Executive Summary

of the

National Natural Gas Transmission System Adequacy Study

May 2023

Scope

The present Executive Summary of the National Natural Gas Transmission System Adequacy Study aims to give information about the hydraulic behavior and the limitations of the Greek National Natural Gas Transmission System (NNGTS) to the participants of the ongoing Market Test, DESFA has launched in March 2023. The limitations in gas transmission are strongly dependent on the geographical distribution of the gas delivery points. Power Production (PP) units have a significant impact on the above due to their significant gas consumption and their unpredictable consumption profile, in view of the increasing penetration of renewable energy production sources. A short description of the NNGS with the main gas consumption points as well as a short description of the main projects related to the expansion and enforcement of the NNGTS according to the latest TYDP are presented. Finally, the current limitations as well as the current technical capacities of the System are presented, so as to provide to all those market participants who would like to use the NNGS for their activities a clear picture for the anticipated bottlenecks and give them the opportunity to participate in the ongoing Market Test, with the view to fulfill their requests through an efficient capacity increase, in the case this is needed.

Description of the System

According to its initial design, the Greek Gas System (National Natural Gas Transmission System or NNGTS) was constructed to import natural gas from Russia, through Bulgaria, towards the main consumption points, primarily located in the South of Greece while Revithoussa LNG Terminal would provide flexibility to the NNGTS, as well as to act as a second import point of gas to Greece. Flows of Russian gas started in 1996 from the Greek-Bulgarian border at Sidirokastro, while Revithoussa started its operations in 2000. In 2007, a new Entry Point at the Greek-Turkish border, Kipi, became operational, importing gas from Turkey. In December 2020, the interconnection with TAP at Nea Messimvria, near Thessaloniki, became also operational, allowing gas quantities from Azerbaijan and Italy to be imported to Greece. In the future new additional interconnections will become operational. The interconnection with IGB at Komotini[1], transporting gas to Bulgaria, will become operational from the beginning of 2024, while a new interconnection with North Macedonia is currently under construction and is expected to become operational in the second half of 2025. At the Entry Points "Kipi" and "Nea Messimvria", reverse (backhaul) flows are also supported.

[1] IGB has started its operation in October 2022.

