Assignment for DESFA

Economic Assessment of South Kavala Investment

Final report

FTI CONSULTING | COMPASS LEXECON
ENERGY

23 December 2021

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0. Executive summary

FTI Consulting modelled the benefits (incl. security of supply value) and costs of creating a storage at South Kavala, under two network upgrade scenarios

Section summary

1 Context

DESFA asked FTI Consulting to **quantify the welfare benefits** in Greece of building an Underground Gas Storage (UGS) facility at **South Kavala and related network upgrades, under two network upgrade scenarios** – a Full Investment scenario at EUR 750m CAPEX, and a Partial Investment at EUR 422m CAPEX.

We simulated the gas and power markets from commissioning date (2027) to 2050 with and without the Investment to quantify the Investment's welfare creation. On top of the normal, most likely conditions, and in line with regulatory approaches, we also quantified the security of supply value brought by the Investment using extreme events scenarios.

2 Simulation tool

To model the European gas and power market to 2050, we relied on **a Plexos platform as used by ENTSOG and ENTSOE for their TYNDP**.

The model accounts for all gas & power infrastructure, supply and demand across Europe, with additional granularity for the Greek gas system. Model inputs stem primarily on ENTSOG & ENTSOE data, with specific complements from DESFA for Greece.

3 Methodology for welfare quantification

To quantify the increase in Greek welfare as a result of the Investment, we **followed ENTSOG's CBA methodological guidelines**, and computed 4 metrics **measuring wholesale price reduction (externalities) and private trading benefits** created by the Investment.

The metrics are modelled in normal conditions from 2027 to 2050, but are also modelled under **six stress scenarios to measure the security of supply value** under a range of circumstances, with four stress scenarios constructed based on historical precedents, on two based on RAE's 2020 National Risk Assessment Study

4 750 €m investment scenario results

In the Full Investment, total welfare benefit is EUR_{2021} 481m over 2027-2050 under normal conditions, with stress cases bringing additionally EUR_{2021} 293m of benefits, **below the sum of costs at EUR_{2021} 913m**.

5 422 €m investment scenario results

In the Partial Investment, total welfare benefit is EUR_{2021} 446m over 2027-2050 under normal conditions, with stress cases bringing additionally EUR_{2021} 274m of benefits, **above the sum of costs at EUR_{2021} 632m**.

DESFA asked FTI Consulting to quantify the welfare benefits of building South Kavala UGS and related network upgrades, under two Investment scenarios

Overview of Investment scenarios

Partial Investment scenario, with 422 M€ network upgrade

"Small" network upgrade: 422 m€ CAPEX

Full Investment scenario, with 750 M€ network upgrade

"Large" network upgrade: 750 m€ CAPEX

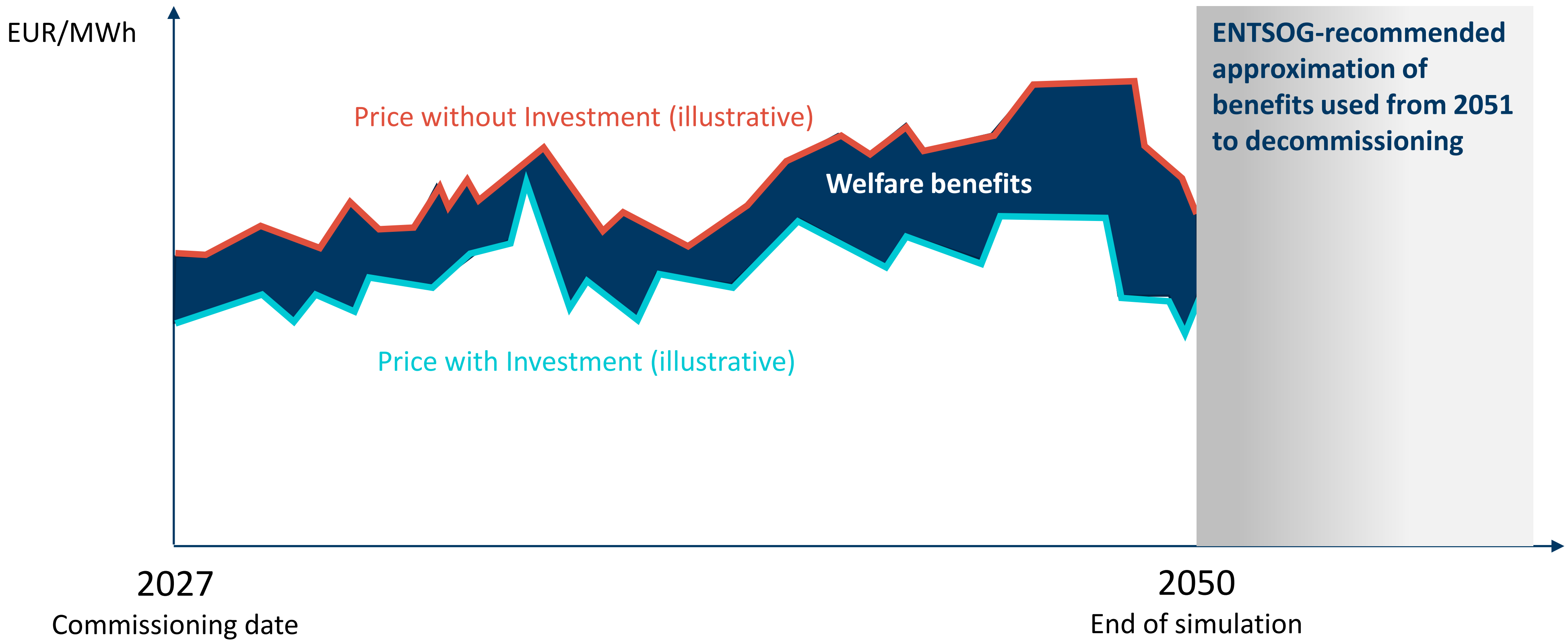
Same investment considered in the UGS at South Kavala in both Investment scenarios

Source: ENTSOG and DESFA

Note: A network upgrade more limited than the Partial Investment scenario was also envisaged by DESFA, but such limited upgrade would have required to significantly constrain the storage use, and therefore was not retained as appropriate by DESFA.

We simulated the gas and power markets from commissioning date to 2050 with and without the Investment to quantify the Investment's welfare creation

Illustration of quantification of welfare benefits: wholesale market externalities



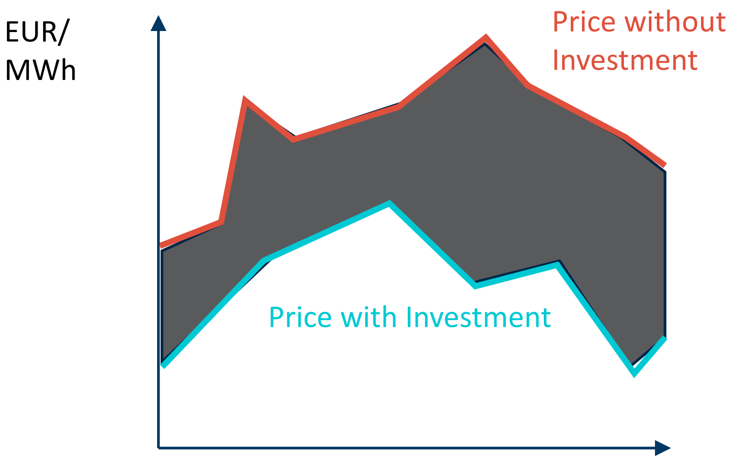
In line with regulatory approaches, we also quantified the security of supply value brought by the Investment through the modelling of extreme events

Approach to capture value put on security of supply

Illustration of normal system conditions

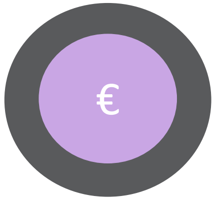
Welfare benefits under
normal conditions

Illustration of stress system conditions



Welfare benefits under
stress conditions

Total welfare benefits



Normal conditions & (ΔStress vs. Normal)

To model the European gas and power market to 2050, we relied on a Plexos platform as used by ENTSOG and ENTSOE for their TYNDP

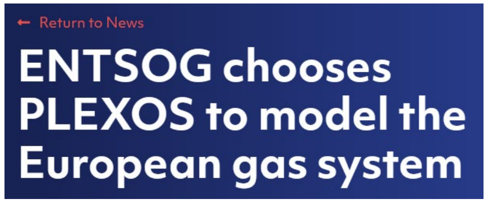
Main features of the gas & power integrated model built for DESFA's CBA

Plexos model

- Mixed Integer Linear Programming model.
- Platform used by ENTSOG & ENTSOE for TYNDP.
- Modelling from 2027 to 2050.
- Regular backcast of the power leg of the model., which has been used in major energy projects in Europe by FTI-CL energy.

