numbers 701 trading units, for a total of nearly 107 Mm³. Of these, 608 units (87% of the total fleet) are standard sized units of 120000-199999 m³ of capacity.[104]

Only 48 trading units, or 7% of the fleet, are smaller than 120000 m³ and also only 45 trading units are larger than 200000 m³.[104]

Figure 12 LNG fleet growth (2014-2026)



During the last years the evolution of LNG carriers availability has resulted in an almost constant increase although with not so significant shares (between 4% and 9% y-o-y).

In particular, in 2023 net fleet growth for all LNG Carriers was +4,9% with respect to the previous year[104].

Fleet expansion is expected to continue at around +11,1% in 2024 and then at around +13,2% in 2025, as demonstration of future further development of LNG trade.

Forecast for 2024-2026 is based on the current orderbook after assuming slippage and expected demolition.

To conclude, from this risk assessment emerged that from the point of view of transmission infrastructure no particular criticalities, while on the basis of the monitored indicators, the two critical points that require particular attention are:

- the political and social stability of Algeria, since it is crucial to ensure a steady flow of natural gas to Italy. Any political and economic instability, as well as social tensions could negatively impact gas production and supply disruptions, and also have direct impact on economic aspects

- the gas price fluctuation. Strong fluctuations in prices create a risky market primarily because they introduce uncertainty and unpredictability into the trading environment.

5. Conclusions

This analysis has presented an in-depth study on the energy transition process among the Mediterranean countries, underlying the differences among the three shores, the current status of the installed renewable energy systems and an overview on the main technologies employed for the transition of these countries.

Moreover, a Business-As-Usual scenario at year 2030 on the installed capacity and generation of renewables has been developed in order to evaluate the progress status of each country and highlight the gap that they should fulfill to meet their own national objectives and their projected electricity demand.

The need for further efforts in renewable energy development clearly emerges especially for some countries, thus demonstrating that it is a far-from-immediate process. This development is anyway expected in the coming years or, in any case, by 2030, as also evidenced by the description of national objectives and European policies and regulations.

Beyond the crucial role of renewables, also natural gas, as energy commodity has the potential to support the transition. Concerning its supply system, it has undergone a significant reshaping process over the past few years, both in terms of infrastructure and market dynamics. A closer examination of the sources of natural gas imports among Mediterranean countries highlights a discernible shift from traditional suppliers, such as Russia, towards new and emerging players like Algeria and Azerbaijan. These new entrants are increasingly establishing themselves as prominent contributors to the market.

From an infrastructural perspective, there is a noteworthy trend in the continuous growth of liquefied natural gas procurement, this trend contrasts with the diminishing reliance on pipeline transportation. This strategic shift not only reflects the evolving preferences in transportation methods but also signifies a deliberate effort towards diversifying the resource base. The maritime transport of gas, thanks to its higher flexibility, allows for higher energy security, contributing to a more adaptable and resilient supply system.

It not only reflects a shift in the geopolitical dynamics of energy trade but also aligns with a broader strategy aimed at enhancing energy security in the face of dynamic global challenges.

In this context, the interconnection between Algeria and Italy regarding natural gas supply has witnessed a significant. The strengthening of this partnership has represented a good opportunity for the diversification of Italian energy mix. Algeria, with its abundant natural gas resources, has emerged as a key player, contributing to Italy's energy security and diversification goals. This link is expected to continue and grow also during next years net of the fact that the social and geopolitical stability of Algeria must be consistently assessed and taken into consideration. In the current dynamic energy landscape there has been, especially during the last years, an increase in uncertainty caused by events such as conflicts, political crises, and international tensions, directly impacting energy supplies. Therefore, in a world where geopolitical dynamics can change rapidly, adaptability and flexibility in procurement strategies as well as risk assessment become key elements in addressing the energy transition process.

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