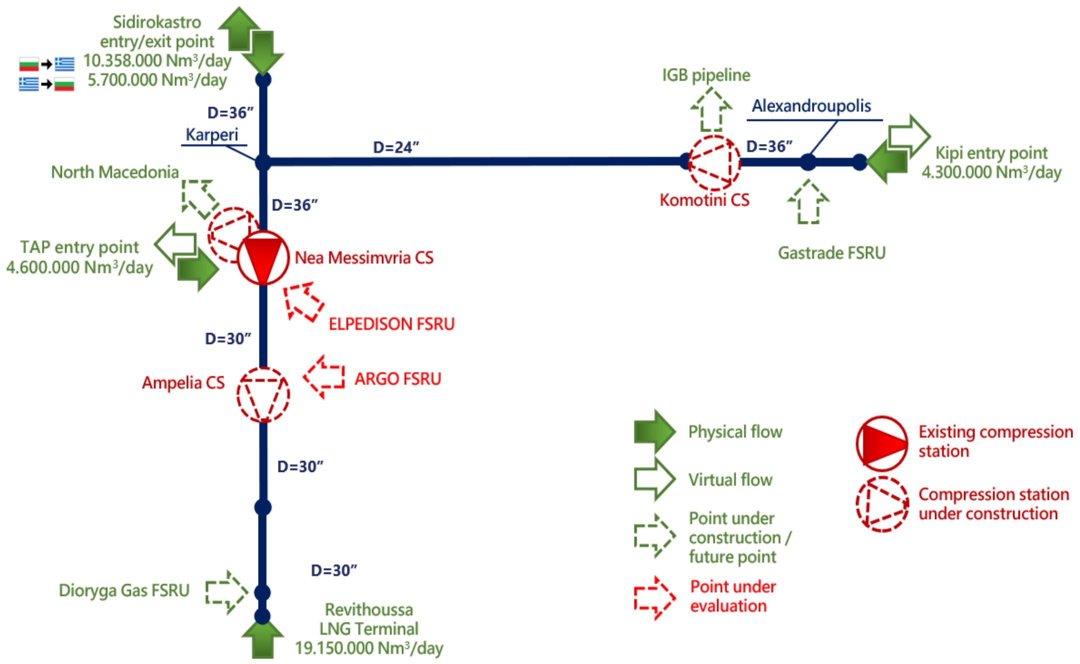

Figure 1. Simplified diagram of the NNGTS

The NNGTS's consists of two main branches (Fig.1): a main pipeline, from the Greek-Bulgarian borders (Sidirokastro) up to the area of Attica and a North to East (NE) branch which starts from the Greek-Turkish borders (Kipi) and connects to the main pipeline in the area of Karperi (Serres). Currently, one Compression Station (CS) is already in operation in Nea Messimvria. Three other CSs are under construction, one in the main pipeline southern of the existing one, at Ampelia (Larissa) area, another one at Komotini area in the NE branch of the NNGTS and finally a third one at Nea Messimvria area close to the existing one, which will serve exclusively exit flows from the NNGTS towards TAP. Finally, the upgrade of the existing CS at Nea Messimvria with the addition of a third compressor unit, is also at a final stage.

The technical capacity of Kulata (BG)/Sidirokastro (GR) IP in the direction BG→GR is 10.36 mill. Nm^3/day while in the opposite direction GR→BG the technical capacity is equal to 5.7 mill.Nm^3/day. The technical capacity of Kipi IP in the direction TR→GR is 4.3 mill. Nm^3/day currently (and until the already projected expansion of the System that includes the new CS at Ambelia and the upgrade of the CS at Nea Messimvria) offered only as competing capacity with Nea Messimvria IPs. Additionally, approx. 0.45 mill. Nm^3/day are offered at Nea Messimvria IP as entry capacity without any competition increasing the capacity of that point to 4.75 mill. Nm^3/day. Until now, the NNGTS provides the necessary gas quantities to all customers on a firm basis. However, conditional products are also foreseen to be offered according to the Greek Gas Network Code as a temporary solution until the completion of the projects (Ampelia CS and Nea Messimvria CS upgrade) that will enable the offer of firm capacity to all NNGTS points. At Kipi and Nea Messimvria IPs the only feasible flow direction is from the upstream connected transmission systems towards the NNGTS. Reverse flows are offered but only in interruptible basis as backhaul. Physical reverse flow will become feasible at Nea Messimvria IP, only after the completion of a dedicated booster CS at Nea Messimvria IP, totally separated from the existing Nea Messimvria CS.

Revithoussa LNG Terminal, located on the southern part of the NNGTS, serves as the entry point of LNG and consists of three storage tanks of more than 220,000 m^3 LNG, storage capacity in total. The Sustainable Maximum Send-out Rate of LNG gasification is equal to 1,400 m^3LNG/h. The technical capacity of the Entry Point (Agia Triada) that is connected to the LNG Terminal is approx. equal to 19.15 mill. Nm^3/day. The following table summarizes the existing technical capacities of the NNGTS:

Existing firm Technical Capacities of NNGTS			
Point	**Capacity (Nm³/d)**	**(kWh)***	**Notes**
Sidirokastro (entry)	10,358.220	117,493,289	*firm capacity*
Kipi[1, 2]	4,300,000[1]	48,592,292	*firm capacity*
	2,498,250[3]	28,070,227	*conditional capacity*
Nea Mesimvria[1]	4,741,780[1]	53,368,256	*firm capacity*
	3,150,000[3]	35,000,000	*conditional capacity*
Agia Triada	19,150,000	224,592,985	*firm capacity*
TOTAL entry	**34,250,000**	**395,454,530**	*firm capacity*
	34,250,000[4]	**395,454,530**	*including conditional capacity*
Sidirokastro (exit)	5,700,000	66,285,300	*firm capacity*

* *Values on energy units may vary from the actual offered by DESFA due to changes in the GCV used in the transformation from volumetric units.*

[1] *Until Oct.2023, the capacity at the Entry Points Kipi and Nea Mesimvria is available as competing capacity. The amount of competing capacity is equal to 4,300,000 Nm^3/d.*

[2] *From January 2024, until October 2024 there will be no gas flow through Kipi Entry Point.*

[3] *The offer of conditional capacity has currently been approved by RAE until 1/10/2023 and is done exclusively through competing capacity products at Nea Mesimvria and Kipi points*