Hourly modelling run

- Yearly independent modelling runs from 2027 to 2050.
- 8760 hours * 24 years = 210,240 optimisations, run together on a weekly basis.



Note:
When we model energy markets on Plexos, we face a trade off between accuracy of results and modelling running time, which led us to select a weekly grouping of hourly optimisations.
TYNDP always refers to Ten-Year Network Development Plan 2020 (latest available) published by ENTSOE and ENTSOG. Next TYNDP expected in 2022.
FTI-CL Energy = Energy team of FTI Consulting and its wholly owned subsidiary Compass Lexecon

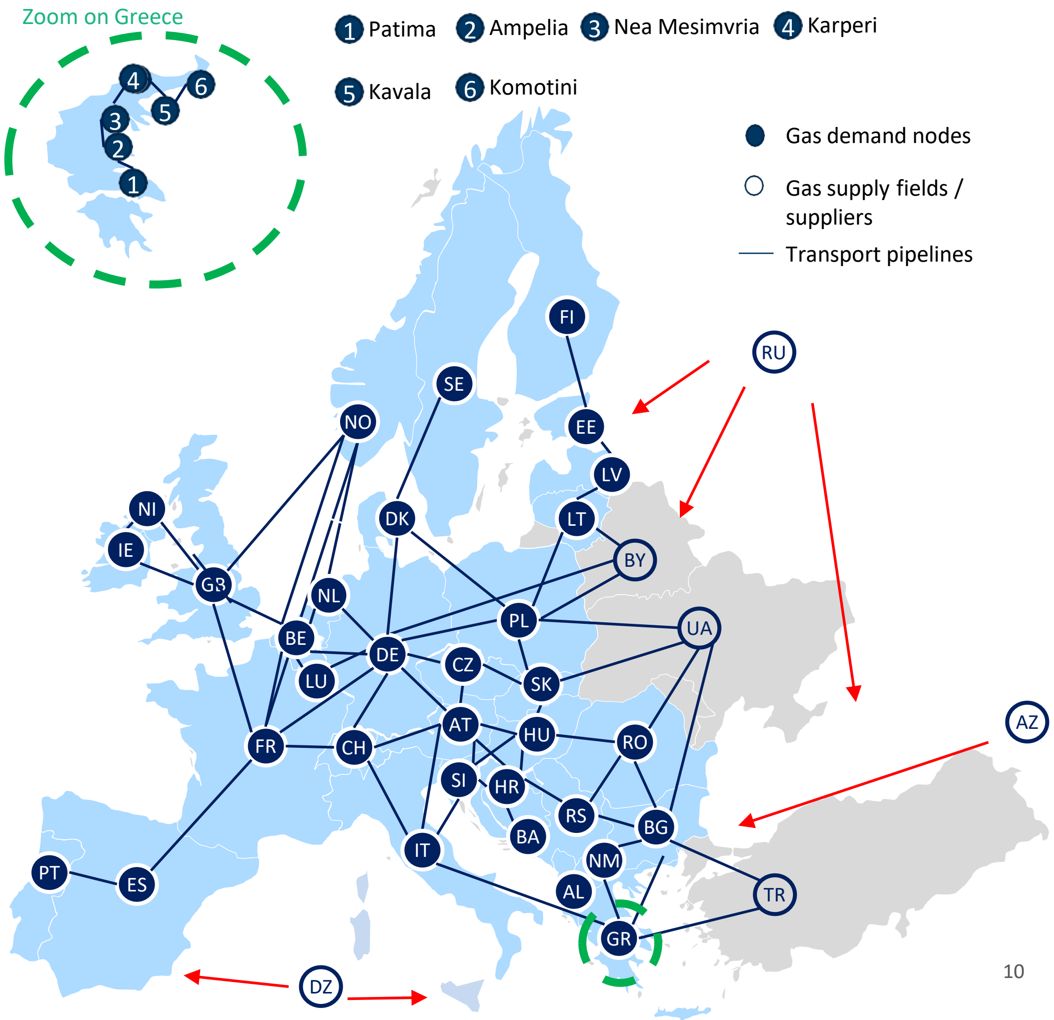
The model accounts for all gas infrastructure, supply and demand across Europe, with additional granularity for the Greek gas system

Focus on gas

Overview

- FTI-CL Energy's gas market model covers the EU-27 countries as well as the UK, Switzerland, Norway and the Balkans.
- The model considers supply stacks of European indigenous gas fields, as well as stacks of Russia, Azerbaijan and Algeria's gas fields.
- The model determines endogenously:
  - The hourly marginal price ensuring demand is served by supply
  - Hourly flows at every gas node across Europe
  - Gas demand for power generation as a result of the gas and power optimisation process
- The model considers cross-border transport constraints across Europe.
- The model also considers Power2Gas and battery capacities as required for power security of supply.

Geographic scope



Source: FTI-CL Energy

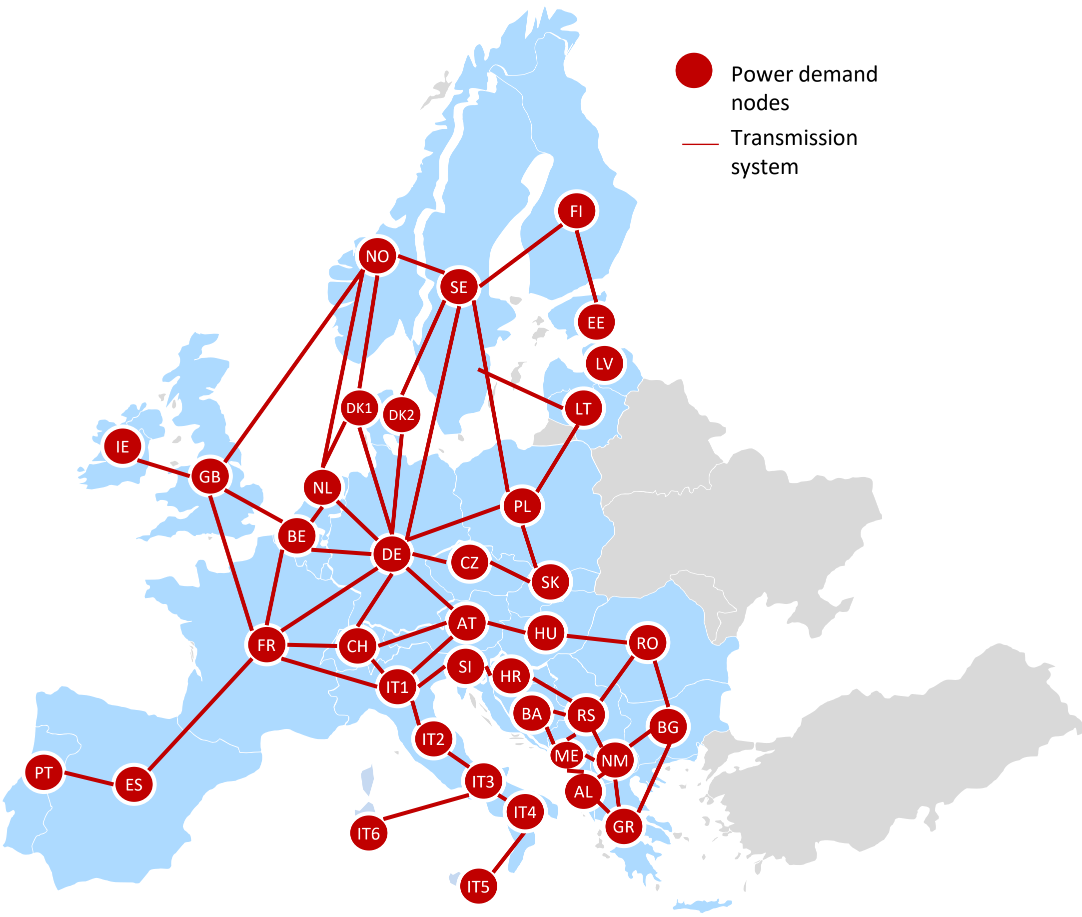
The model accounts for all power infrastructure, supply and demand across Europe, including major sub-country price zones

Focus on power

Overview

- FTI-CL Energy's power market model covers the EU-27 countries as well as the UK, Switzerland, Norway and the Balkans.
- FTI-CL Energy's power market model constructs supply in each price zone based on aggregated power plants:
    - Zonal prices are determined as the marginal value of energy accounting for generators' bidding strategies.
    - The model takes into account cross-border transmission and interconnectors, and unit-commitment plant constraints across Europe.
    - The model also provides hourly prices and flows at every power node across Europe.
- FTI-CL Energy's power market model uses ENTSOE Pan-European Climate Database for hourly time series for wind and solar production, hydro inflows and demand pattern.

