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Communication

Potential Solutions for the Short to Medium-Term Natural Gas Shortage Issues of Europe: What Can Qatar Do?

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Abstract: European countries are required to look for alternative gas suppliers to deliver energy security for Europe. Qatar has been proposed to be an alternative gas supplier; however, there are problems that limit Qatar from exporting more gas to Europe, namely: the limited LNG quantities available for export, the long-term fixed contracting strategy, and the lack of room to receive additional gas in European LNG terminals. As these problems are critical and limit Qatar from exporting more gas to Europe, this research aims to propose potential solutions to overcome them. The results show that to solve the issue of the limited LNG quantities available for export, Qatar can produce electricity from renewable sources and export the gas consumed for power production, and can produce renewable natural gas (RNG) from green hydrogen and captured carbon dioxide. Two BCM of natural gas can be exported if 15% of the electricity required is produced from renewables in Qatar. In addition, 0.45 BCM of RNG can be exported if Qatar uses its natural resources to produce 5000 MW of renewable power. Redirecting contracts coming to an end and increasing dependence on spot markets can resolve the issue of a long-term fixed contracting strategy. Finally, using floating import terminals may alleviate the problem of European LNG terminals running out of room to receive more gas.

Keywords: gas crisis; natural gas; supply shortages; LNG; Europe; Qatar

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1. Introduction

As the risk of a conflict between Russia and Europe rises, and with it, the possibility of a gas crisis as Russia is the primary gas exporter to Europe, solutions to cover some of the gas shortage in Europe are needed [1,2]. About 52% of Europe's natural gas supply comes from Russian pipeline exports, which total 167.7 BCM [3]. Russia may weaponize the gas supply, having a tremendous influence on the economy of Europe as it cuts off natural gas to Bulgaria and Poland [4]. Presently, there are not enough nearby gas reserves to cover a significant supply interruption from Russia [5]. Therefore, European countries have begun preparing by diversifying their energy supply to replace Russian imports and implementing energy efficiency programs [6–12]. Due to gas shortages in European countries because of the conflict between Russia and Europe, energy poverty levels in European counties have increased, leading to an economic crisis. Electricity prices have been identified as the primary cause of energy poverty in Europe [13]. European countries also launched the Green Deal. The European Green Deal is the collection of policy measures on sustainable development, and it provides the European Commission (EC) with a chance to clarify sustainability methods and emphasize environmental preservation [14]. The EC aims to attain a climate-neutral economy by 2050, with energy transformation playing the most crucial role. To develop a well-defined framework that would contribute to this purpose, member states have been invited to submit their final National Energy and Climate Plans (NECPs), in which they were required to identify comprehensive national objectives, targets, and contributions, as well as policies and strategies to accomplish the objectives, particularly the 2030 EU energy and climate targets. However, the COVID-19 situation

may have prevented these member states from drafting, creating, and submitting their final NECPs in a timely manner. Variations in the strategies and compliance of member states may also limit the submission of the final NECPs [15].

Several solutions have been proposed to overcome the natural gas shortage issues in Europe. The IEA proposed a 10-point plan to minimize the EU's reliance on Russian natural gas: (i) there will be no new gas supply agreements with Russia, (ii) Russian gas will be replaced with gas from other sources, (iii) minimum gas storage requirements will be enforced to improve market resiliency, (iv) new wind and solar projects will be deployed faster, (v) current low-emissions sources such as bioenergy and nuclear power will be used to their fullest extent, (vi) short-term steps need to be taken to protect vulnerable power users from rising rates, (vii) heat pumps will be installed as quickly as possible instead of gas boilers, (viii) building and industrial energy efficiency will be improved as quickly as possible, (ix) consumers should be encouraged to temporarily lower their thermostats, and (x) decarbonization is planned, and efforts to diversify power system flexibility will be increased [16]. The European Commission also proposed a REPowerEU plan to reduce dependence on Russian gas. The plan consists of a number of activities, including: (i) reducing the dependency on fossil fuels by installing more solar panels, heat pumps, and energy-efficient appliances in European houses, (ii) increasing the pace of renewables deployment, which means less time is needed for grid infrastructure upgrades and the roll-out of new renewable projects, (iii) increasing supply security through reducing reliance on Russian gas, collaborating with foreign partners, and putting money into the essential infrastructure, (iv) decarbonizing the economy through speeding up the transition to renewable hydrogen and electric vehicles, as well as strengthening European low-carbon industrial capacity, (v) aiming for 35 BCM per year of biomethane production by 2030, mostly from agricultural waste and residues, and (vi) introducing theEU's hydrogen accelerator which support developing hydrogen infrastructure, storage facilities, and ports, as well as to replace demand for Russian gas with an extra 10 million tons of imported renewable hydrogen from a variety of sources, and a further 5 million tons of local renewable hydrogen [17]. Misík also has proposed three options to increase the EU's energy security [18]. The first option is to decouple the short-term market and political circumstances from end consumers by providing help for the energy-poor, reducing taxes, and freezing energy prices. A number of EU member states have taken similar measures, but they are tied to social and budgetary policies that are entirely at the control of the individual countries. The second option is that exterior energy policy cooperation among EU member states on a regional rather than EU-wide level may potentially lead to a stronger position with respect to energy suppliers. The third option is that the Commission examination of Intergovernmental Agreements also provides a mechanism to improve the positions of member states with respect to energy-supplying nations by ensuring that they adhere to the rules [19,20]. After these rules have been adopted by member states and their energy providers, the Commission obtains authority to assess energy agreements against the already existing internal energy-market regulations.

