LNG Bunkering Technologies in Ports: An Empirical Application of the SWOT Analysis

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ABSTRACT

Liquefied Natural Gas (LNG) as a marine fuel constitutes a valuable technological solution for making the maritime and port industry more sustainable. However, the progressive diffusion of LNG requires huge investments for bunkering and storage facilities in the port domain to develop an LNG supply chain capable to satisfy the demand of LNG-propelled ships. Although this topic is attracting increasing attention from both academics and practitioners, no prior scientific contributions have provided a holistic and structured conceptual framework to disentangle the main pros and cons related to the diverse LNG bunkering and storage solutions. This study investigates the four most promising LNG bunkering technologies (i.e., Truck-to-Ship, Ship-to-Ship, Port-to-Ship and Terminal-to-Ship, and Mobile Fuel Tanks) by applying the SWOT analysis methodology to the Mediterranean port context. The analysis focuses on relevant technical and managerial, including storage capacity, bunkering efficiency, plant scalability, operational flexibility, economic and financial performances, social and environmental impacts. The outcomes unveil the managerial strengths, weaknesses, opportunities, and threats of each technological solution, feeding the academic debate on this topic. Moreover, the paper provides empirical implications for public authorities and port managers improving the knowledge concerning LNG bunkering and storage solutions available in the maritime and port domain.

Key words : LNG bunkering, LNG technologies, SWOT analysis, marine propulsion.

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Received May 3, 2021; Received in revised form June 15, 2021; Accepted June 24, 2021

1. Introduction

The last years have shown increasing attention on the environmental impact of maritime logistics operations and development (Dinwoodie et al, 2012; Lam and Lai, 2015; Puig et al., 2020). Port managing bodies (PMBs), port authorities (PAs) and shipowners are facing higher pressure from the public in terms of performing their environmental and social responsibility (Tang and Gekara, 2018; Geerts and Dooms, 2020; Ashrafi et al., 2020). The introduction of more restrictive regulatory requirements at both national and international level have also forced these maritime and port actors to carry out green strategies and investments for reducing emissions and other environmental impacts (Lam and Notteboom, 2014).

A wide array of green technical and operational solutions is currently available on the market, both on landside and seaside (Ren and Lützen, 2015; Lee and Nam, 2017; Metzger and Schinas, 2019). Among them, Liquefied Natural Gas (LNG) as an alternative fuel for marine propulsion is argued as one of the most mature and commercially diffused technical solutions (Balcombe et al., 2019). It provides shipowners with potential cost savings in addition to ensuring compliance with the international environmental regulation and very positive impacts concerning environmental issues. Indeed, LNG is capable to eliminate Sulphur Oxides (SOx) emissions and reduce up to 20-25% of Greenhouse Gas (GHG) emissions, 85% of Nitrogen Oxides (NOx) emissions, 95% of Particular Matter (PM), compared to traditional marine fuels (Burel et al., 2013; Acciaro, 2014). These benefits turn out pivotal for protecting the environment as well as the health of people living and working in port and coastal areas where the impact of ships' exhaust pollutants has a direct effect on the local communities (Tzannatos, 2010; Dragović et al., 2018).

Although LNG-propelled ships still constitute a small proportion of the worldwide merchant fleet and the overall demand for the LNG bunkering facilities is still in its inception phase, the investments carried out by shipowners in LNG as an alternative marine fuel are rapidly increasing, especially in Europe as well as both within the cruise and the container line industries (Aronietis et al., 2016; DNV, 2018), as suggested also by the most recent dynamics experienced by international shipping new orderbooks. Huge investments are required to refit existing vessels and to acquire newbuilding but also to plan and construct adequate bunkering and storage facilities in ports for meeting the increasing LNG demand (Wang and Notteboom, 2015). Indeed, the development of a capillary LNG supply chain capable to satisfy the bunkering demand of LNG-propelled fleet is attracting increasing attention from the industry. In particular, Mediterranean ports are challenged to take relevant strategic decisions to define their supply of LNG bunkering services (TDI RETE-GNL, 2020). Given the novelty of LNG as alternative greener fuel for shipping and the complexity of estimating the uprise of

LNG maritime demand as well as the innovative and unexplored nature of LNG bunkering technological solutions and related high investment costs, the decision-making process for planning, constructing, and financing LNG bunkering facilities in the port domain would greatly benefit from a comprehensive methodological approach to evaluate alternative strategic options.

In this context, the SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) constitutes a valuable managerial tool for evaluating alternative technical solutions, especially when assessing technological investments characterised by a high level of uncertainty concerning their adoption and market success (Leigh, 2009). This approach has already been applied in some previous academic port management studies. Among others, Chang and Huang (2006) use the SWOT analysis to assess the competitiveness of container terminals in the Far East by analysing alternative investment plans. Similarly, Celik et al. (2009) identify the main key success factors and business limits emerging from Turkish container terminals' growth strategies. More recently, Keceli (2011) provides a SWOT analysis of different information and communication technologies (ICT) platforms supporting port activities and operations. These contributions stress the potential of this methodological approach that is expected to be particularly suitable to evaluate alternative investments in LNG bunkering facilities in the maritime and port domain.