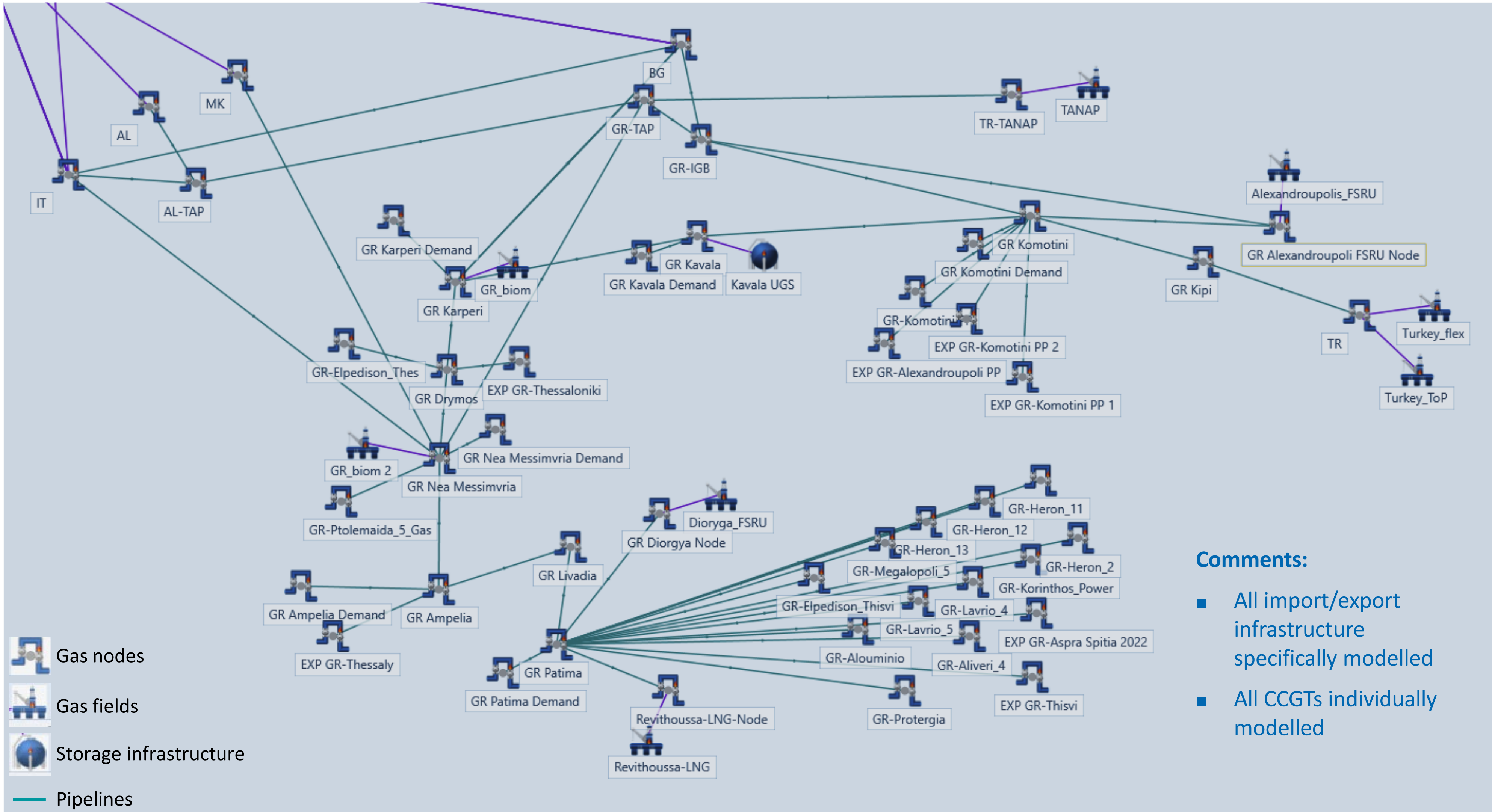
Geographic scope



Source: FTI-CL Energy

Our integrated gas & power model considers a granular mapping of Greece

Map of Greece and neighbouring countries gas and power main infrastructures – From Plexos model



Comments:

- All import/export infrastructure specifically modelled
- All CCGTs individually modelled

Source: Plexos and FTI-CL

Our model relies primarily on ENTSOG & ENTSOE data, with specific complements from DESFA for Greece

Main sources used

	Demand	Supply	Infrastructure
Gas	▪ **Annual demand** [1] DESFA's Development Study and ENTSOG's TYNDP. ▪ **Daily demand profile** University College Cork Plexos' gas model ("UCC").	**Volume and prices** [2] ▪ Volume and cost of indigenous gas supply in Europe by Rystad. ▪ Russian export prices based on expected strategy to be competitive in major European markets vs. LNG. ▪ LNG price based on IEA and ICIS data.	**Pipelines' capacity** [3] ▪ DESFA's Development Study 2021-2030; and ▪ ENTSOG TYNDP 2020 Low Scenario (includes existing infrastructure and post-FID infrastructure).
Power	▪ **Annual demand** [4] ▪ National Energy and Climate Plan (NECP) demand scenarios. ▪ EU Commission Energy Roadmap 2050. ▪ **Daily demand profile** ▪ ENTSOE'S TYNDP data.	**Long term capacity scenarios derived from:** [5] ▪ Dynamic long-term optimization; combined with ▪ Long term capacity scenarios based on energy policies and regulation. **Short term capacity scenarios derived from:** ▪ Hourly supply in each price zone based on aggregated plants constraints.	**Transmission' lines capacity** [6] ▪ Based on the ENTSO-E and FTI-CL Energy's expertise.

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To quantify the increase in Greek welfare as a result of the Investment, we followed ENTSOG's CBA methodological guidelines, and computed 4 metrics

Overview of approach used to quantify the welfare impact of the Investment, through its main monetized benefits

ENTSOG

ENTSOG:

Recommended Methodology for CBA for Gas Infrastructure Projects (2018, 2nd version).

Approach developed for gas pipelines, used here as guiding principle.

No specific ENTSOG methodology available to measure value of storage in Energy Transition.

Period	Approach	Metrics used
From 2027 (Expected commissioning); **to 2050** (End of ENTSOG & ENTSOE forecasts).	**Modelling of welfare impacts** of Investment in the power and gas markets across Europe, hour by hour.	α **Greek gas consumers externality** based on wholesale market price change. β **Greek power consumers externality** based on wholesale market price change. γ **Greek storage margin created** for storage operator and users.
2051 to decom-missioning	**Residual value** of Investment until end of technical life of the Investment.	δ **Annual depreciation** of the Investment in Greece, used a measure of benefits (as recommended in ENTSOG CBA Methodology)

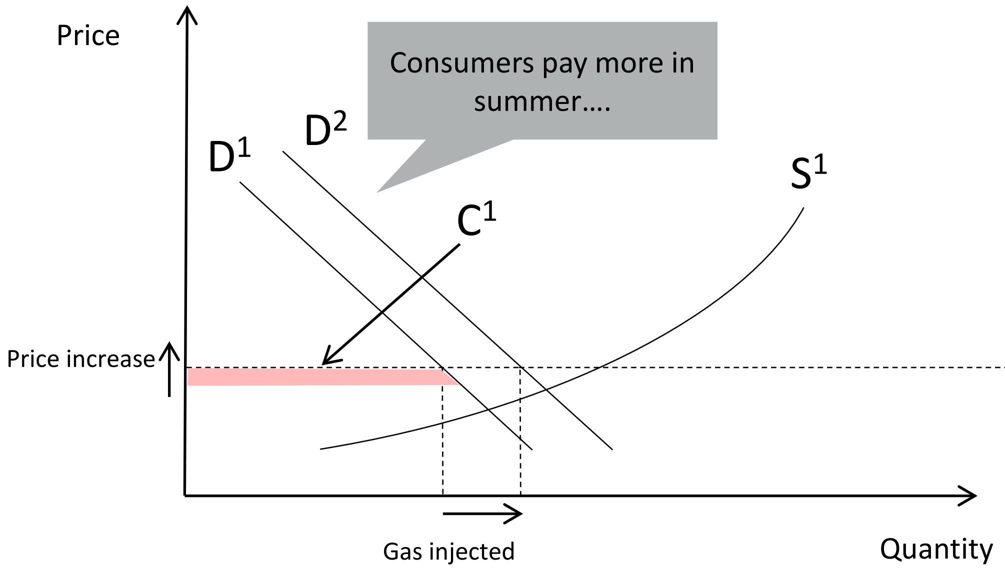
Combination

Annual benefits are discounted to decision time (2021) using a 4% annual real social discount rate (Recommended value of ENTSOG CBA Methodology).