[4] *The condition for the use of conditional capacity does not allow the increase of natural gas deliveries from the Entry Points of the table above the sum of the technical capacities on a firm basis.*

During the last period, DESFA has received a significant number of connection applications for new FSRU projects. One of them, Alexandroupolis FSRU, is currently under construction, while for a second one, Dioryga Gas FSRU, a binding Market Test process has been finalized. In addition, two other connection requests for FSRU projects are currently under evaluation by DESFA. The first concerns an FSRU project in the area of Volos (Magnesia) in the central part of Greece while the second one concerns an FSRU project in Thessaloniki area in Northern Greece. However, the current configuration of the NNGTS is not able to transmit the requested full quantities from all abovementioned FSRUs towards the Greek VTP.

On the consumption side, regarding Sidirokastro IP, even though physical reverse flows towards Bulgaria is feasible, until mid-2022 only rarely did the NNGTS supplied the Bulgarian territory with physical gas flows. However, the interruption of Russian gas to Bulgarian market in April 2022 and the increase of the importance of LNG for the SEE region, led to an increase in the physical reverse flows through Kulata (BG)/Sidirokastro (GR) IP. As a result, from the beginning of April until the end of November 2022 more than half of the days, Sidirokastro IP operated as an Exit Point.

Following the dynamics of the gas market, in the following years, NNGTS will be required to supply with gas currently non-gasified domestic areas (i.e. West Macedonia, West Greece) but also new interconnections with neighboring countries (North Macedonia, Bulgaria, and trough TAP to Albania and Italy). Reversal of flows and physical gas exports to neighboring countries is currently the case and may be also continue in the future. In the NE branch of the NNGTS (Karperi-Kipi), the prevailing flow direction was from the East towards the West. However, in the future, this trend may also change substantially. In case of minimization or disruption of gas flows from the northern Entry Points, the NNGTS can operate in reverse mode. In this case, gas flows from Revithoussa LNG Terminal or other future Entry Points in the South, can be addressed to the northern part of the NNGTS. Nea Messimvria CS may also operate in reverse mode and send further away the gas quantities coming from the southern part of the NNGTS. Ampelia CS will also be able to operate in reverse flow mode when completed.

Regarding the domestic consumption, until now, gas consumption in Greece is mainly located in the southern part of the NNGTS. Historically in Greece, the main gas consumers are the gas-fired power plants with more than 60% of the total domestic consumption. A fact that is expected to further increase with the addition of new gas-fired power plants to be connected to the NNGTS in the next few years, according to the announced plans.

Until now, there are 15 gas-fired units in Greece. The installed capacity of the existing gas-fired power plants ranges from 49MWe to 811MWe, with most of them at around 400MWe. Most of the units are located in the southern part of the NNGTS and only two are located northern of Nea Messimvria (Thessaloniki). In addition to the gas-fired power plants already in operation, DESFA has received applications for the connection with the NNGTS of new gas-fired power plants that are described below. These new power plants have higher nominal capacity compared to the existing (above 800 Mwe) and are located mainly in the northern part of the NNGTS (Figure 2). The location of the power plants becomes crucial for the hydraulic behavior of the NNGTS.