In the light of the above considerations, the objective of the paper is to apply the methodological approach of the SWOT analysis to identify the strengths and weaknesses as well as the opportunities and threats characterizing the four main LNG bunkering technological solutions (i.e., Truck-to-Ship, Ship-to-Ship, Port-to-Ship or Terminal-to-Ship, and Mobile Fuel Tanks) in the Mediterranean ports. The study focuses on technical, managerial, and organizational profiles, such as storage capacity, bunkering efficiency, plant scalability, operational flexibility, economic and financial performances, technical requirements as well as social and environmental impacts.

The results of the SWOT analysis feed the academic debate on the introduction of innovative green technological solutions in maritime logistics. The paper highlights the strengths, weaknesses, opportunities, and threats of each LNG bunkering solution, providing a more comprehensive understanding of the operational benefits and criticalities. This stimulates future studies on sustainability and innovation management in the industry. Finally, the considerations arising from the Mediterranean port domain suggest empirical implications for public authorities and port managers when they are called to take investment decisions concerning LNG bunkering and storage facilities within this specific geographic and institutional context.

The paper is structured as follows. Section 2 provides the main theoretical constructs of the SWOT analysis, stressing the managerial benefits both at strategic and operational levels of its application for decision-makers. In Section 3, the four LNG bunkering solutions are introduced and discussed. Then, the paper describes the methodological approach and the application of the SWOT analysis on the specific European domain of LNG bunkering operations. Section 4 reports the outcomes of the analysis. Empirical implications are debated in Section 5 before the conclusion (i.e., Section 6).

2. The SWOT Analysis

From the 1980s the SWOT analysis has begun to be applied for evaluating public interventions (Pickton, 1998). The comparison of multiple development scenarios provides policymakers with valuable insights for interventions and policies. This managerial model is still widely used by also academics and practitioners within the management and marketing domain, especially for market analysis and evaluation of alternative investment strategies (Hitt et al., 2016). Indeed, the SWOT analysis enables managers to rationalize data gathering and improve the evaluation procedure of alternative strategic decisions (Leigh, 2009).

Nowadays, most organizations fail in engaging in strategic management because they wrongly allocate their resources (see, e.g., Gürel and Tat, 2017). This deals with strategic planning and the continuous process of creating, implementing, and evaluating decisions that enable an organization to achieve its objectives in the long run (David et al., 2013). In this scenario, the SWOT analysis emerges as a relevant managerial tool for external and internal analysis of the business (Gürel and Tat, 2017). While external analysis focuses on the threats and opportunities emerging from the competitive environment, internal analysis supports an organization with the evaluation of its strengths and weaknesses, also identifying the resources and capabilities that are likely to be sources of competitive advantage (Hitt et al., 2016).

The SWOT Analysis provides managers with a 2x2 matrix that highlights strengths and weaknesses (i.e., internal factors and attributes of the organization), opportunities and threats (i.e., external factors and attributes of the competitive environment). Although it may appear as a simple tool, it can size up the organization's resource capabilities and deficiencies, as well as market opportunities for developing the business and external threats which may harm its competitiveness (Thompson et al., 2013). In this vein, it can significantly support decision-makers with a systematic and operational representation of pros and cons related to a specific project or investment, easing strategic choices of growth and positioning in the market (Hitt et al., 2016). This also allows identifying drivers and actions to be prioritized as well as key performance indicators (KPIs) to be selected as selection criteria or technical support within monitoring systems.

From the methodological perspective, endogenous factors are analysed through ad hoc evaluation parameters related to the specific project/investment or/and the investigated domain. On the contrary, the opportunities and threats (i.e., exogenous factors) arise from the socio-economic, political, environmental, and demographic factors of the external environment and thus are more complex to evaluate. While opportunities are linked to potential spill-overs of the investment, such as the opening of new markets, economies of scale, availability of new technologies, and synergies, threats are dangers and risks that the organization is exposed to when investing in a specific project (e.g., political uncertainty, market instability, increased competition in the sector, etc.). Typically, these factors cannot be directly managed or predicted by the decision-makers.

Given the above, the SWOT analysis represents a pivotal managerial tool to evaluate all alternative possibilities and potential drawbacks. For this reason, it is widely used in uncertain and dynamic contexts, especially those characterised by the frequent introduction of innovative technologies or products/services, such as the high-tech and science-based industries (Hitt et al., 2016).