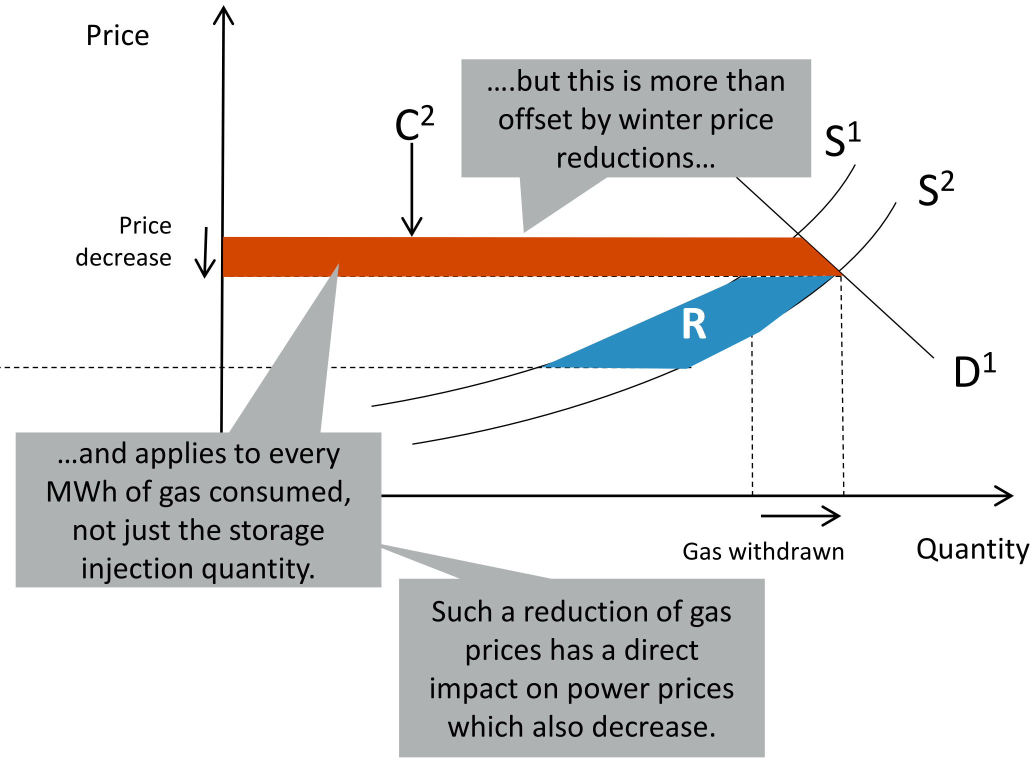
The Plexos model allows us to quantify the metrics impacted by the storage creation: wholesale price reduction (externalities) and private trading benefits

Focus on a typical storage impact - Illustrative

Summer



Winter



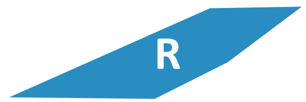
Externalities – Impact for all gas consumers α

ΔPrice <0

ΔPrice >0

Private impact – Storage margin shared between storage operator and storage clients γ

Revenues >0



On top of normal conditions, we have considered six stress scenarios to measure the security of supply value under a range of circumstances

Overview of stress tests conducted

	European Demand				European Supply					Extra Europe prices	
	Climate event		Infra. outage	Loss of demand	Climate event	Infra. outage		Loss of supply		Price level	Price volatility
	Cold spell	Heat wave			Low wind	NMK+BG interco. outage	Reduced pipe supply to Greece	TAP & Kipi interruption	No LNG for a short period	2021 TTF prices for LNG&RU	2021 TTF peak price
A **Gas price volatility as in 2021**										✓	
B **Pronounced pan-European 2-week cold spell**	✓										✓
C **Pronounced pan-European 2-week cold spell & part power line outage**	✓					✓					✓
D **Pronounced heat wave as in 2021 & part power lines outage**		✓			✓	✓					
E **Azeri interruption** (based on scenario Γ2b from RAE's 2020 National Risk Assessment Study)								✓			
F **Reduced pipeline supply to Greece & no LNG** (based on scenario B5b from RAE's 2020 National Risk Assessment Study)							✓		✓		

Based on RAE's 2020 National Risk Assessment Study

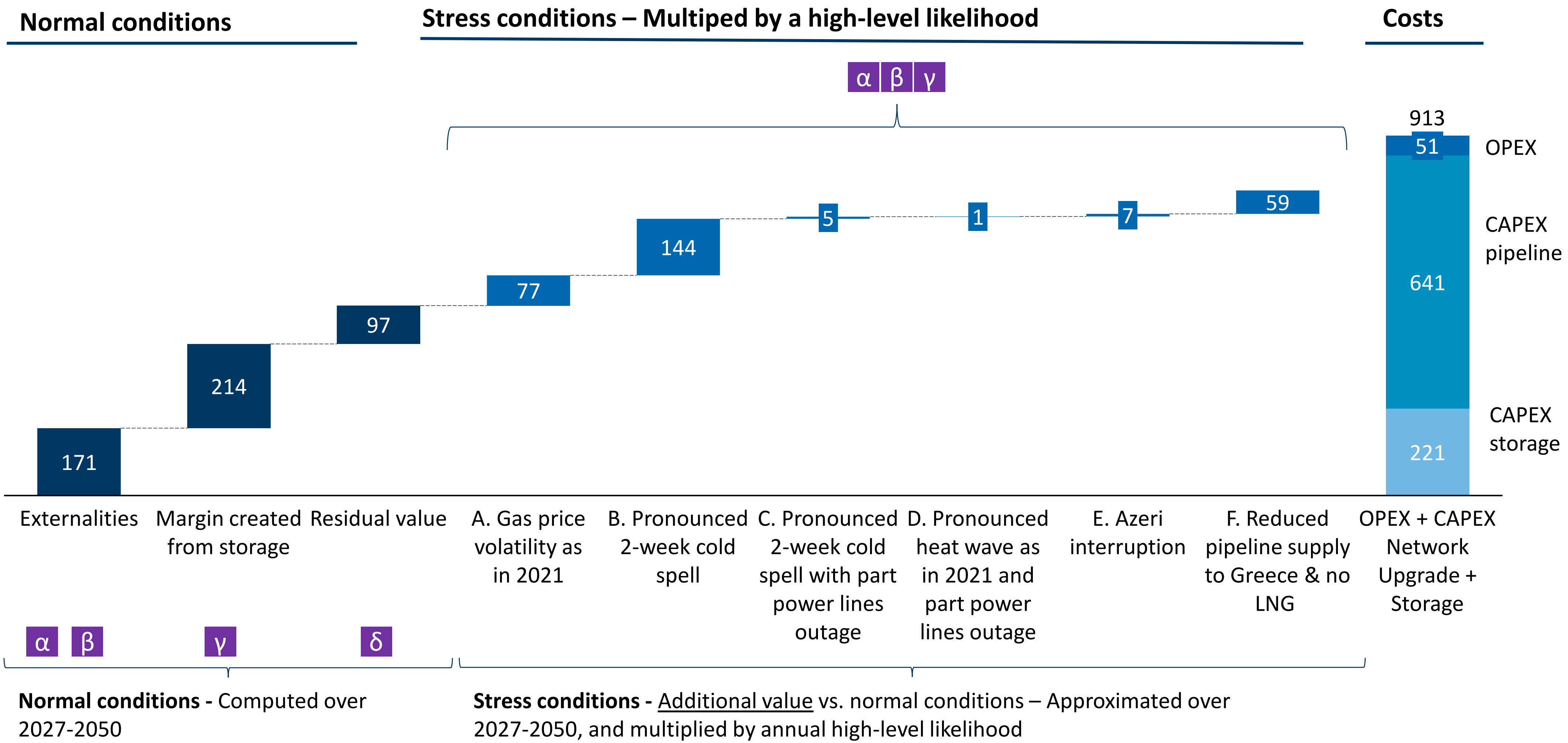
Stress cases "A" to "D" were constructed based on historical precedents, and stress cases "E" and "F" based on RAE's 2020 National Risk Assessment Study