In addition, talks have been initiated with North African and Central Asian governments in an effort to secure extra gas supplies in the event that Europe's supply is cut off [21]. Furthermore, the EU has had discussions with some nations regarding expanding gas and liquefied natural gas (LNG) exports via contract swaps or additional shipments. Countries such as Qatar, Egypt, Azerbaijan, the United States, South Korea, and Nigeria are among those mentioned [22]. Recent talks between the U.S. and Qatar show that Qatar seems to be a potential candidate for making up for the loss of supplies to Europe [23]. However, the state-owned company "Qatar Energy" (previously named "Qatar Petroleum") was at the center of a major conflict fight over EU antitrust laws in 2018. This was because the EC was trying to clarify if liquefied natural gas supply deals between Qatar and European utility companies limited those companies' ability to change shipments within the region [24]. Since the investigation that was supposed to look at 20-year gas contracts began three years ago, it is unlikely that the EU will take any more antitrust action against Qatar Energy. The

EU decided to stop looking into Qatar's gas contracts because they were concerned that if there was a conflict, the supply could be cut off. Despite the fact that Qatar is one of the top three gas exporters in the world, its long-term agreements with significant clients in Japan, China, and South Korea suggest that it may fall short of EU officials' aspirations in terms of completely supplanting the gas provided by Russia. Qatar has a major role in supplying Europe with more gas. It has one of the largest LNG export capacities in operation worldwide, generating 77.4 million metric tons per year [25]. For Europe, Qatari gas may be a viable option; however, Qatar is now producing at or near its full capacity, with most of its supply bound by long-term contracts [26]. Qatar has worked with Europe in the past on energy issues. Due to an energy emergency, Qatar sent four LNG ships to the United Kingdom in late 2021 [27]. Lastly, in order to keep up with the increased worldwide demand for LNG, Qatar's terminals are already working at their maximum capacity.

Still, the issue of how Qatar would get the LNG to Europe remains open. For off-take and regasification to occur, Qatar must have the shipping capacity, and Europe must have the necessary infrastructure in place. In 2019, Qatar shipped 104.8 billion cubic meters of LNG using its 45 Q-Flex and Q-Max LNG carriers, maintaining its position as the world's leading LNG exporter [3]. To satisfy the rising global demand for gas, Qatar has just begun an expansion project to increase its LNG production capacity by 64% by 2027 (from 77 to 162 MT) [28]. Regarding regasification terminals in European countries, there is not enough capacity. Europe's regasification capacity has the capacity to import 150 MT of LNG yearly [26]. Therefore, the novel aspect of this study is to identify the major problems that limit Qatar from exporting gas to Europe and propose potential and fast-implemented solutions to overcome these problems.

The rest of the paper is structured as follows: Section 2 contains materials and methods. The tool used to identify the problems that limit Qatar from supplying more gas to Europe was identified, and solutions to overcome these problems were mentioned in Section 2. Section 3 contains the results and a discussion. This section has three main problems that limit Qatar from exporting gas to Europe, and it has potential solutions for each problem. Finally, Section 4 contains the conclusion of the study.

2. Materials and Methods

After analyzing the literature on the natural gas market of Qatar, a list of problems that limit Qatar from supplying Europe with more gas was identified as presented in Table 1. One of these problems is that European countries depend on natural gas that is supplied by Russia. About 52% of Europe's natural gas supply came from Russia in 2020, which totals 167.7 BCM [3]. Although Qatar is being considered as a candidate for replacing Russian gas, Qatar cannot replace 100% of the gas supplied by Russia to Europe for a number of reasons, namely Qatar's commitments to supply gas to customers and the fact that Qatar mostly sells its natural gas under long-term contracts. These problems limit Qatar from exporting more gas to Europe. Moreover, there is no gas pipeline transportation option, so Qatar can supply gas to Europe using LNG only. However, there is limited available capacity in European terminals to absorb extra supplies of LNG [29]. Thus, this also limits Qatar from exporting more gas to Europe. The problems that limit Qatar from exporting more gas to Europe were taken up to 2022. There might be more problems that occur in the future. In summary, these problems can be categorized into three main problems that limit Qatar from exporting more gas to Europe, namely: (i) the limited LNG quantities available for export, (ii) the long-term fixed contracting strategy, and the limited space available to receive more gas in European LNG terminals.

In this research, these problems were investigated in detail, and solutions to overcome them were proposed. Reasons that cause these problems were mentioned. Potential solutions for solving these problems were proposed to increase the supply of gas to Europe from Qatar. The proposed solutions were short to medium-term solutions (present to 2027). The statistics used in the proposed solutions were obtained from the literature (more details about the statistics were mentioned in the Results and Discussion section.

Table 1. Major problems that limit Qatar from suppling more gas to Europe, according to the literature.

Problems	Source
The volume of gas supply by Russia to Europe is large, and the gas transfer via pipelines is stopped	[30]
Qatar's commitments to supply gas to customers	[31]
Qatari gas is mostly marketed to Asian purchasers under long-term contracts, leaving little room for quota increases. Qatar has no intention of jeopardizing its position as a dependable supplier by breaching or renegotiating its long-term contracts, which Qatar regards as essential.	[22]
Qatari contracts are extremely restrictive, prohibiting LNG shipments from being diverted to foreign countries or resold.	[32]
Limited available capacity by European terminals to absorb the extra supply of LNG	[29]

3. Results and Discussion

This section covers some problems that limit Qatar from exporting more gas to European countries and the proposed solutions to overcome the energy crisis in Europe. A summary of problems that limit Qatar from exporting more gas to Europe and proposed solutions to overcome these problems are presented in Figure 1.