3. Empirical Background and Methodology

3.1 The main LNG bunkering technological solutions

In line with the academic literature (e.g., Näslund, 2012; Acciaro et al., 2019; Satta et al. 2019a; Satta et al. 2019b) as well as the most recent European institutional documentation (EMSA, 2018) and consultancy reports provided by experts of the industry on the technical-engineering and economic-managerial aspects related to LNG bunkering (ABS, 2014; DNV, 2015; Wärtsilä, 2019), the paper addresses the four main technological solutions for LNG bunkering in the port domain:

- Truck to Ship (TTS);
- Ship to Ship (STS);
- Port-to-Ship or Terminal-to-Ship (PTS)
- Mobile Fuel Tanks.

The TTS solution requires a tank ruck for both the storage and transport of LNG. The vehicle is positioned on the quayside following safety procedures of the port and hoses between 2 and 3 inches are connected from the truck to the ship's tanks (ABS, 2014). LNG is transferred through a pump installed on the truck or attached externally to the tank when the truck is not sufficiently equipped. When bunkering operations are over, the truck leaves the quay and reach the LNG storage facilities which may be located inside or outside the port area to resupply the tanks. In this case, flexible pipes are used to connect the tank to the LNG storage plant which speeds up the operation. Although the temperature must be constantly controlled for preventing risks and the evaporation of LNG (i.e., the temperature of the tank must be above -162°C), this procedure allows to drastically reduce the time necessary to resupply the tank.

The STS solution employs barges or small naval units (also called bunker supply ships). Bunkering operations are carried out both offshore and within the protected waters of the port. The bunker supply units come alongside the vessel to be supplied and transfer LNG using flexible pipes and pumping systems onboard. In the same way, barges are pulled/pushed by tugs to approach the vessel and start the operations. Thanks to the large storage capacity of bunker supply units, the STS solution is appropriate to refuel ships with an LNG demand between 1,000 and 10,000 m^3. Moreover, they can be used to reach ports or coastal areas where there are no LNG storage and/or bunkering facilities. The design of barges and bunker supply ships must comply with the standards of the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) which provides international standards for the safety of transport by sea bulk of liquefied gases and other substances with similar criticalities[1].

The PTS solution deals with the refuelling of LNG-propelled ships through pipelines directly connected to the LNG bunkering station at the quayside. The pipelines allow speeding up the operations and serving different types of ships without changing the layout of the bunkering system. The LNG storage tank is located inside the bunkering station on the quayside and can have either a large dimension (at atmospheric pressure) or a small dimension (in the case of pressure tanks). The PTS solution requires ships to be docked at the quay where the bunkering station (or plant) is located. However, alternative solutions have been recently developed at the international level based on the floating pontoon where the LNG storage tank is placed. In this case, ships can refuel even at a certain distance from the quay.

Finally, the Mobile Fuel Tank solution involves the use of tanks or cryogenic ISO-containers with double-walled or single-walled polyurethane insulation as temporary fuel storage facilities. Indeed, when ships are docked, these tanks are transported to the quay to refuel the LNG-propelled ships (Wärtsilä, 2019). The advantage of this solution is the possibility of moving fuel tanks where they are needed, using simple rails or trucks. Therefore, it is a very flexible solution that allows to quickly modulate the supply according to the manifested LNG demand. However, the storage volumes are quite small, about 40-45 m^3 for the 40-foot ISO LNG containers, making it suitable only for small supplies. At the operational level, bunkering procedures are carried out in the same way as the TTS solution, even though ISO containers can be also loaded on board and used as a

1 The IGC code establishes the design and construction standards of ships involved in liquefied gas operations and indicates the set of equipment required to minimize risks to the ship, its crew, and the environment. Together with the International Maritime Dangerous Goods (IMDG) Code, the IGC code also provides the principles and recommendations to transport dangerous substances and materials. Practices, packaging, storage, and handling of such cargo are included in these recommendations.

tank to power the ship during navigation. This innovative solution is particularly advantageous when the ship has enough space on board to accommodate the ISO container because it greatly reduces the time for bunkering.

Each technological solution has distinctive characteristics and features resulting in strengths and weaknesses that are not extensively investigated by academics and practitioners yet. In light of these considerations, the SWOT analysis appears as a promising tool for evaluating and identifying the most suitable LNG bunkering solutions. Indeed, the endogenous factors of the innovative bunkering technologies and the exogenous variables related to each port region as well as the high uncertainty of the LNG maritime demand worldwide put a lot of pressure on port managers concerning the decision of new investments on LNG bunkering facilities. In this perspective, the SWOT analysis can provide decision-makers with an overarching framework to deepen the comprehension of this emerging challenge. Moreover, it enables the comparison of alternative available LNG bunkering solutions supporting the strategic planning of value creation in the port domain.

Therefore, the application of the SWOT analysis can unveil both the endogenous factors (i.e., strengths and weaknesses) and the exogenous factors (i.e., opportunities and threats) associated with each LNG bunkering technological solution.