Description of stress tests and associated high-level likelihood of occurring

Stress scenario	Storyline	High-level annual likelihood	Source of likelihood estimate
A Gas price volatility as in 2021	European gas prices experience unusually high volatility, fuelled by energy transition uncertainty.	~10%	2 main events had a significant impact on gas prices volatility over the past 20 years: Fukushima in 2011 and the recent gas price spike in 2021: we assume price spikes are **a one in ten year event = 10%.**
B Pronounced pan-European 2-week cold spell	A two week cold spell event is observed in February.	23%	**ENTSOE** calculates that, since 1981, 23.5% of years have been cold years. We assume similar occurrence in the future and adjust from 23.5% to 23% to account for stress scenario C which is also built on a cold year.
C Pronounced pan-European 2-week cold spell & part power line outage	Same as scenario "B" but together with a power infrastructure outage.	0.5%	We rely on the same weather likelihood as in stress scenario B (23.5%). We multiply this figure by an estimate of the likelihood of power outage (2%) derived from historic data on power interconnection unavailability. **23.5%*2%=0.5%**
D Pronounced heat wave as in 2021 & part power lines outage	A two week heatwave is observed in June/July in line with 2021 events in Greece together with limited availability of wind capacity.	1%	ENTSOE calculates that, since 1981, 50% of years have been warm years. We assume similar occurrence in the future. We multiply this figure by the estimate of likelihood power interconnections unavailability **as in scenario "C"**. **High-level likelihood = 50% * 2% = 1%.**
E Azeri interruption	Azeri transit (TANAP) is interrupted leading also to a full curtailment at Kipi. This scenario is based on Γ2b scenario from RAE 2020 National Risk Assessment Study.	5%	RAE's Scenario Γ2b is similar to Scenario E, but scenario Γ2b is more extreme as it assumes additionally a partial unavailability of LNG imports. We therefore **use scenario Γ2b's probability (5%)** as lower bound for scenario E's high-level likelihood.
F Reduced pipeline supply to GR & no LNG	Pipeline import capacity is significantly reduced in Greece, reflecting severe network outages. This scenario is based on B5b scenario from RAE 2020 National Risk Assessment Study.	2%	RAE's Scenario B5b is similar to Scenario F, but scenario B5b is more extreme as it assumes outages lasting a full winter (6 months duration), while scenario F only assumes an outage for 1 peak month. We therefore **use scenario B5b's probability (2%)** as lower bound for scenario F's high-level likelihood.

In the Full Investment, margin created from storage and externalities in normal conditions bring more than half of the measured benefits

Welfare benefits and costs of the Full Investment in Greece – Discounted values in million EUR_{2021}

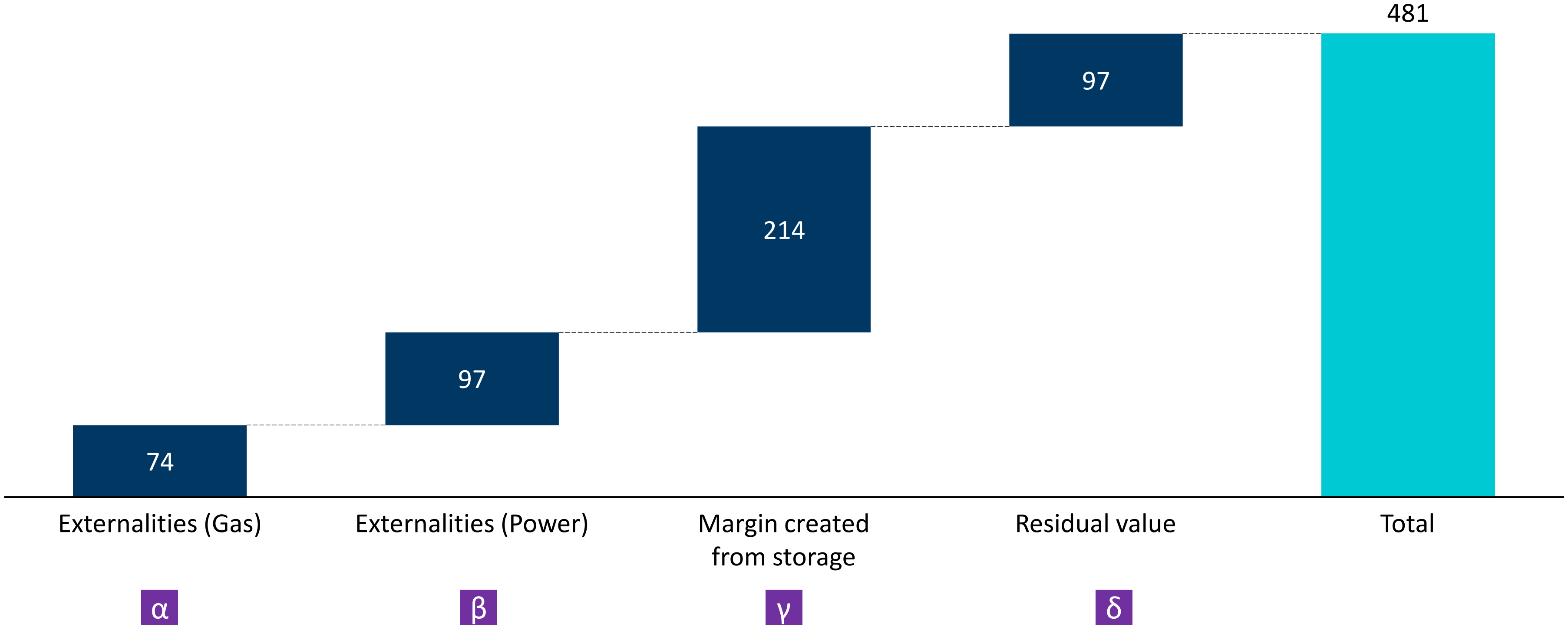


1) Stress case benefits are calculated and compared to normal conditions benefits to present here only the additional welfare creation in the stress case.
2) We have estimated annual stress case results by assuming that the values computed for 2027 with Plexos would decrease linearly to zero by 2050. 2027 could be expected to be most impactful year due to the generally declining role of gas imports over time.
3) We assume that the OPEX of DESFA's pipelines pre and post Investment are the same because volumes flown are very similar: only storage OPEX have been included them in this analysis as extra costs.
4) The realisation of the Investment could also bring non-monetised benefits as discussed in Section 1 of this deck.

In the Full Investment, total welfare benefit is 481m EUR over 2027-2050 under normal conditions

Externalities and private benefits in Greece – Full Investment - 2027 to 2050 – Discounted values in EUR_{2021}

- Values discounted to 2021, using an annual discount rate of 4% (Recommended value of ENTSOG CBA Methodology).
- The benefit in gas and power is calculated as the delta of the wholesale price pre and post investment multiplied by the demand in both segments separately.
- Based on yearly independent modelling runs from 2027 to 2050.



Notes:
*Conservatively, the surplus linked to a variation in quantities of **power** is not included here, only surplus linked to a variation in prices is accounted for at this stage, taking into account the minimum demand volume.*

In the Full Investment, the stress cases show that externalities and storage margins both contribute to Security of Supply benefits

Summary of stress conditions results – 750 EUR m network upgrade – Additional welfare benefits multiplied by high-level likelihood – EUR_{2021} m