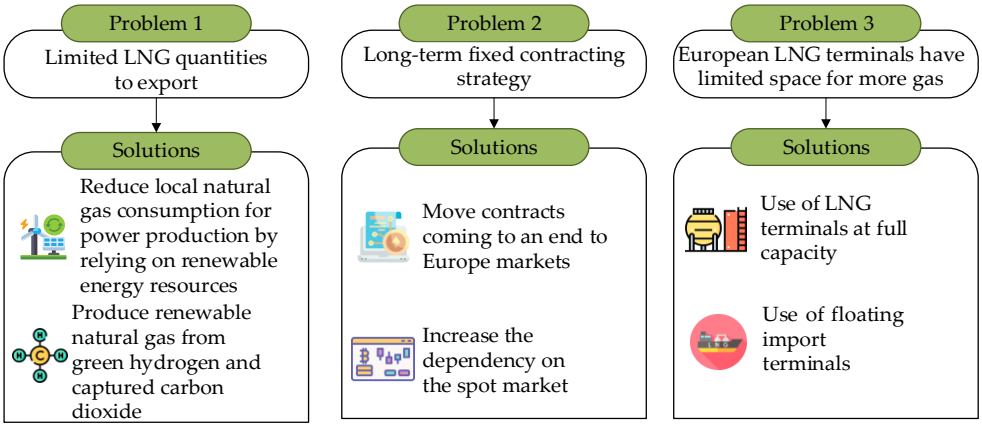

Figure 1. A summary of problems that limit Qatar from exporting more gas to Europe and proposed solutions to overcome these problems.

3.1. Problem 1—Limited LNG Quantities to Export

Until 1971, the significance of the discovery of natural gas off Qatar's northeast coast was hardly recognized. Only after drilling 15 appraisal wells over a 14-year period was it determined that Qatar's North Field was the world's largest non-associated natural gas field. Around 24,700 BCM of recoverable reserves exist in the North Field, accounting for around 10% of all known reserves worldwide [33]. Natural gas production from the field is about 171.3 yearly. The domestic market in Qatar is small and requires only 35.0 BCM of natural gas. The remaining gas goes to export markets. Due to its geographical location and natural gas market needs, Qatar exports around 75% of its natural gas production, where LNG exports account for 62%, and 13% are traded by pipeline. Figure 2 summarizes the amounts of natural gas production, consumption, and exportation in Qatar. The green arrow represents natural gas production in Qatar per year. The natural gas produced is divided into 4 streams: the blue arrow covers LNG exports, the orange arrow covers NG export by pipeline, and the gold arrow covers NG local consumption.

Figure 3 illustrates natural gas and LNG trade movements between Europe as importers and Qatar and Russia as exporters. Currently, 71.8 BCM of Qatari LNG exports go to the Asian Pacific, 3.2 BCM to the Middle East and Africa, and 0.9 BCM to North America. Around 30.2 BCM of LNG is exported to Europe, as shown in the blue box in Figure 2.

The total LNG exports from Qatar to Europe account for 9% of the total imports of natural gas in Europe. Europe imports yearly a total of 321.8 BCM. 66% of the total gas import to Europe are throughpipeline. Russia transported 167.7 BCM of natural gas by pipeline to Europe and 17.2 BCM as LNG, as shown in the yellow box in Figure 3. 57% of the total gas capacity in Europe was imported from Russia in 2020.

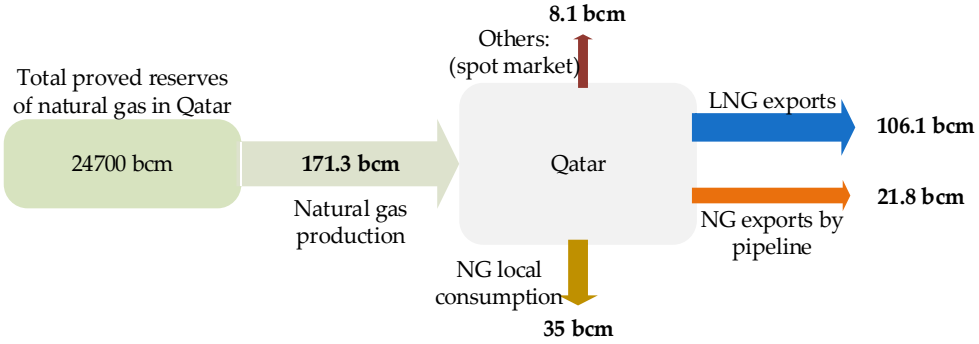

Figure 2. Distribution of natural gas quantities in Qatar (data from [3]).