3.2 Methodological approach

According to the theoretical constructs of the SWOT analysis (Leigh, 2009; Hitt et al., 2016; Gürel and Tat, 2017), the applied methodological approach is divided into two phases. The preliminary phase deals with the most challenging and pivotal tasks of the whole process: the designing of the evaluation process and related parameters. All the Authors were involved in this phase since it significantly affects the reliability of the results. The set of parameters was defined based on the Authors' managerial knowledge on maritime logistics issues and practical experience gained during the three-year European project "TDI RETE-GNL"[2] on which they worked on. To validate and integrate the set of parameters as well as to deepen knowledge on each technological solution, a panel of European stakeholders of the maritime logistics industry, LNG providers, experts, and consultants for the assessment of the environmental impacts from infrastructure projects was composed, including, among others, two associations of Italian shipowners, namely Confitarma and Assarmatori, and the Port System

2 The project "Technologies and size of bunkering and storage facilities for the LNG network" (TDI RETE-GNL) is a European project financed by the Programme INTERREG MARITTIMO 14-20 with an overall budget nearly €0.8 million and leaded by the University of Genoa. It aims to identify the most efficient and effective technological solutions for the distribution and bunkering of LNG in the ports within the cross-border maritime area of the North Mediterranean Sea between the Italian and French regions. The project provides shared operating standards for LNG bunkering operations. Moreover, it identifies the possible location of bunkering and storage facilities for the LNG primary distribution network, stressing their potential externalities as well as the economic and financial sustainability of investments.

Authority of the Western Ligurian Sea. The Authors organized several one-to-one meetings and two focus groups in the period 2018-2020 to debate the features of each LNG bunkering solution and related opportunities as well as the threats that may endanger the environment and surrounding port areas. The considerations of the experts were transcribed in an ad-hoc database developed by the Authors with the technical documentation presented and shared during these events. The Authors defined specific labels to code each meaningful statement and document. This organisation of data gathered was pivotal to not omit valuable information.

In line with this process and the general criteria suggested by the management literature on the SWOT analysis, the selected evaluation parameters and potential KPIs for monitoring the performance of LNG bunkering solutions are reported in Table 1.

Table 1. The evaluation parameters for SWOT analysis.

Parameter	Description	KPIs
Storage and transport capacity	It quantifies the volume of LNG that can be stored and transported.	· Overall storage capacity of the solution (m^3) · Storage capacity of the single facility (m^3) · Number of storage facilities (no.) · Transport capacity of the single vehicle/barge/ship/container (m^3) · Time necessary to complete the refuelling of the facilities/tanks in port (hours)
Efficiency	It deals with the efficiency of bunkering operations and the possibility of carrying out simultaneous operations (SIMOPs)[3].	· Bunkering time (hours) · Time necessary to complete bunkering (hours) · Speed of bunkering operations (m^3/h) · Number of vehicles/barges/ships/tanks to perform bunkering (no.) · SIMOPs (Yes/No)
Scalability of the plant	It evaluates the adaptability of the plant to market-changing conditions.	· Minimal number of vehicles/barges/ships/tanks used to perform bunkering (no.) · Maximum number of vehicles/barges/ships/tanks used to perform bunkering (no.)
Flexibility	It evaluates the adaptability of the plant to spot changing conditions (e.g., weather conditions).	· Number of meteorological events that do not allow to perform bunkering (no.) · List of meteorological events that do not allow to perform bunkering (qualitative)

3 The refueling of the ship can be carried out during the simultaneous loading/unloading of goods and/or passengers (Stavros, 2015).

Parameter	Description	KPIs
Financial and economic implications	It includes Capital Expenditure (CAPEX) and Operating Expenses (OPEX).	· Capital Expenditure (CAPEX) · Operating Expenses (OPEX)
Specific requirements of the plant	It covers all the aspects related to specific requirements of investigated technological solutions, both technical (e.g., occupied areas, accessibility, etc.) and legal (e.g., certificates and approvals).	· Permanent occupation area (m^2) · Temporary occupation area (m^2) · Time occupation area (hours) · Distance port gate–quay (metres) · Time necessary from port gate to quay (minutes) · Water depth (metres) · Length of the quay (metres) · List of specific equipment necessary to perform bunkering (qualitative) · Number of certificates/approvals necessary (no.) · List of certificates/approvals necessary (no.)
Environmental impact	It evaluates the negative implications on the environment.	· Number of incidents per year which cause environmental impacts (no.) · List of incidents per year which cause environmental impacts (qualitative)
Safety and risks	It deals with the potential risks for the surrounding port area and people who work or live within.	· Number of incidents per year (no.) · Number of injuries per year (no.)

Source: authors' elaboration

The SWOT analysis of the technological solutions for LNG bunkering in the port domain cannot be separated from the evaluation of exogenous factors, including the location and size of the port, the volumes of LNG maritime demand, the license to operate from local communities for the installation of new facilities in the port area, the regional, national, and international regulations. However, most of these factors are strictly related to specific port cases (e.g., normative, and social issues). Therefore, the effort of the Authors was to generalize the results achieved in the European project "TDI RETE-GNL" on the West Mediterranean ports, providing an overarching comprehension of this unexplored topic.