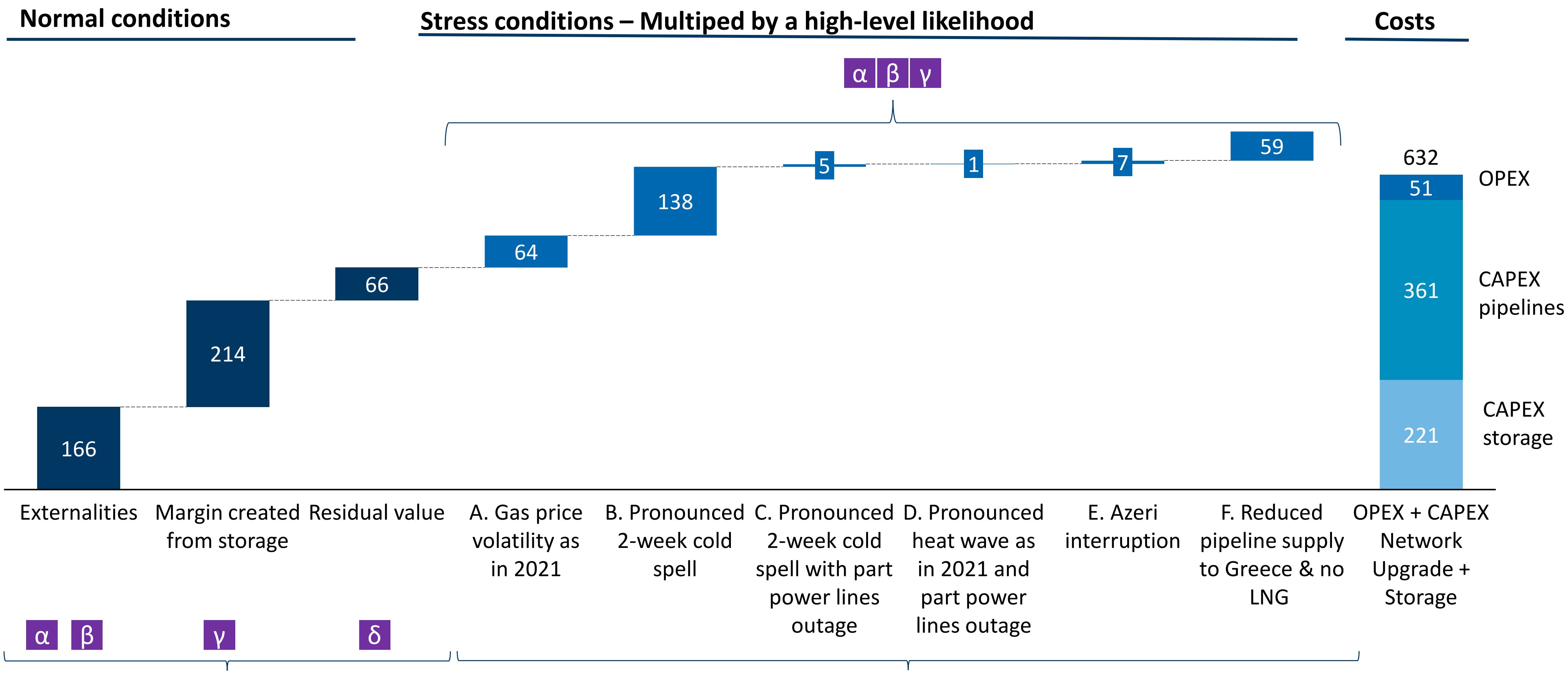
Stress conditions	α Gas externalities	α Avoided gas shortages	β Power externalities	γ Margin created by storage	Total
A. Gas price volatility as in 2021	10		22	46	**77**
B. Pronounced pan-European 2-week cold spell	15		26	103	**144**
C. Pronounced pan-European 2-week cold spell & part power line outage	1		2	2	**5**
D. Pronounced heat wave as in 2021 & part power lines outage	0		0	0	**1**
E. Azeri interruption	0		2	5	**7**
F. Reduced pipeline supply to Greece & no LNG	7	45	7	1	**59**
	∑ = 136			∑ = 157	**∑ = 293**

Notes on computation:

1) Stress case benefits are calculated and compared to normal conditions benefits to present here only the additional welfare creation in the stress case. We assume these additional benefits are realized in the middle of the year.
2) We have estimated annual stress case results by assuming that the values computed for 2027 with Plexos would decrease linearly to zero by 2050. 2027 could be expected to be most impactful year due to the generally declining role of gas imports over time. This estimation may however be conservative in terms of benefits given the expected peak gas consumption in Greece in the early 2030s.

In the Partial Investment, margin created from storage and externalities in normal conditions bring more than half of the measured benefits

Welfare benefits and costs of the Partial Investment in Greece – Discounted values in million EUR_{2021}



Normal conditions - Computed over 2027-2050

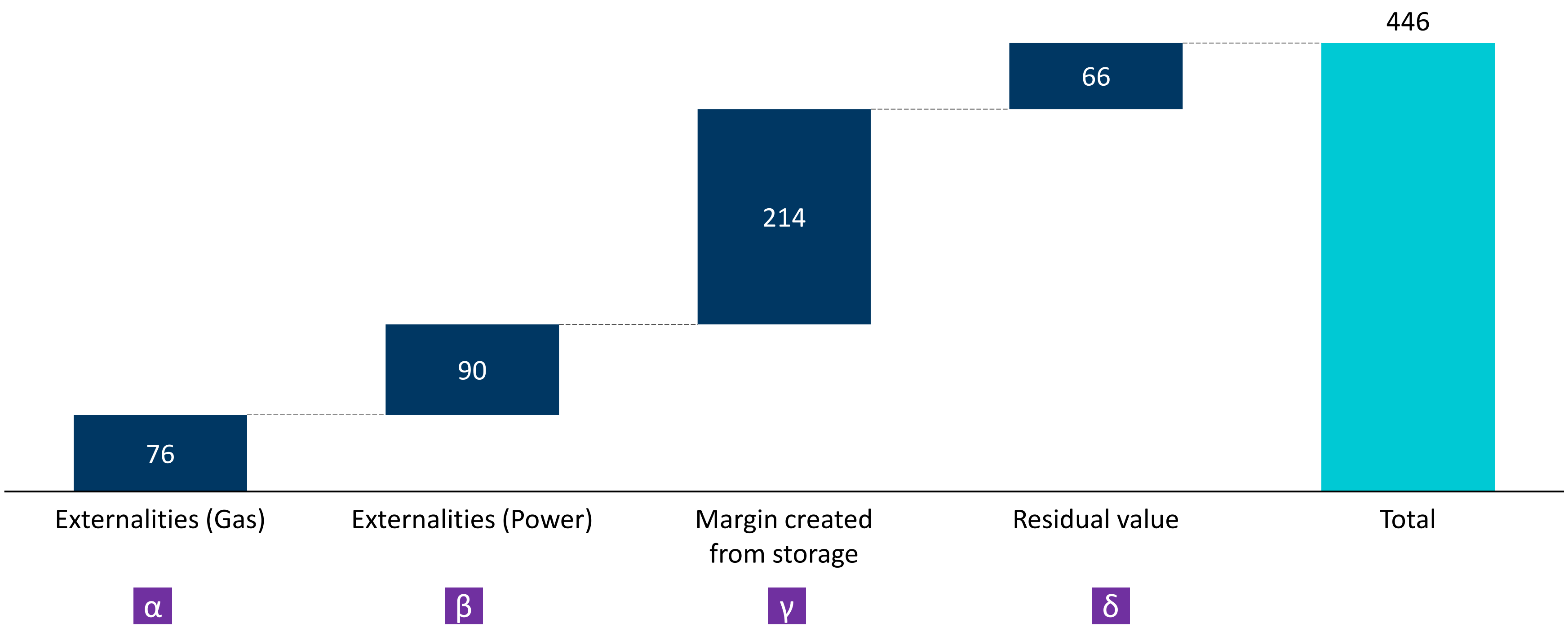
Stress conditions - Additional value vs. normal conditions – Approximated over 2027-2050, and multiplied by annual high-level likelihood

1) Stress case benefits are calculated and compared to normal conditions benefits to present here only the additional welfare creation in the stress case.
2) We have estimated annual stress case results by assuming that the values computed for 2027 with Plexos would decrease linearly to zero by 2050. 2027 could be expected to be most impactful year due to the generally declining role of gas imports over time.
3) We assume that the OPEX of DESFA's pipelines pre and post Investment are the same because volumes flown are very similar: only storage OPEX have been included them in this analysis as extra costs.
4) The realisation of the Investment could also bring non-monetised benefits as discussed in Section 1 of this deck.

In the Partial Investment, total welfare benefit is 446m EUR over 2027-2050 under normal conditions

Externalities and private benefits in Greece – Partial Investment - 2027 to 2050 – Discounted values in EUR_{2021}

- Values discounted to 2021, using an annual discount rate of 4% (Recommended value of ENTSOG CBA Methodology).
- The benefit in gas and power is calculated as the delta of the wholesale price pre and post investment multiplied by the demand in both segments separately.
- Based on yearly independent modelling runs from 2027 to 2050.



Notes:
*Conservatively, the surplus linked to a variation in quantities of **power** is not included here, only surplus linked to a variation in prices is accounted for at this stage, taking into account the minimum demand volume.*

In the Partial Investment, the stress cases show that externalities and storage margins both contribute to Security of Supply benefits

Summary of stress conditions results – 422 EUR m network upgrade – Additional welfare benefits multiplied by high-level likelihood – EUR_{2021} m

Stress conditions	α Gas externalities	α Avoided gas shortages	β Power externalities	γ Margin created by storage	Total
A. Gas price volatility as in 2021	6		14	45	**64**
B. Pronounced pan-European 2-week cold spell	14		22	101	**138**
C. Pronounced pan-European 2-week cold spell & part power line outage	1		2	2	**5**
D. Pronounced heat wave as in 2021 & part power lines outage	0		0	0	**1**
E. Azeri interruption	0		2	4	**7**
F. Reduced pipeline supply to Greece & no LNG	7	45	6	1	**59**
	∑ = 121 (α + β)			∑ = 153	**∑ = 274**

Notes on computation:

1) Stress case benefits are calculated and compared to normal conditions benefits to present here only the additional welfare creation in the stress case. We assume these additional benefits are realized in the middle of the year.
2) We have estimated annual stress case results by assuming that the values computed for 2027 with Plexos would decrease linearly to zero by 2050. 2027 is generally expected to be most impactful year due to the generally declining role of gas imports over time. This estimation may however be conservative in terms of benefits given the expected peak gas consumption in Greece in the early 2030s.