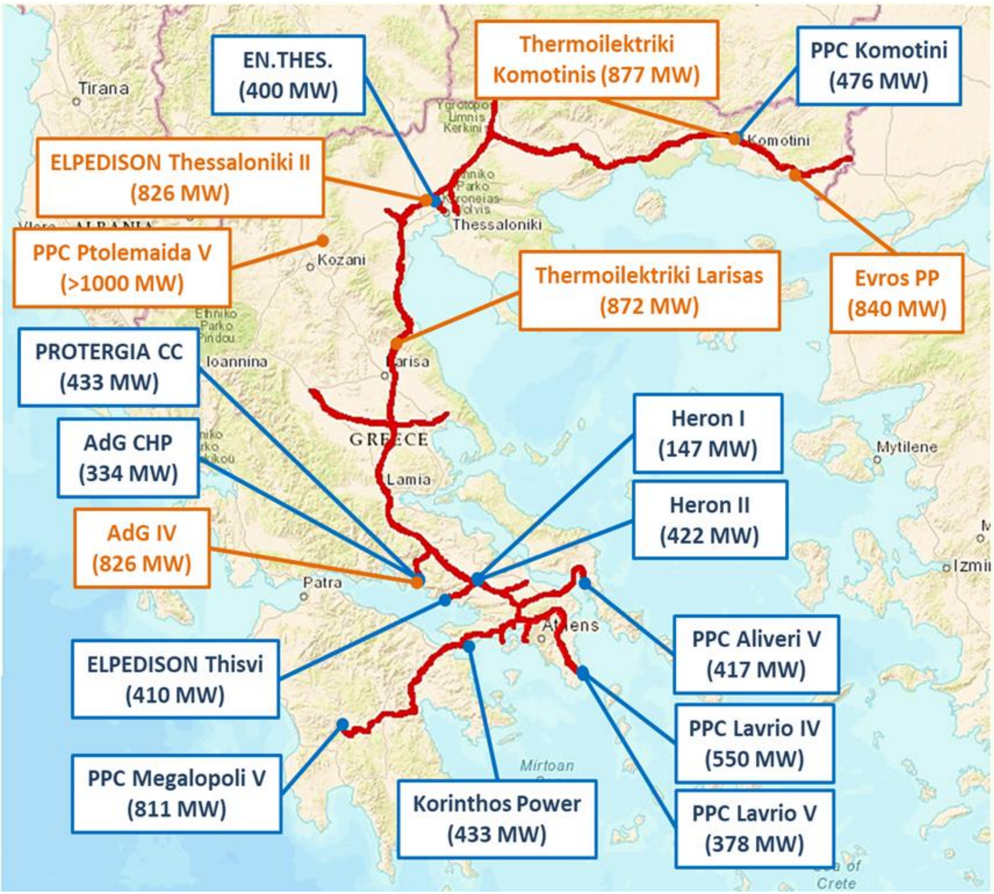

Figure 2: Existing and projected/planned/under construction PPs in Greece.

Other main domestic gas consumers, excluding power plants, are concentrated in the south as well, either in the city of Athens or closely located industrial areas of MOH, AdG, ELPE and Inofyta. The gas consumption of Thessaloniki is generally lower compared to the respective to Athens', however, is comparable in peak gas consumption periods. Other cities (Volos, Larissa etc.) have significantly reduced gas offtakes. Gas consumption is not balanced between the northern and the southern part of the country. Historically, more than 60% of gas in Greece is consumed in the southern Exit Points and rarely this percentage drops below 55%, while there are periods when it exceeds even 90% of the total gas consumption. The percentage of gas consumption in the south has slightly increased throughout the years and is nowadays constantly between 70% and 90%.

From the abovementioned, it is clear that in the near future, the NNGTS will face the challenge of transformation. New Entry Points will be introduced with the aim to cover the domestic gas demand and substitute the Russian gas supplies. New Exit Points with significant gas consumption, like new gas-fired power plants will also be connected to the NNGTS, altering the established profile of gas consumption. The geographical allocation of gas consumption will also be altered. The daily profile is expected to be affected by the increasing RES penetration. Given that the LNG share in gas supply is expected to increase, access of neighboring countries to the existing, but also to new Greek LNG terminals, will increase the total throughput from the NNGTS. DESFA must, in any case, ensure the safe, economic and reliable operation of the NNGTS and at the same time implement an ambitious development program, which will secure the supply of the Greek and the regional gas market. The injection of renewable gases (including hydrogen) in the NNGTS and the transmission through the NNGTS would be another challenge to be faced off.

Demand forecast

From 2015 until 2021 gas consumption was constantly increasing, from less than 3bcma in 2014 to more than 6 bcma in 2021. During 2022 a drop in domestic gas consumption was noted that was more than counterbalanced by an increase in gas demand for exports. The peak day demand has already exceeded 27 mill. Nm^3/day (Jan.2021) and is expected to exceed 60 mill. Nm^3/day by 2030, including approx. 15 mill. Nm^3/day for exports. A significant increase in the expected annual gas transported quantity is also foreseen for the period 2023-2032.