The second phase of the SWOT analysis that consists of evaluating strengths, weaknesses, opportunities and threats related to each technical solution is reported in the following Section 4, being the core part of the research outcomes.

4. The SWOT Analysis of LNG Bunkering Solutions

4.1 Truck to Ship (TTS)

The SWOT analysis of the TTS solution is reported in Figure 1 which summarizes the endogenous and exogenous factors of this bunkering technology.

Figure 1. The SWOT analysis of TTS solution.

Strengths	Weaknesses
· Operational and management flexibility · Low investment costs and reduced sunk costs · Refuelling ships even in adverse weather conditions · Bunkering supply mainly aimed at spot demand	· Small tank capacity · Low refuelling speed · Specific safety regulations · Need of different units for meeting single demand

Opportunities	Threats
· Cost-sharing between different ports and stakeholders · A suitable solution to test the LNG bunkering market · A technological solution to stimulate the LNG transition	· Distance from LNG storage and LNG storage facilities · Costs of motorway tolls and fuel usage · Traffic congestion in surrounding port area · Slowing down operations of loading/ unloading of cargo and passengers

Source: authors' elaboration

The main strength of the TTS technological solution is the high level of operational flexibility. Bunkering procedures can be carried out in different port quays depending on the demand of LNG-propelled ships docked in the ports and can be arranged rapidly even at short notice. Furthermore, tank trucks can move from one port to another, thus grouping the supply of different stakeholders (EMSA, 2018). The possibility of changing the place of refuelling is also crucial from safety issues. Indeed, bunkering operations can be performed in adverse weather conditions as the tank truck can be placed near the most sheltered basin where the ship is safely moored (MarTech LNG, 2014).

When it comes to financial and economic perspectives, the TTS solution requires low initial investments and maintenance costs which significantly reduce potential sunk costs. In this perspective, the TTS solution is particularly suitable to verify the economic convenience of developing a new system for the supply of LNG bunkering services by local public authorities, PMBs, PAs as well as various public and private stakeholders especially when the maritime LNG demand is particularly uncertain. In other words, the TTS solution can be seen as a pilot solution for medium and large size ports to test the LNG bunkering market as well as to stimulate the maritime demand and incentive the transition of shipping towards the use of greener fuel. Finally, it can be adopted as a "back-up solution" to allow LNG-propelled ships to refuel just enough to reach a port equipped with better LNG bunkering facilities. In this perspective, the TTS solution may contribute to the development of the overall LNG distribution network, by strengthening the resilience of the entire LNG supply chain.

Although the above strengths, the TTS solution has multiple weaknesses concerning operational issues. First, tanks have a small capacity (usually between 40 and 80 m^3) and the refuelling speed is very low (around 50 m^3/h). This results in a long time to complete the bunkering procedure and thus increasing port dues for shipowners, especially in the case of large ships with a high LNG demand. A further critical aspect is the location of LNG storage facilities. If the distance from port terminals is too long, it may reduce the overall efficiency of the TTS solution because of the increasing time needed for the travel and the higher costs of motorway tolls and fuel usage of the truck. Therefore, the feasibility of the TTS solution depends not only on the specific costs of bunkering operations but also on the costs related to the transport of LNG and the availability of trucks and tanks. This demonstrates the TTS solution is efficient only for small LNG maritime demand (i.e., small-scale ships).

Besides, safety and security issues may emerge. In this perspective, the national and international regulations establish a maximum number of LNG tank trucks that can transit/stay simultaneously within the port area. This limit is defined according to the size of the port and the specific safety measures adopted by PMBs in accordance with the Maritime Authority and other local public authorities. Moreover, the bunkering operations carried out in the TTS solution can interfere with the loading/unloading of cargo and/or passengers. This increases the risk of damage to third parties as well as a slowing down of terminals' activities.

4.2 Ship to Ship (STS)

The SWOT analysis of the STS solution sheds light on several strengths related to storage capacity and bunkering speed. The bunker supply units (i.e., barges and small naval units) have large LNG storage capacity and the bunkering speed can reach up to 1,000 m^3/h. Another advantage is the possibility of SIMOPs, even though specific authorizations are required from the PMB and local public authorities to ensure the safety of the procedures. This constitutes a relevant strength of this solution that reduce the port dues incurred by shipowners. Therefore, the STS solution is particularly suitable for meeting the LNG demand of big ships.

Unlike the other technologies, the STS solution can be performed both inside and outside the port, although specific meteorological conditions have to be taken into account (EMSA, 2018). In the case of offshore bunkering operations, the risks for coastal territories arising from possible technical incidents are reduced (Arnet, 2014). Moreover, the option of offshore LNG bunkering facilities simplifies the strategic decisions related to their localization which often cause debates with local communities. As concerns operational issues, the refuelling at the sea does not require specific land-side investments and reduces the risks of inefficiencies caused by port activities. Based on the above considerations, the flexible features of the STS allow using this solution in countries or ports where an efficient LNG distribution network has not been developed yet. Therefore, it constitutes a relevant technology to stimulate the adoption of LNG by shipowners.