1. Context

FTI Consulting was mandated by DESFA to quantify the net welfare benefits in Greece of building the South Kavala storage based on a simulation of future gas and power markets from 2027 to 2050

Section summary

A

Mandate

DESFA asked FTI Consulting to quantify the net welfare benefits in Greece of building an Underground Gas Storage (UGS) facility at South Kavala and related network upgrades:

- South Kavala storage will have a working gas volume of 6,360 GWh.
- The network upgrades cover eight pipelines from Kipi to Patima which have between 60 to 245 GWh/day of current capacity.

B

Approach

i. We quantified the net welfare benefits following ENTSOG's Cost Benefit Analysis (CBA) methodological guidelines, estimating:
   - The impact of the storage and related network upgrades (the Investment) on gas and power wholesale prices, and
   - The storage margin created for storage operator and storage users.

   In addition, we note that the realisation of the Investment could also bring non-monetised benefits.

i. We simulated the gas and power markets, from commissioning date in 2027 to 2050, with and without the Investment to quantify the Investment's welfare creation.

ii. Gas regulators place a value on security of supply, adopting a risk-adverse position.

iii. We therefore quantified welfare creation in a central case reflecting normal conditions as well as in six stress cases to measure the security of supply value on top of these normal conditions.

C

DESFA's Investment scenarios

i. We have been instructed by DESFA to consider a “small” and a “large” Investment scenarios of 422 M€ and 750 M€ CAPEX respectively.

ii. DESFA defined the Greek network configurations in both Investment scenarios, which included other expected infrastructures to be realized in line with its Ten-Year Development Plan.

DESFA asked FTI Consulting to quantify the net welfare benefits in Greece of building a UGS facility at South Kavala and related network upgrades

Overview of Investment required for an Underground Gas Storage (UGS) at South Kavala

Storage

South Kavala storage creation:

- Working Gas Volume = 530 mil. m3 (or 6,360 GWh)

Network Upgrades

The network upgrades concern the following eight pipelines from Kipi to Patima:

1. Kipi-Komotini
2. Komotini-Kavala
3. Kavala-Karperi
4. Karperi-Drymos
5. Drymos-Nea Messimvria
6. Nea Messimvria-Ampelia
7. Ampelia-Livadia
8. Livadia-Patima

Note: Commissioning dates of both storage and network upgrades are in 01/2027

Source: Entsog and DESFA

Our approach compares (i) welfare benefits created in the gas and power markets by the Investment to (ii) the costs of the Investment

Overview of benefits and costs used in FTI Consulting's economic assessment of the Investment

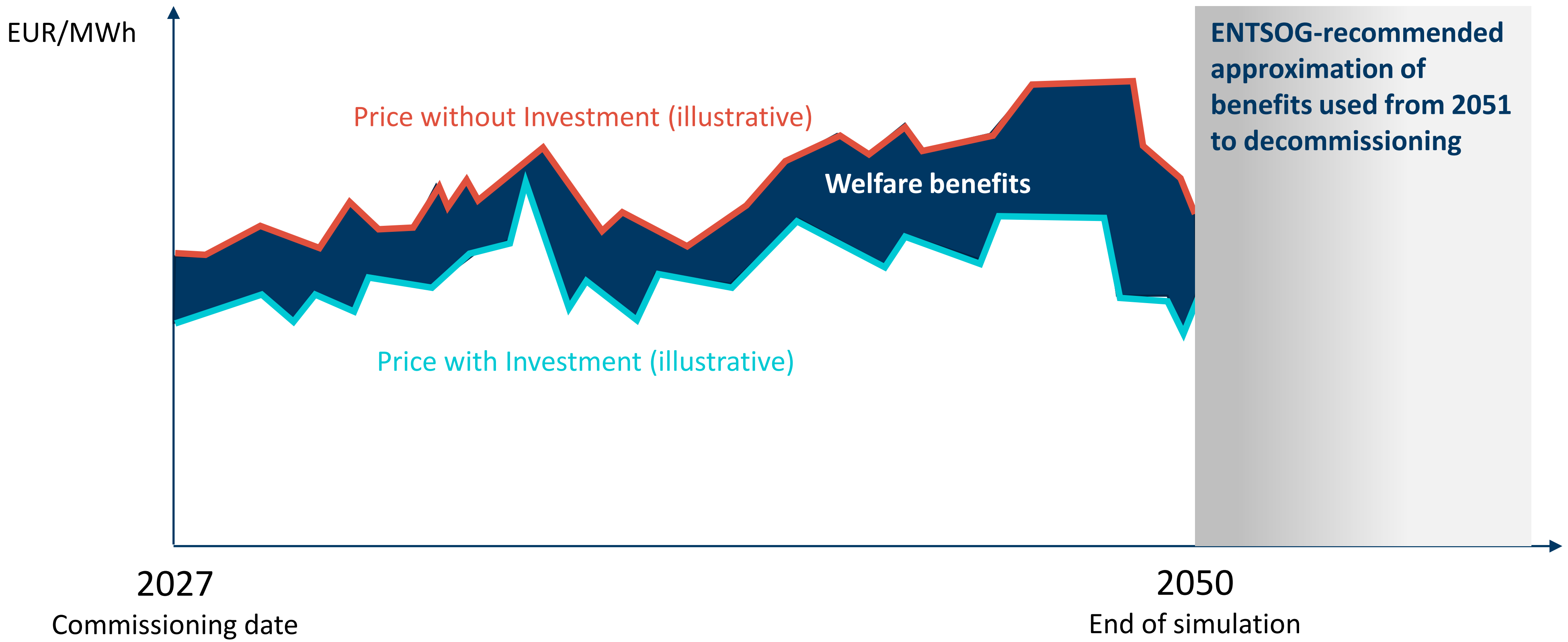
	Benefits	Costs

Monetized	▪ Externalities
	  ▪ Impact on gas wholesale prices.
	  ▪ Impact on power wholesale prices.
	▪ Storage margin created for storage operator and storage users.
		▪ Storage
		  ▪ OPEX
		  ▪ CAPEX
		▪ Network upgrade
		  ▪ Extra CAPEX
		  ▪ Extra OPEX

Non-monetized	The realisation of the Investment could also theoretically produce the following benefits that we have not been monetized in this study:
	  ▪ Reduce the volatility of gas prices in Greece, which would in turn reduce the premium charged by producers and traders to consumers for reducing price risks. As part of this premium is charged by non-EU exporters of gas, the reduction of the premium would benefit EU players; and/or
	  ▪ Reinforce DESFA's grid and support the feasibility of other investments which require additional network capacity, e.g. Alexandroupolis' LNG terminal, TAP's expansion, etc.; and/or
	  ▪ Brings more liquidity to the wholesale gas market, increasing the quality of the price signals.
		N/A

We simulated the gas and power markets from commissioning date to 2050 with and without the Investment to quantify the Investment's welfare creation

Illustration of quantification of welfare benefits: wholesale market externalities



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We quantified the increase in Greek welfare as a result of the Investment following ENTSOG's CBA methodological guidelines

Overview of approach used to quantify the welfare impact of the Investment, through its main monetized benefits

ENTSOG

ENTSOG:

Recommended Methodology for CBA for Gas Infrastructure Projects (2018, 2nd version).

Approach developed for gas pipelines, used here as guiding principle.

No specific ENTSOG methodology available to measure value of storage in Energy Transition.

Period	Approach	Metrics used
From 2027 (Expected commissioning); **to 2050** (End of ENTSOG & ENTSOE forecasts).	**Modelling of welfare impacts** of Investment in the power and gas markets across Europe, hour by hour.	α **Greek gas consumers externality** based on wholesale market price change. β **Greek power consumers externality** based on wholesale market price change. γ **Greek storage margin created** for storage operator and users.
2051 to decom-missioning	**Residual value** of Investment until end of technical life of the Investment.	δ **Annual depreciation** of the Investment in Greece, used a measure of benefits (as recommended in ENTSOG CBA Methodology)

Combination

Annual benefits are discounted to decision time (2021) using a 4% annual real social discount rate (Recommended value of ENTSOG CBA Methodology).