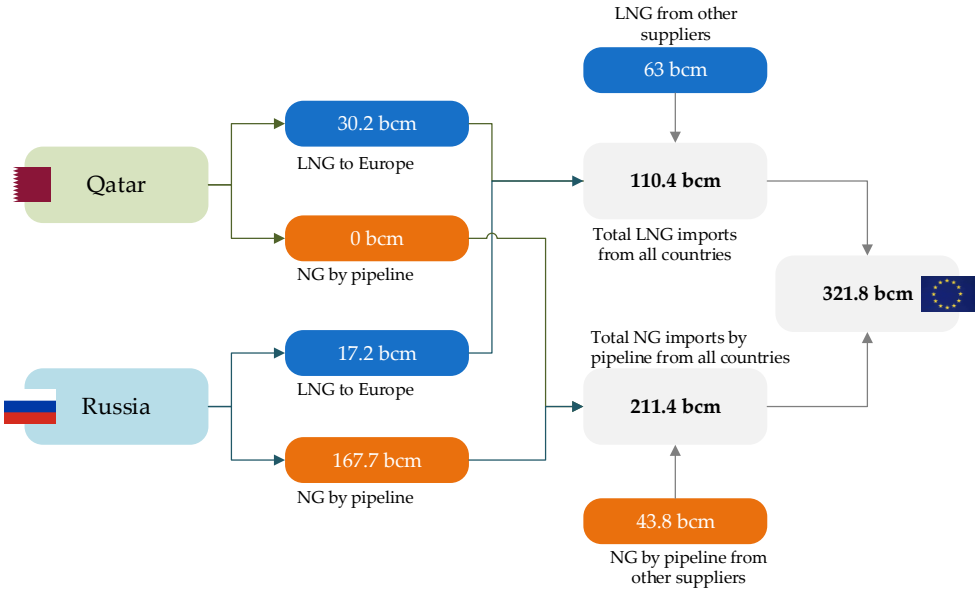

Figure 3. Natural gas and LNG trade movements between Europe as importers and Qatar and Russia as exporters (data from [3]).

If Europe stops importing natural gas from Russia, around 184.9 BCM of natural gas is needed to replace Russian gas. Qatar can be an alternative gas supplier to Europe; however, Qatar has limited free LNG available for export to Europe.

3.2. Problem 2—Long-Term Fixed Contracting Strategy

Qatar started producing LNG in the mid-1990s and presently has 14 liquefaction trains, producing 77.1 Mtpa of LNG. ExxonMobil is now Qatar's biggest corporate partner, and its Qatari assets are among the most valuable in its portfolio. Table 2 contains a list of the significant Qatari LNG project partners. The Asset section covers asset names. There are eight assets available in Qatar including RasLaffan1 (LR1), RasLaffan2 (LR2), RasLaffan3 (LR3), QatarGas1 (QG1), QatarGas2 (QG2), QatarGas3 (QG3), andQatarGas4 (QG4), The number of trains per asset and train capacity are also covered in Table 2.

Table 2. A list of the significant Qatari LNG project partners (data from [34]).

Asset	Number of Trains Per Asset	Train Capacity (Mtpa)	LNG Capacity Per Asset (Mtpa)	Major Equity Owners
RL1	2	3.3	6.6	QP (63%), XOM (25%)
RL2	3	4.7	14.1	QP (67%), XOM (31%)
RL3	2	7.8	15.6	QP (70%), XOM (30%)
QG1	3	3.3	10.0	QP (65%), XOM (10%), TOT (10%)
QG2	2	7.8	15.6	QP (70%), XOM (30%) QP (65%), XOM (16.7%), TOT (16.7%)
QG3	1	7.8	7.8	QP (68.5%), COP (30%)
QG4	1	7.8	7.8	QP (70%), RDS (30%)
RL1	2	3.3	6.6	QP (63%), XOM (25%)

These assets mostly sell their LNG quantities to Asian customers under long-term contracts. Because downtime has a negative influence on project income and economics, operators often aim for 100% or better operational efficiency. As a result of contractual obligations, only minimum amounts will remain uncontracted to serve as a buffer. A small amount of LNG quantities may still be sold on the spot market since the Qatari liquefaction trains are running at a 99% efficiency level on average. Table 3 shows the LNG quantities sold on a long-term contract and a spot and short-term contract from Qatar in 2020. Only 8.1% of the total natural gas production in Qatar is sold on the spot market and on short-term contracts. It is clear that Qatar depends on long-term contracts for its LNG selling strategy. A fixed (long-term) contracting strategy makes LNG trading inflexible. Due to this strategy, Qatar faces challenges in exporting LNG to Europe. As mentioned in a number of reports, one of the issues that limit Qatar from exporting LNG to Europe is the long-term fixed contracts with Asian countries [35,36].

Table 3. Sold Qatari LNG quantities on a long-term contract and on a short-term contract in 2020 (data from [26]).

From	To	LNG Quantities Sold on a Long-Term Contract (BCM)	LNG Quantities Sold on a Spot and on a Short-Term Contract (BCM)
Qatar	Asia	72.2	10.1
	Europe	30.2	3.8
	Americas	0.86	0.001
	The Middle East and Africa	3.23	0.004

3.3. Problem 3—European LNG Terminals Have Limited Space for More Gas

A rising number of European countries have turned to LNG in an effort to minimize their dependency on Russia for natural gas. There were 356.1 MT of LNG traded on the worldwide market in 2020, with Europe purchasing roughly 81.6 MT of the total [37]. While the majority of LNG trading is on long-term contracts, shorter-term and spot trades are growing in popularity and currently account for more than a third of LNG trade [26]. Although LNG has not been widely used in Europe as of yet, several countries are seriously investigating it. There are 28 LNG import terminals in Europe, including LNG terminals in Turkey. With six LNG terminals with a combined yearly capacity of 74.3 MT, Spain has the most LNG terminals in Europe. An annual capacity of 56.1 MT of LNG is maintained by the United Kingdom's three LNG terminals, followed by four LNG terminals in France with a combined annual capacity of 42.9, as well as three LNG terminals in Italy, which can import 19.75 annually. While Turkey has four LNG import terminals, Belgium, Greece, Portugal, the Netherlands, and Poland all have one. In addition, Turkey has two floating LNG terminals, while Lithuania and Croatia each have one floating LNG terminal. Small-scale LNG import facilities in countries such as Norway, Sweden, and Malta are not included in the list. Table 4 lists all LNG terminals in European countries and their send-out capacity.