Although the above strengths, Figure 2 reports the weaknesses related to the STS solution. Indeed, significant initial investments are required for the acquisition of the bunkering units for the supply of LNG (i.e., barges and ships) which are also associated with high maintenance costs (Mat Tech LNG, 2014).

The SWOT analysis stresses the high risk of collisions between the bunkering units and the LNG-propelled ships to be refuelled (especially when bunkering takes place offshore due to potential adverse weather-marine conditions), port facilities (e.g., port infrastructure and superstructures), and third parties (e.g., other ships within the port). In this perspective, the extension of the port basin and the dimension of ships to be supplied must be considered to limit safety risk.

Finally, the efficiency of the STS solution is related to the localization of coastal LNG storage facilities. Range distances must be calculated to outline the area within bunkering operations via STS economically feasible.

Figure 2. The SWOT analysis of STS solution.

Strengths	Weaknesses
· Large storage capacity of bunkering units · High bunkering speed · Operational flexibility and SIMOPS · No use of land-port spaces	· Strong initial investment · High maintenance costs

Opportunities	Threats
· Reduction of negative externalities for coastal areas and local communities (in case of offshore bunkering) · Greater accessibility to the service · Reduction of investment in port facilities and equipment · Reduction of inefficiencies related to port activities	· Distance from coastal storage facilities · Risk related to weather-marine conditions · Risk of damage to collisions third parties

Source: authors' elaboration

4.3 Port to Ship (PTS)

The results of the SWOT analysis related to the PTS solution are summarised in Figure 3. When it comes to the strengths and opportunities, the PTS solution can manage large volumes of LNG thanks to ground-placed tanks with a total storage capacity between 500 and 30,000 m^3 (EMSA, 2018). The refuelling speed is also higher than the other examined bunkering solutions, reaching up to 2,000 m^3/h. This drastically reduces the time needed for completing bunkering procedures and the costs incurred by shipowners. Bullet tanks with a volume of about 1,000 m^3 can be additionally installed to meet the potential increase of maritime LNG demand. Indeed, given the high uncertainty of LNG demand, the scalability of storage facilities is a valuable technological opportunity.

Figure 3. The SWOT analysis of PTS solution.

Strengths	Weaknesses
· Large storage capacity · High bunkering speed	· Strong initial investment · High maintenance costs · Operational rigidity · Usage of port/terminal areas

Opportunities	Threats
· Scalability of the facilities · Constant and regular bunkering services · Direct connection via pipeline with the natural gas distribution network	· Negative externalities on the surrounding territory · Restrictive safety regulations · Accessibility of port and terminal

Source: authors' elaboration

The characteristics and features of the PTS facilities make this solution particularly suitable to serve ships that operate regular services and have a constant LNG bunkering demand or naval units used for port activities and/or services, such as tugs or pilot boats.

As regards the refuelling of the LNG storage tanks, bunker ships or road trucks are employed. The operations can be also carried out through pipelines connected to the inland natural gas distribution network. Although this latter solution requires high investment costs related to the implementation of additional infrastructure and equipment, including a regasification plant, it allows the direct provision of gas in the port area.

Despite the above strengths and opportunities, the PTS solution shows some obvious weaknesses related mainly to the initial investment and maintenance costs. Storage and bunkering facilities require high investments that may turn out into grave sunk costs if the maritime LNG demand decreases over time. Decision-makers should also consider the costs for the purchase of the equipment and pipelines needed to safely provide bunkering services. Another weakness is the localization and dimension of the plant because it occupies large port areas which can be alternatively used for commercial activities and operations. This may constitute a loss of opportunities for the port and related maritime clusters. Finally, the PTS solution is characterized by a strong operational rigidity. Although a margin of flexibility exists, the size of the plant can be hardly modified without major changes. Moreover, simultaneous operations (SIMOPs) cannot be carried out during bunkering operations.

Accessibility to the quay where the plant is located may constitute a major threat for the PTS solution because it affects the size of the ships that can be refuelled. In this perspective, the characteristics of the port and the availability of spaces for the construction of the LNG bunkering station are critical factors in the evaluation of the PTS solution.

In conclusion, decision-makers are expected to consider also normative issues. Local public authorities, as well as the Port Authority, may establish specific regulations to limits the externalities arising from the LNG bunkering and storage facilities as well as to ensure the safety of operations. Since the LNG tanks are permanently positioned on the ground in port areas, they may constitute a threat to the surrounding territory.

4.4 Mobile Fuel Tanks

The Mobile Fuel Tank solution shows several affinities with the TTS solution since they exploit the same or similar technologies (Figure 4). One of the main strengths is the high operational flexibility: it allows SIMOPs and favours the capillarity and simplicity of the LNG bunkering services. A further positive factor is the low initial investment for the purchase of the necessary equipment. Mobile tanks and ISO containers can be also used for different purposes than LNG bunkering services thus eliminating the risk of potential sunk costs.