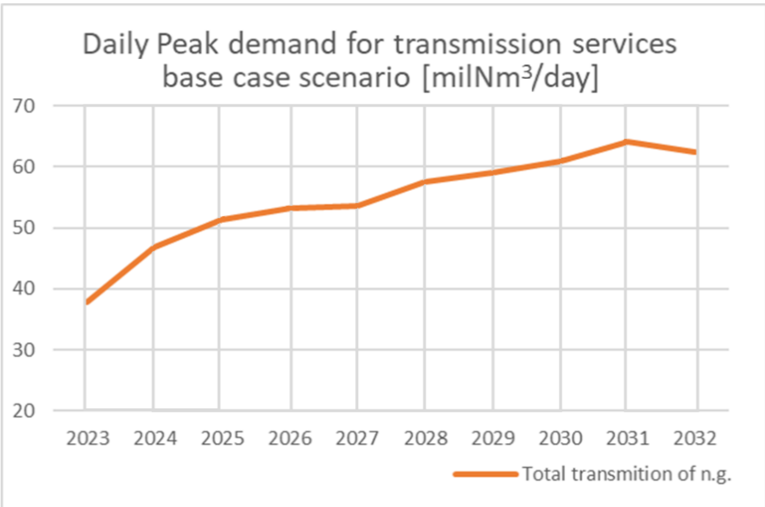

Figure 3. Estimated peak demand trend (including exports) until 2032

The gas demand increase is mainly driven by the significant increase in gas exports. This significant increase in exports reflects the impact of Russia's invasion of Ukraine, expected to last for the next few years, but also aligns with the EU target on reducing dependency on Russian gas on the long run. High exports to neighboring countries, are expected to continue, reflecting stronger market integration with those countries. Yearly gas demand for power production is expected to be relative stable in the following years, however the clear increase in peak demand, that is expected, demonstrates the new role and mode of operation that gas-fired units will play in the power generation mix of the future.

Gas demand of final consumers is also expected to be increased due to the anticipated gasification of new areas (i.e. West Macedonia, West Greece, Peloponnese) and new investments from industrial consumers. So, focusing on the daily peak demand, this substantial increase throughout the next ten years, is attributed both on demand of the Greek gas market but also for gas exports. However, it must be mentioned that according to the projected technical capacities of the NNGTS, the projected daily peak demand cannot be covered by the existing transmission capacity of the NNGTS on a firm basis. The projected trend for the daily peak capacity requires a significant upgrade of the NNGTS.

Expansion of the NNGTS

The following years, the NNGTS will have to supply gas to new consumers, but also, incorporate new Entry Points such as FSRU projects that will be also connected both in the southern and the northern part of the NNGTS. For the upgrade of the NNGTS, DESFA assesses all new connection applications considering only already approved projects for the upgrade of the System (development projects for the increase of capacity of the NNGS). However, the implementation of the currently approved development projects (as per above) cannot fully satisfy the requests for new entry and exit firm capacity that have been received by DESFA. To do so, the NNGTS must be further upgraded, with significant pipeline duplications and new CS units.

DESFA prepares on a yearly basis, a Development Program for the next ten years (TYDP), providing information to market participants for the new or planned, upgrades of the NNGTS. Two main categories of projects with significant importance for the hydraulic adequacy of the NNGTS are included in the TYDP. The first category includes expansion projects to new areas, which lead to increased flows through new and existing pipelines, to cover the new demand. The second category includes projects related with upgrades of the existing infrastructure, which will enable increased flows through the NNGTS.

New expansion projects include the high-pressure pipeline to West Macedonia and the respective one to Patras, the interconnection between Greece and North

Macedonia and the interconnection with IGB at Komotini as well as the interconnection with FSRU projects (Alexandroupolis and Dioryga Gas). Finally, the connection of new gas-fired power plants like Agios Nikolaos (AdG IV), Thermoilektriki Komotinis and Elpedison also belong to this category. On the other hand, the new compressors (at Komotini, Ampelia and Nea Messimvria) and new proposed duplications of pipelines (Karperi - Komotini branch, Patima – Livadeia branch and Livadeia – Karperi branch) will significantly increase the transmitted natural gas quantities through the System.

Technical constraints of the NNGTS

As already mentioned, three Entry Points, Sidirokastro, Kipi and Nea Messimvria are located in the northern part of the NNGTS. Sidirokastro is a bi-directional point while at Kipi and Nea Messimvria Entry Points only virtual reverse flow is feasible. From a hydraulic perspective, the fact that the main gas consumption points, are located in the southern part of the NNGTS, while the majority of the Entry Points are located in the northern part of the NNGTS leads to hydraulic limitations, because significant gas quantities must be transmitted long distance through the single 30” pipeline of the NNGTS. The same also applies in the opposite direction when flows from the South of the System must be transmitted in the northern exit points (including export points).