The send-out capacity of these terminals is taken from [38]. Terminals in Europe have the capacity to import 277.8 BCM of LNG yearly [26]. However, the total import capacity by LNG terminals in Europe was 110.4 BCM in 2020 [3]. Europe, which relies on LNG to provide a quarter of its gas demands, is only using around 39.7%% of its capacity. This indicates that there is an additional 167.4 BCM of capacity available. Spain uses 3% of its capacity, the United Kingdom 38%, Italy 82%, the Netherlands 77%, Belgium 90%, France 66%, Portugal 70%, and Greece 49%, according to the statistics [26].

Table 4. The send-out capacity of LNG terminals in European countries [38].

Country	Terminal	Send-Out Capacity (BCM/year)
Belgium	Zeebrugge	12
France	Dunkerque	13
	Fos Cavaou	16.5
	Fos Tonkin	3.4
	Montoir-De-Bretagne	10
Greece	Revithoussa	8.25
Italy	La Spezia	8
	Olt Offshore LNG Toscana	3.75
	Porto Levante	8
Lithuania	Klaipėdos	4
The Netherlands	Gate	16
Poland	Świnoujście LNG	7.5
Malta	Delimara	0.7
Portugal	Sines—Ren Atlântico	7.6
Spain	Barcelona	17.1
	Cartagena	11.8
	Huelva	11.8
	Bilbao Bahía De Bizkaia	8.8
	Sagunto	8.8
	Mugardos El Ferrol	7.2
	El Musel—Gijon	8.8
Turkey	Aliaga	6.2
	Marmara Ereglisi	6.2
	Aliaga	5.3
	Dörtyol	11
United Kingdom	Grain Lng	27.5
	South Hook LNG	21
	Dragon LNG	7.6
Total	28 terminals	277.8

3.4. Solutions for Problem 1

To overcome the problem of the limited LNG quantities available for export, there are two short to medium-term options that can increase the LNG export capacity in Qatar, including (i) reducing local natural gas consumption for power production by relying on

renewable energy resources and (ii) producing RNG from green hydrogen and captured carbon dioxide.

Regarding the first option, Qatar generated about 49.26 TWh of electricity in 2020 [39]. The electricity produced is mainly from natural gas; however, only 0.02% of electricity is produced by renewable resources (solar energy) [40]. Assuming that the process used for electricity generation is an open cycle, inputting 1.0 BCM of natural gas into a plant produces 3700 GWh of electricity, according to the literature [41]. Considering this, the quantity of natural gas used to produce 49.26 TW of electricity is 13.31 BCM. Moreover, Qatar is planning to increase its shares of renewable resources, namely solar and wind, in electricity generation. Currently, a solar power project of 700 MW is in progress [39]. As a result, if Qatar increases its dependence on renewable energy resources to produce electricity, the natural gas used in power consumption can be converted into LNG and exported overseas. This will increase the quantities of LNG exports. Figure 4 shows the free natural gas quantities that can be obtained when Qatar increases its dependence on renewable energy. The green column presents the quantity of NG used per year to produce electricity in Qatar in 2021. The blue columns show the unusedquantities of natural gas in Qatar when renewables are used to produce electricity. For example, if 30% of the electricity demand is produced by renewables, around 3.99 BCM of natural gas can be saved and exported as LNG to European countries. Moreover, around 9.99 BCM of free natural gas can be saved and exported to European countries when 75% of the electricity in Qatar is produced using renewables.

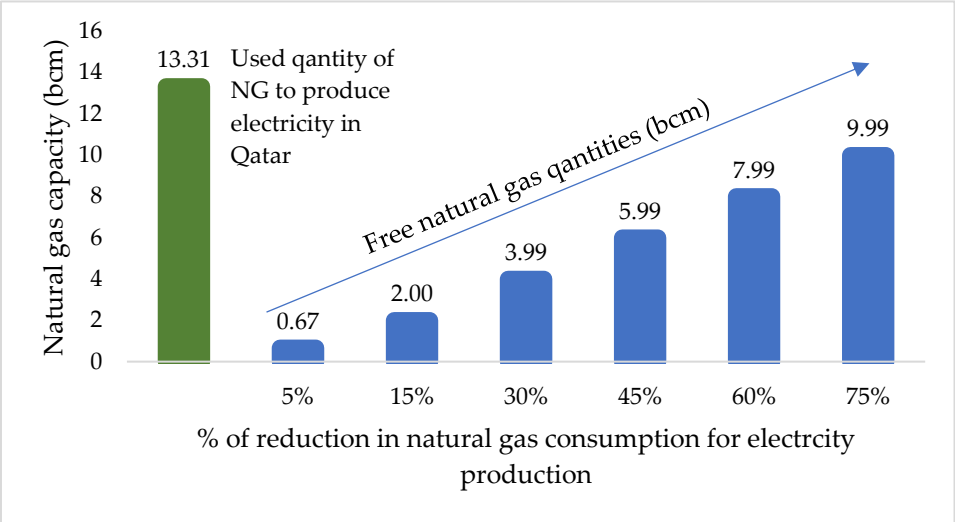

Figure 4. Natural gas quantities that can be obtained when Qatar increases its dependence on renewable energy.