When it comes to the opportunities, the Mobile Fuel Tank solution is argued to be easily scalable. Mobile tanks and ISO-containers can be transported to different ports where the maritime LNG demand shows up. This is a suitable solution for spot demand, especially in those ports where there are not LNG bunkering facilities.

However, the Mobile Fuel Tank has obvious weaknesses concerning the limited capacity of the LNG tanks and the low bunkering speed. Moreover, ISO-container must be constantly connected to the power grid to maintain the temperature under -162°C and thus to avoid fuel leaks. This may cause problems in terms of urgent technical interventions. As concerns safety matters, specific procedures must be followed to transport and handle cryogenic LNG container ISOs in the port area. Moreover, the vehicles used for the bunkering operations may be hinder terminal operations because they must be parked in the quay near the ship to be refuelled.

Figure 4. The SWOT analysis of Mobile Fuel Tank solution.

Strengths	Weaknesses
· Operational flexibility · Possibility to carry out SIMOPs · Low initial investment	· Limited tank capacity · Limited bunkering speed · Need to connect to the power grid

Opportunities	Threats
· Scalable solution · Possibility to load the ISO tank directly on board the ship and reducing bunkering time · Suitable for spot demand	· Risks related to the transport and handling of tanks within the port area · Identification of park area for the vehicles used for bunkering operations

Source: authors' elaboration

5. Empirical Implications

Based on the outcomes of the SWOT analysis reported in Section 4, it is possible to scrutinise the pros and cons related to each LNG bunkering technological solution. Table 2 summarizes the main operational benefits and criticalities as well as the potential risks emerging from their application in Mediterranean ports.

The comparison provides a deeper understanding of LNG bunkering technologies. It also suggests European decision-makers the most appropriate application of each solution consistent with the endogenous and exogenous factors shaping the specific port case. Indeed, the results may support public bodies (e.g., local, regional, or national institutions) and port managing bodies with the planning of investments related to new LNG bunkering facilities in the port area.

The TTS and Mobile Fuel Tank solutions turn out suitable for ports characterized by a low LNG maritime demand. The high operational flexibility and the absence of infrastructure investments suggest their application in ports not served by the LNG supply network or in those with multiple terminals that require the movement of bunkering facilities. Furthermore, the possibility of sharing the initial investment among multiple actors enables TTS and Mobile Fuel Tank solutions to be used by different ports, boosting the supply of LNG bunkering services and, consequently, the demand of shipping companies.

Given the high risk of collisions between bunker units (i.e., bunker supply ships and barges) with ships or port infrastructure/superstructure and the complexity in managing bunkering operations, the STS solution appears appropriate for ports with large watery mirrors and not particularly prone to adverse weather conditions. However, the operational flexibility and the possibility of bunker supply ships to move from one area to another enables the STS solution to optimise the supply of LNG bunkering services among different ports within a specific range.

Finally, the PTS solution is characterised by a large LNG storage capacity and high bunkering speed. In this perspective, it can be adopted by medium or large ports with stable or easily predictable LNG maritime demand. Indeed, the high initial and maintenance costs make the PTS solution economically unsustainable in the long run if the LNG maritime demand does not reach an acceptable level.

To exemplify the above argumentation, the Authors provide anecdotal evidence referring to one of the most important Mediterranean ports (i.e., the port of Genoa in Italy). Since 2018 the Port System Authority of the Western Ligurian Sea has begun to evaluate alternative investments for the installation of LNG bunkering and storage facilities in the port of Genoa. However, the port suffers from the lack of available areas that restrict the potential storage capacity of LNG facilities. This is also affected by the proximity of Cristoforo Colombo airport that imposes further limitations on the dimension of the plants for safety reasons. Moreover, the urban planning restrictions and conflicting expectations of the local community, that have just expressed opposition to the installation of LNG facilities, have narrowed the pool of potential LNG solutions. Given the importance of the port of Genoa for the maritime traffic in the Mediterranean Sea and the high number of ship calls every year, the STS solution appears as the most suitable for meeting the growing demand for LNG-propelled ships, especially cruises. Therefore, the Port System Authority of the Western Ligurian Sea is expected to invest in bunker barges or ships, even though there are still other possibilities it can evaluate. In the last case, potential synergies may arise from the collaboration with the nearby Port System Authority of the East Ligurian Sea (i.e., the port of La Spezia[4]) to optimise the supply of LNG bunkering services within the ports managed by these two port authorities. Indeed, in October 2020 the first LNG bunkering in Italy was carried out at the port of La Spezia by using the STS solution. The Costa Smeralda cruise ship was refuelled by the Shell's Coral Methane ship with an LNG storage capacity of 7,600 m^3, which have previously completed this operation 49 times at the Mediterranean ports of Barcelona and Marseille. The bunkering took place in just 5 hours with a maximum bunkering speed of 630 m^3/h. After this positive experience, the Port System Authority of the East Ligurian Sea stated the STS solution will be adopted by the port for providing future LNG bunkering services.