In case of gas flows from the North to the South, there is a physical constraint in the transmitted gas quantities through the main pipeline of the NNGTS from Nea Messimvria to Patima node. In case of reverse gas flows a corresponding physical constraint also exists. The abovementioned limits are defined through hydraulic simulations of the NNGTS. For the identification of those constraints, the so-called worst-case” flow scenarios are identified. Those scenarios describe the worst case that can realistically be observed in terms of gas supply/consumption but also in terms of their geographical allocation within the country.

The hydraulic adequacy of the NNGTS is achieved when all the operational parameters (pressure, velocity levels etc.) throughout it, range within acceptable levels. It is highlighted that in general, the technical capacities Entry and Exit Points are not defined by technical parameters of the points themselves but by hydraulic limitations on other points of the NNGTS. (i.e., the technical capacity of an Entry Point in the northern part is strongly correlated to the pressure levels of remote gas consumption points in the southern part of the NNGTS).

It is obvious that the existing technical capacities have already incorporated the existing hydraulic limitations of the NNGTS. In other words, the existing technical capacities are the outcome of the interpretation of hydraulic simulations of the NNGTS and conversely any hydraulic simulation of the existing configuration of the NNGTS that respects the existing technical capacities will lead to hydraulicly stable results. When examining new points in the NNGTS, it is important to identify if the newly increased flows lead to non-acceptable hydraulic behavior. In this case, the need for enforcement in specific parts of the NNGTS is revealed.

For forward flow cases in the main pipeline (flow direction N→S) the "worst case scenario" consists of high gas consumption in the southern part of the NNGTS and low gas consumption in the northern part, including exports. In this case, the northern Entry Points are considered to operate at their technical capacity (maximization of gas inflows), and gas flows through the southern Entry Point(s) are calculated so to respect the mass balance of the NNGTS. Following this approach, the gas flow transmitted from the northern part of the NNGTS towards the southern part through the main pipeline as well as the pressure drop and the velocity levels are maximized.

The NNGTS north of Nea Messimvria has two simultaneous technical limits, concerning the quantities transmitted from North Entry Points to South consumption points. The sum of the daily firm flows from Entry Points in the northeastern branch cannot exceed 4.3 mill.Nm^3/day, without the installation of a CS in the NE branch (i.e the already projected CS at Komotini), or 8.1 mill.Nm^3/day, after the installation of such CS. In addition, the sum of daily firm flows from Entry Points northern of Nea Messimvria (Nea Messimvria Entry Point, included) currently cannot exceed approx. 15 mill.Nm^3/day currently, and will be increased to approx. 19.5 mill.Nm^3/day, after installation of Ampelia CS (anticipated in Q3 2024) and upgrade of Nea Messimvria CS (anticipated in Q3 2023).

In case of physical reverse flow (flow direction S→N) in the main pipeline, the worst-case scenario is formulated by maximizing the flow from the southern part of the NNGTS towards the Exit Points in the north, while minimizing the northern Entry Point inflows. The gas flow from the southern part of the NNGTS is maximized in case of incoming flows from Revithoussa LNG terminal equal to the existing technical capacity and minimization of the consumption in the southern part of the NNGTS. In this case the gas flow results to the maximum pressure drop and the maximum velocity in the main pipeline. The maximum flow through Agia Triada Entry Point cannot exceed the Sustainable Maximum Send-out Rate of Revithoussa LNG Terminal which is currently equal to 1,400 m^3 LNG/h. This SMSR corresponds to a daily quantity equal to approx. 19.15 mill.Nm^3/day. This limitation is relevant to the technical characteristics of the Revithousa LNG terminal only.

Examining reverse flow scenarios (flow direction S→N) has an additional complexity compared to forward flow scenarios (flow direction N→S). In case of reverse flow scenarios, the maximization of flow in the main pipeline is also based in maximization of incoming flow from southern Entry Point(s), but in this case it is not realistic to switch off all the existing power plants located in the South. A realistic worst-case scenario with gas consumption from power plants in the South must be formulated. This worst-case scenario must be based on the historical data for gas consumption between the southern and the northern part of the NNGTS, excluding exports. The latter must be maximized according to the technical capacity of the respective Exit Points. In this case the total firm exit capacity may reach 12 mill.Nm^3/day or even more.