The other option is to produce renewable natural gas (RNG) from green hydrogen and captured carbon dioxide. To produce RNG, seawater is used as a feedstock for an electrolysis process to produce hydrogen gas (H_2) and captured carbon dioxide gas (CO_2) is obtained from emissions of industrial processes. Both gases (H_2 and CO_2) are then sent to a methanation process to produce RNG. Since Qatar is a peninsula with an area of 11,586 km^2 located on the South shore of the Arabian Gulf, where most of the areas are flat and low-lying deserts, such a location has rich solar and wind resources. For solar photovoltaic (PV) systems, Qatar has an annual worldwide horizontal irradiation of 2140 kWh per m^2 [42]. For wind power, at 100 m, wind power density ranges from 149.46 to 267.08 W/m^2 onshore and from 210.02 to 335.06 W/m^2 offshore [43]. For the production of CO_2, CO_2 emissions in Qatar were around 99.5 million metric tonnes in 2020 [44]. The statistics given above make Qatar an optimal place for RNG production.

To calculate the production of RNG, 800 MW of renewable power is assumed to be supplied into a polymer electrolyte membrane (PEM) electrolysis process with an efficiency of 70%. The output of the PEM electrolysis process is hydrogen gas (H_2), having a mass of 4.66 kg/sec of H_2 (using the lower heating value of 120 MJ/kg) [45]. The produced H_2 is then sent into a methanation process with an efficiency of 65%. Thus, the output rate of the methanation process is 6.07 kg/sec of RNG. Therefore, assuming Qatar uses its natural resources to produce 800 MW of renewable power, around 0.07 BCM of RNG can be produced per year, and around 151 million kg of CO_2 is captured, as shown in Figure 5. The amount of RNG produced can be increased to reach 0.45 BCM if Qatar uses its renewable resources (such as solar and wind) to produce 5000 MW of power. Considering these amounts of RNG, natural gas quantities in Qatar will increase, resulting in supplying Europe with higher LNG quantities. For example, a 5000 MW of renewable power production leads to the production of 0.45 BCM of RNG, which can increase total LNG exports to Europe from Qatar by 1.5% (from 30.2 BCM to 30.65 BCM).

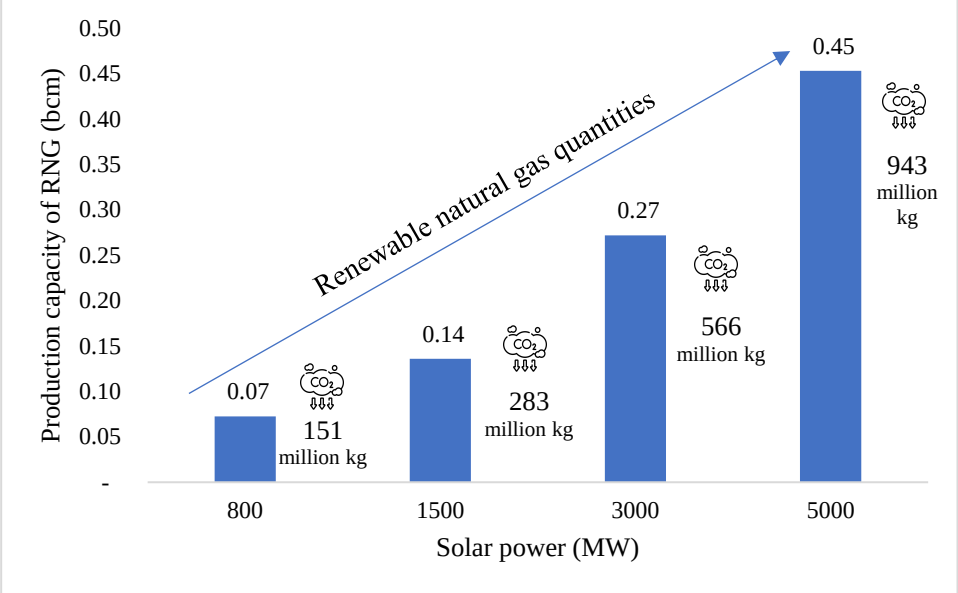

Figure 5. Relation between renewable power production and produced RNG in Qatar with CO_2 saving potentials.

3.5. Solutions for Problem 2

Regarding the long-term fixed strategy, there are two solutions that can be implemented to reduce the effect of this problem and lead to an increase in LNG export quantities to Europe from Qatar. The first solution is to move the long-term contracts which are coming to an end in the near future (from present to 2027) to Europe markets. According to a report published by GIIGNL, the medium-term and long-term contracts in force in 2019 are listed in Table 5. This table contains only contracts ending before the end of 2027. The total amount of the summed LNG is about 14.6 BCM from different LNG assets. These LNG quantities can be exported to Europe to secure energy shortages. Assuming that the Qatari contracts which are ending (by 2027) are redirected to Europe, the capacity of LNG exported will increase to reach 44.8 BCM (an increase of about 48% of the exported LNG volume compared to the year 2020).