4 The port of Genoa and La Spezia are distant approximately 100 kilometres.

Table 2. Benchmarking of LNG bunkering solutions and their applications in Mediterranean ports.

	Truck to Ship	Ship to Ship	Port to Ship	Mobile fuel tanks
LNG volumes	Less than 200 m^3	Between 1,000 and 10,000 m^3	No limits in terms of volumes	Between 20 and 50 m^3 per unit
Speed of bunkering operations	50 m^3/h	1000 m^3/h	2000 m^3/h	50 m^3/h
Advantages	· High operational flexibility; · No infrastructure investment; · Low initial investment; · Reversibility.	· SIMOPs (reducing ship turn-around time); · No use of dedicated port spaces; · Operational flexibility in terms of localization and LNG volumes handled.	· High bunkering speed; · Operational flexibility; · Scalability of the overall capacity of the bunkering storage facilities.	· Distribution capillarity; · No dedicated infrastructure investment; · Low initial investment;
Disadvantage	· Low bunkering speed; · Small storage capacity; · Risks related to the absence of specialized technical staff; · High transport costs per m3 of LNG; · Presence of trucks on the quayside with consequent increased risks for people and cargo.	· High investment in bunker units (ships and barges); · High operating costs; · Risk of collisions between bunker units and ships or port infrastructure/superstructure; · Complexity in managing bunkering operations.	· Single port area for carrying out bunkering operations; · Impossibility of SIMOPs; · High investment in infrastructure and equipment; · Occupation of large port areas.	· Low storage capacity; · High risk of transport and handling of LNG tanks; · Investment in specific cranes for handling the tanks.
Port applications	· Ports characterized by low LNG bunkering demand; · Start-up of LNG bunkering services; · Ports with multiple terminals that require the movement of bunkering facilities; · Ports not served by the LNG supply network.	· Ports with mixed traffic (inland and seagoing ships); · Ports with large watery mirror; · Ports not particularly prone to adverse weather conditions	· Medium- or large ports; · Ports characterized by a high frequency of LNG bunkering operations; · Ports with stable or easily predictable LNG maritime demand.	· Ports characterized by low maritime LNG bunkering demand; · Start-up of LNG bunkering services; · Ports called by numerous container shipping companies.

Source: authors' elaboration.

6. Conclusion

The paper applies the managerial approach of the SWOT analysis to deepen the understanding of LNG bunkering solutions in the port domain. Based on recent studies and empirical evidence of Mediterranean cases, it examines and compares the four main available technological solutions worldwide (i.e., Truck-to-Ship, Ship-to-Ship, Port-to-Ship and Mobile Fuel Tanks).

The urgent global environmental challenge, the rapid growth of the LNG market and the increasing demand for LNG bunkering services urge ports to provide effective answers to shipping companies for boosting the diffusion of this greener alternative marine fuel. In this perspective, the paper shows the strengths, weaknesses, opportunities, and threats of each LNG bunkering technological solution in a holistic and structured manner according to the theoretical constructs and methodological steps characterizing the SWOT analysis. The study focuses on both endogenous factors (e.g., storage capacity, bunkering efficiency, plant scalability, operational flexibility, economic and financial performance, technical requirements, etc.) and exogenous factors (e.g., social and environmental aspects) to support public authorities and port managers with the investment decisions on LNG bunkering technological solutions.

The outcomes provide useful insights and empirical implications for both academics and practitioners. From the academic perspective, the paper suggests a valuable managerial tool (i.e., the SWOT analysis) to evaluate innovative technological investments in the port domain, opening new avenues of research. From the industrial and practical perspective, the paper reports a systematic framework for each LNG bunkering solution, identifying the most appropriate port application according to the endogenous and exogenous factors, thus supporting both private and public port managers in related strategic and operational decisions.

The paper essentially grounds on the research performed by the Authors during the three-year European project “TDI RETE-GNL” on Mediterranean ports. Although the endogenous factors related to each LNG bunkering technological solution are not affected by the competitive environment, the exogenous factors do. This represents an inherent limit of the study that may be overcome in future research by performing an analysis on Asian or American ports and comparing the outcomes with the present work. Differences and similarities should be discussed to unveil to what extent exogenous factors influence strategic investment decisions. Moreover, future empirical contributions could benefit from a GAP analysis of LNG bunkering projects in combination with the results of the SWOT analysis. The GAP analysis could provide port managers and institutions involved in the decision-making process with valuable managerial implications to identify the deficiencies of the LNG bunkering solutions adopted. Academics are also expected to further investigate KPIs for monitoring the performance of LNG bunkering in the port domain which are only introduced by the Authors. Indeed, potential improvements or radical changes in LNG bunkering facilities and procedures may be evaluated in-depth.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the respective institutions.

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