In the reverse flow direction, firm flows from the southern part of the NNGTS, cannot significantly exceed the existing technical capacity of Revithoussa LNG Terminal (19.15 mill.Nm^3/day). The limitation is set by the flow passing through Ampelia CS which cannot exceed approx. 590,000 Nm^3/h. This flow results to maximum allowable pressure drop and the velocity level in the main pipeline. The operation of Ampelia CS and Nea Messimvria CS in reverse mode (flow direction from South to North) reassures that pressure levels and velocities remain at acceptable levels in the northern part of the NNGTS. Those limitations have been incorporated in the announced technical capacities, so without any significant upgrade to the NNGTS the transmitted firm quantities cannot be further increased.

The hydraulic behavior of the eastern branch of the NNGTS (Karperi-Kipi branch) in case of flow from West towards the East is dependent on the maximum flow that do not violate the minimum pressure level at Komotini node, considered equal to 28 barg. In this case the highest pressure level in the 24" pipeline is at the western point (node of Karperi) and is constantly reduced as the quantities move towards the East. In the worst-case scenario, no gas flows pass through Kipi or Alexandroupolis FSRU. So, without any investment, the maximum flow through the 24" pipeline in the direction from Karperi to Komotini which results to a minimum pressure level at Komotini node equal to 28 barg, is approx. 240,000 m^3/h which can hardly cover the demand of the existing PPC power plant (476 MWe) at Komotini plus one new power plant with nominal capacity approximately 850MWe. **It is obvious that without any investment in the 24" pipeline there is no firm exit capacity to any other Exit Point in the area east of Karperi. The interconnection with IGB at Komotini, new power plants connections but also the possible interconnection with the UGS in the area of Kavala, require the upgrade of the 24" pipeline (either a CS or a duplication).** The duplication with a 30" pipeline can transmit additional flows equal to approximately 9 mill. Nm^3/day towards Komotini node, enough to cover the demand of any new power plant in the area but also significant firm exports to IGB.

The technical capacities of the domestic Exit Points (not including IPs), in general, are considered equal to the maximum capacities of the respective metering stations. The reason is that in general, domestic Exit Points do not impose additional hydraulic restrictions, other than those examined for the calculation of the firm Entry Points capacities. In other words, when the hydraulic restrictions considered for the calculation of firm Entry Points capacities are not violated, in general, there is no need to examine additional restrictions in the Exit Points.

As already mentioned, the formulation of the worst-case scenario is based on the maximization of gas flows through the examined pipelines. This maximization requires the adoption of a realistic minimum gas consumption scenario on specific parts of the NNGTS and a corresponding maximization of flows on different parts of the NNGTS. In general, the formulation of the minimum gas consumption scenario is based on historical data. On the other hand, gas consumption from specific power plants is highly unpredictable and is affected by operational and regulatory parameters, maintenance plans and of course gas and CO_2 prices. Until now, in the northern part of the NNGTS there are only two power plants in operation, so in the formulation of the worst-case scenario those power plants are considered to be out of operation. Until now this scenario is considered realistic and was used in the calculation of the technical capacities of the northern Entry Points. However, in the future, it must be assessed if the discussed scenario must be amended to adopt the new gas consumption profile that is expected to appear in the upcoming years. The connection of at least two new power plants in the North as well as the new interconnection for the supply of North Macedonia will add significant gas quantities in the North. In that case, if it is proved that the minimum gas consumption level in the North has undoubtfully been increased, the technical capacities of the northern Entry Point may be increased

Conclusion

Summarizing the above, it becomes evident that in the near future, the NNGTS will face the challenge to transmit increased gas quantities from existing but also new supplying points towards new gas consumers. Alongside with the new interconnections with adjacent transmission systems, new power plants will be implemented altering the gas consumption map of the country. However, without any further upgrade, the NNGTS will not be able to fulfil this target. The hydraulic limitations of the NNGTS have already been reflected in the existing technical capacities, meaning that any significant increase in the entry/exit capacities requires a relevant upgrade of specific parts of the NNGTS. Thus, it becomes obvious that it is high time to design but also to assess the economic feasibility of the expansion of the NNGTS.