The other solution to overcome the issue of a fixed long-term strategy is to increase the dependency on the spot market. According to statistics published by BP report, Qatar is the country with the lowest dependency on the spot and short-term contracts compared to the main LNG exporters (the USA, Australia, and Nigeria) [26]. Figure 6 shows the sales of spot and short-term LNG quantities by the top 4 main LNG exporters in 2020. The quantities of spot and short-term sales are taken from [26]. Qatar sold about 15.12 BCM of

its natural gas on the spot market, and only 3.81 was sold to Europe. In comparison, the USA sold about 41.92 BCM of its natural gas in the spot market (20.6 BCM of it to Europe). It is clear that if Qatar increases its dependency on the spot market, more LNG quantities will be exported to Europe.

Table 5. Qatari medium-term and long-term contracts ending in 2026 [26].

Export Country	Seller	Buyer	Amount (BCM)	Duration
Qatar	QG 1	Naturgy Energy Group	1	2005/2024
	QG 1	Naturgy Energy Group	1	2006/2025
	QG 3	RWE Supply & Trading	1.5	2016/2023
	QG 5	Centrica	4.2	2014/2023
	QG 5	Petronas	1.6	2014/2023
	QG 5	Shell	1.5	2019/2023
	QG 1	Endesa	1	2005/2025
	RL 3	KOGAS	2.8	2007/2026
Total			14.6	

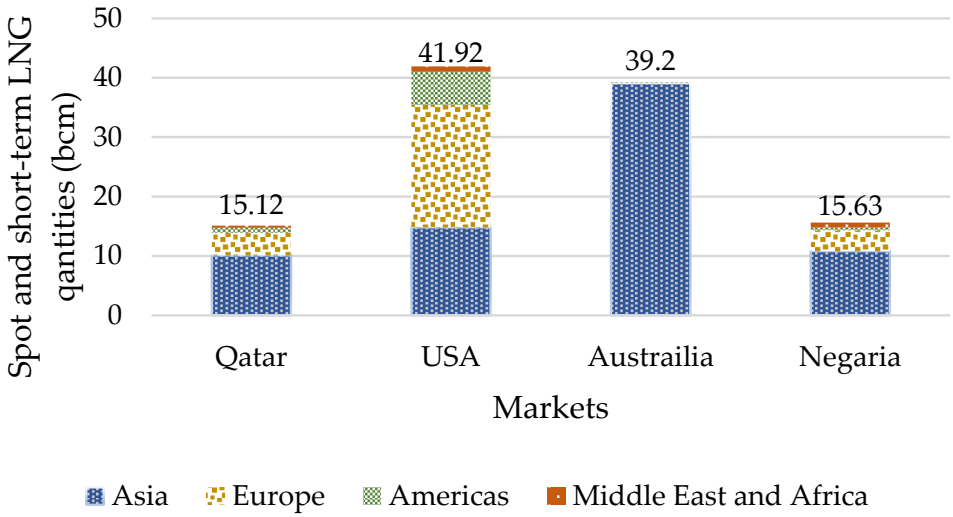

Figure 6. Sales of spot and short-term LNG quantities from Qatar, USA, Australia, and Nigeria [26].

3.6. Solutions for Problem 3

The other issue that means Europe depends on Russian natural gas is not using LNG terminals at full capacity. As mentioned in Problem 1, European countries imported in total 184.9 BCM of natural gas from Russia (167.7 BCM by pipeline and 17.2 as LNG). Currently, terminals in Europe have the capacity to import around 277.8 BCM of LNG, and the total yearly imported capacity by LNG terminals is 110.4 [3]. Therefore, there is free space for 167.4 BCM of LNG to be imported to Europe. Eliminating the LNG exported from Russia, the total import capacity is about 113.8 BCM. Thus, if Russia stops exporting natural gas to Europe as either LNG or by pipeline, European countries will need to recover around 184.9 BCM. Assuming that European countries will depend on LNG, current LNG terminals can import around 113.8 BCM of LNG, which can recover around 61.5% of the gas shortage. The missing 38.5% of the gas shortage can be recovered by either using floating import terminals or building new LNG import terminals. The construction of nine LNG terminals is planned in European countries with a total capacity of 46.3 BCM [38], as illustrated in Table 6. Since time is limited, building a new LNG import terminal is not a feasible solution, as constructing an LNG terminal takes around three to four years [46]. The other option which is technically and economically feasible is to use floating import terminals. In fact, Croatia expanded its LNG import capacity by relying on a floating import terminal. The LNG import facility serves the Balkan region with a capacity of 2.6 BCM yearly [47]. Turkey

also expanded its LNG import capacity using two Floating Storage and Regasification Unit (FSRU) with a capacity of 7.3 BCM of each FSRU [38]. Therefore, relying on floating import terminals can recover the 38.8% gas shortage using LNG.

Table 6. Planned LNG import terminals in Europe [38].

Country	Terminal	Initial Capacity (BCM/year)
Albania	Eagle LNG FSRU	8
Croatia	Krk Island FSRU	2
Estonia	Padalski LNG	2.5
Estonia	Muuga (Tallinn) LNG	4
Germany	Brunsbüttel LNG	5
Ireland	Shannon LNG	2.7
Latvia	Riga LNG Terminal	5
Romania	Constanta LNG	8
Ukraine	Odessa LNG	5
Greece	Gastrade	6.1
Italy	Porto Empedocle	8
Total	**13**	**56.3**

Moreover, other studies are trying to solve the same research problem, which is to identify the main problems that limit Qatar from exporting more gas to Europe and proposing solutions to the problems. Table 7 shows a comparison between the problems and solutions given in this study and those in other studies. Other studies emphasize that the main issue that limits Qatar from exporting more gas is environmental constraints and these studies focus only on the supply side (Qatar). On the other hand, this study covers comprehensive problems that limit Qatar from exporting more gas to Europe, and it focuses on the supply side (Qatar) and demand side (Europe). The advantages of this approach are (i) it proposes solutions to overcome the gas shortage issues which can be favored by the gas exporter (Qatar) and the gas importer (Europe), and (ii) it provides practical solutions that can be implemented by the gas supplier and the gas receiver. However, the disadvantage of the approach is that it only focuses on one gas supplier. In this study, Qatar is proposed as a candidate to cover the gas shortage in Europe. Future research that includes other gas suppliers providing Europe with gas, such as the U.S and Australia, will be required.

Finally, Qatar can currently only cover a limited quantity of gas needed by European countries. However, Qatar can increase its export capacity of gas to Europe if they depend on RNG. Moreover, producing RNG meets Qatar's plans to reduce greenhouse gas emissions. Using the renewable energy resources available, such as solar and wind, to produce electricity and export domestic natural gas will increase the exportation capacity of gas from Qatar, which consequently, will lead to economic benefits for the country.

Table 7. Comparison between this and other studies regarding problems that limit Qatar from exporting more gas to Europe and the proposed solutions.

This Study	Other Studies
	Study 1 [48]
	Problems: • Environmental constraints in the LNG supply chain
	Solutions: • Using LNG vessels that are fueled by cleaner fuels, for example using LNG as a bunker
	Study 2 [49]
	Problems: • Dependence on long-term contracts for selling gas • The share of spot and short-term LNG sales is low compared to other large LNG exporters, such as the U.S. • Exportation of gas by pipeline is low in Qatar compared to Russia, which exports most of its natural gas by pipeline to Europe.
Problems: • Limited LNG quantities available for export • Long-term fixed contracting strategy • Limited space for receiving more gas by European LNG terminals.	Solutions: • No solutions were suggested
Solutions: • Reduce local natural gas consumption for power production by relying on renewable energy resources • Produce renewable natural gas from green hydrogen and captured carbon dioxide • Move the long-term contracts coming to an end in the near future to Europe markets • Increase the dependency on the spot market • Use of LNG terminals at full capacity • Use of floating import terminals	Study 3 [50]
	Problems: • Qatar has made a commitment to reduce emission levels to reach the goal of limiting temperature change below 2 °C at the end of 21 century. This commitment requires adopting more renewable energy solutions, and reducing dependence on fossil fuels.
	Solutions: • Start immediately to promote hybrid and electric vehicle use. • Produce electricity using solar energy • Develop district cooling • Introduce CO_2 capture in all economic sectors • Develop a plan for the production of green hydrogen and green ammonia

4. Conclusions

European countries are searching for alternative solutions to overcome the energy crisis in Europe. One of the alternatives is to find other gas suppliers to cover the gas shortage. Qatar is considered an optimal alternative to supply European countries. However, there are three main problems that limit Qatar from exporting more gas to Europe, according to the literature. The problems are the limited LNG quantities available for export, the long-term fixed contracting strategy, and the limited space available for receiving more gas in European LNG terminals. This research investigated these problems and proposed solutions to overcome them. The solutions to overcome the limited LNG quantities available for export are as follows:

- Reducing local natural gas consumption for power production by relying on renewable energy resources can free some quantities of natural gas. If 15% of locally generated electricity is produced from renewables in Qatar, around 2 BCM of natural gas can be

saved and used for exportation purposes. More free natural gas can be obtained if more local electricity is produced from renewables.

- Producing RNG from green hydrogen and captured carbon dioxide results in increasing natural gas quantities which can be exported to Europe. Use of renewable resources (wind and solar) in Qatar to produce 5000 MW of renewable power can lead to the production of 0.45 BCM of RNG, which can be exported to Europe.
- Regarding the other problem that limits Qatar from exporting more gas to Europe, moving the contracts due to end to Europe and increasing dependence on spot markets can reduce the effect of the problem of a long-term fixed contracting strategy. Based on calculations, redirecting all contracts due to end in 2023, 2024, 2025, and 2026 between Qatar and other buyers to Europe will increase the export capacity of LNG to reach 44.8 BCM (an increase of export capacity of about 48% compared to the year 2020). Finally, LNG terminals in Europe have the capacity to import around 207 BCM of LNG, and the total yearly imported capacity is 110.4. Therefore, there is free space for 96.6 BCM of LNG to be imported to Europe. However, this space is not enough to cover the gas shortage if Russia cuts off all gas supplies. Therefore, using floating import terminals can resolve the issue of the limited space available for receiving more gas in European LNG terminals.

This study focuses on potential solutions from Qatar for the gas shortage issues in Europe by stating that Qatar can only cover a limited quantity of the gas required by European countries. However, there are new opportunities, such as renewable natural gas, blue hydrogen or blue ammonia, which can supplement the existing shipments. Further research is needed that considers solutions that involve other gas suppliers covering Europe's gas shortage, such as the U.S and Australia. Moreover, future studies are required to investigate the economic perspective of the various solutions to cover gas shortage issues in Europe.

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