Gas regulators place a value on security of supply, adopting a risk-adverse position

Principles supporting value on security of supply

Evidence of value of security of supply in the EU and Greece (examples)

European Gas Directive[1)]

"The security of energy supply is an essential element of public security and is therefore inherently connected to the efficient functioning of the internal market" (Recital 22)

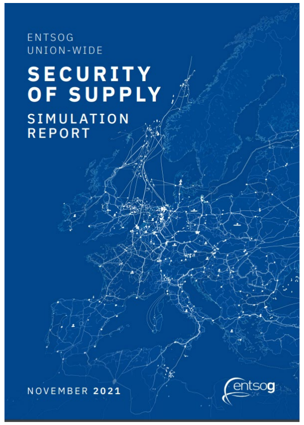
"Member States shall ensure the monitoring of security of supply issues. […]. The competent authorities shall publish, by 31 July each year, a report outlining the findings resulting from the monitoring of those issues, as well as any measures taken or envisaged to address them and shall forward that report to the Commission forthwith." (Article 5)

European Gas Regulation[2)]

"Each Member State or, where a Member State so provides, its competent authority shall ensure that the necessary measures are taken so that in the event of a disruption of the single largest gas infrastructure, the technical capacity of the remaining infrastructure [is able] to satisfy total gas demand of the calculated area during a day of exceptionally high gas demand occurring with a statistical probability of once in 20 years. This shall be done taking into account gas consumption trends, the long-term impact of energy efficiency measures and the utilisation rates of existing infrastructure." (Article 5)

Regular reporting

National Risk Assessment Report



Point of view of Risk aversion

Regulation does place a value on security of supply, mandating certain costs to be incurred to ensure the security of gas supplies.

This defines decision-makers as risk adverse, as security of supply is notably defined as resilience to extreme events.

1) Directive 2009/73/EC of The European Parliament and of the Council of 13 July 2009concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC
2) Regulation (EU) 2017/1938 of the European Parliament and of the Council of 25 October 2017 concerning measures to safeguard the security of gas supply and repealing Regulation (EU) No 994/2010

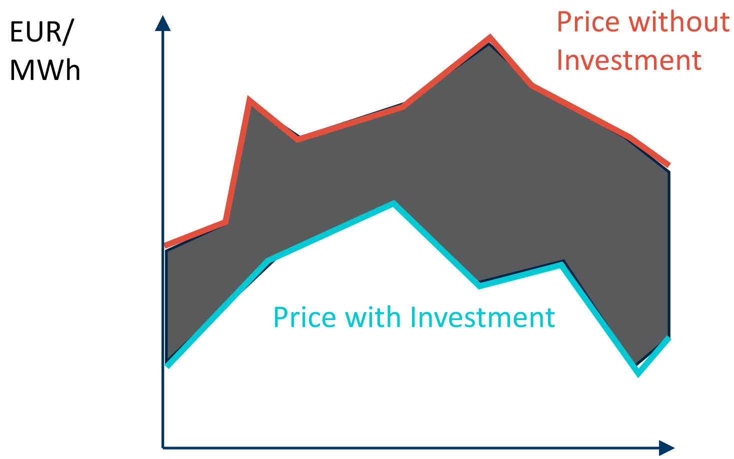
In line with regulatory approaches, we quantified the security of supply value brought by the Investment using extreme events

Approach to capture value put on security of supply

Illustration of normal system conditions

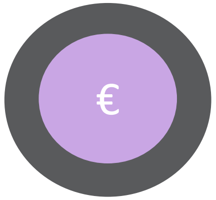
Welfare benefits under
<u>normal conditions</u>

Illustration of stress system conditions



Welfare benefits under
<u>stress conditions</u>

Total welfare benefits



Normal conditions & (ΔStress vs. Normal)

We relied on a central case reflecting normal conditions, and six stress cases to measure the security of supply value on top of these normal conditions

Principles of modelling for central case and security of supply cases

Central case – Normal conditions

- Full availability of import pipeline and LNG terminals.
- Full availability of import power lines and standard availability of power plants.
- Likely weather condition: based on most likely weather conditions based on past 34 years, as measured in the TYNDP.
- Historic gas supply cost profile from the last decade replicated in the future.

Expected to measure the central case impact of the Investment in **normal system conditions**

Security of supply cases – Stress conditions

Combinations of stress conditions on gas and power system:

- Gas supply interruptions (TANAP, LNG…).
- Partial gas infrastructure unavailability (interconnections, DESFA system…).
- Partial power infrastructure unavailability (interconnections, power plants…).
- Extreme climatic conditions (heat wave, low wind…).
- Upper bound of gas market price dynamics (high prices, high volatility…).

Expected to measure additional impacts of the Investment in **stress system conditions**

Note: TYNDP always refers to Ten-Year Network Development Plan 2020 (latest available) published by ENTSOE and ENTSOG. Next TYNDP expected in 2022.

We have been instructed by DESFA to consider two technically feasible Investment scenarios, with different scopes for the network upgrade

Overview of Investment scenarios

Partial Investment scenario, with 422 M€ network upgrade

"Small" network upgrade: 422 m€ CAPEX

Full Investment scenario, with 750 M€ network upgrade

"Large" network upgrade: 750 m€ CAPEX

Same investment considered in the UGS at South Kavala in both Investment scenarios

Source: ENTSOG and DESFA

Note: A network upgrade more limited than the Partial Investment scenario was also envisaged by DESFA, but such limited upgrade would have required to significantly constrain the storage use, and therefore was not retained as appropriate by DESFA.

FTI CONSULTING · COMPASS LEXECON · ENERGY

DESFA defined network configurations in both Investment scenarios, and other infrastructures expected realised, in line with its Ten-Year Development Plan

Base and Investment cases considered to measure the impact of South Kavala UGS

	Base Case	Investment Cases
South Kavala UGS	*Not operational*	**Operational – CAPEX 272 M€ and OPEX 0.3 €/MWh**

DESFA's network

GWh/Day **HP Pipelines**	Current pipelines capacity: Max Daily Flow	Current pipelines capacity: Max Daily Flow Back	Investment – CAPEX 422 M€: Max Daily Flow	Investment – CAPEX 422 M€: Max Daily Flow Back	Investment – CAPEX 750 M€: Max Daily Flow	Investment – CAPEX 750 M€: Max Daily Flow Back
Kipi → Komotini	60	63.6	60	172	268	267
Komotini → Kavala	60	63.6	60	172	268	267
Kavala → Karperi	60	63.6	168	148	268	267
Karperi → Drymos	183.6	183.6	292	268	392	387
Drymos → Nea Messimvria	183.6	244.2	292	268	392	387
Nea Messimvria → Ampelia	238.8	244.2	348	245	448	373
Ampelia → Livadia	238.8	244.2	348	245	448	373
Livadia → Patima	238.8	244.2	348	245	448	373

No significant extra OPEX compared to Base Case, given similar flows

Import infrastructures

All existing and projected infrastructures operational (in line with DESFA's Ten Year Development Plan)

Pipeline imports

- **Azerbaijan** through Nea Messimvria
- **Turkey** through Kipi
- **Russia** through Karperi

LNG import terminals

- Revithoussa
- Dioriga
- Alexandroupolis

Source: DESFA

2. Simulation tool

The 2027-2050 simulation of gas and power prices relies on a pan-European Plexos model, using principally ENTSOG & ENTSOE's TYNDP data

Section summary

A Plexos' market simulation tool

i. We use a Plexos gas & power model built for DESFA. Plexos software is used by ENTSOG and ENTSOE for TYNDP.
ii. Our model accounts for all gas and power infrastructure, supply and demand across Europe.
iii. We treat the Greek gas system with more granularity than the rest of Europe.

B Main input hypotheses

i. Gas:
  - For **demand** inputs, we rely primarily on DESFA's Development Study and ENTSOG's TYNDP data.
  - For **supply** inputs, sources differ depending on indigenous production and extra EU imports.
  - We use DESFA's current and forecasted-for-the-Investment gas **transport** capacity in Greece, and ENTSOG's current and TYNDP-forecasted transport data capacity for Europe.

ii. Power:
  - For **demand** inputs, we rely primarily on ENTSOE's TYNDP data.
  - For **supply inputs**, our model relies on a dispatch optimisation applied to long term capacity scenarios.
  - We created a **transmission** database referencing historic Net Transfer Capacities and future interconnection projects based on ENTSO-E data and our own expertise

Plexos platform is used by ENTSOG and ENTSOE for the TYNDP

Main features of the gas & power integrated model built for DESFA's CBA

Plexos model

- Mixed Integer Linear Programming model.
- Platform used by ENTSOG & ENTSOE for TYNDP.
- Modelling from 2027 to 2050.
- Regular backcast of the power leg of the model., which has been used in major energy projects in Europe by FTI-CL energy.

Hourly modelling run

- Yearly independent modelling runs from 2027 to 2050.
- 8760 hours * 24 years = 210,240 optimisations, run together on a weekly basis.

← Return to News

ENTSOG chooses PLEXOS to model the European gas system

Note: When we model energy markets on Plexos, we face a trade off between accuracy of results and modelling running time, which led us to select a weekly grouping of hourly optimisations.
FTI-CL Energy = Energy team of FTI Consulting and its wholly owned subsidiary Compass Lexecon

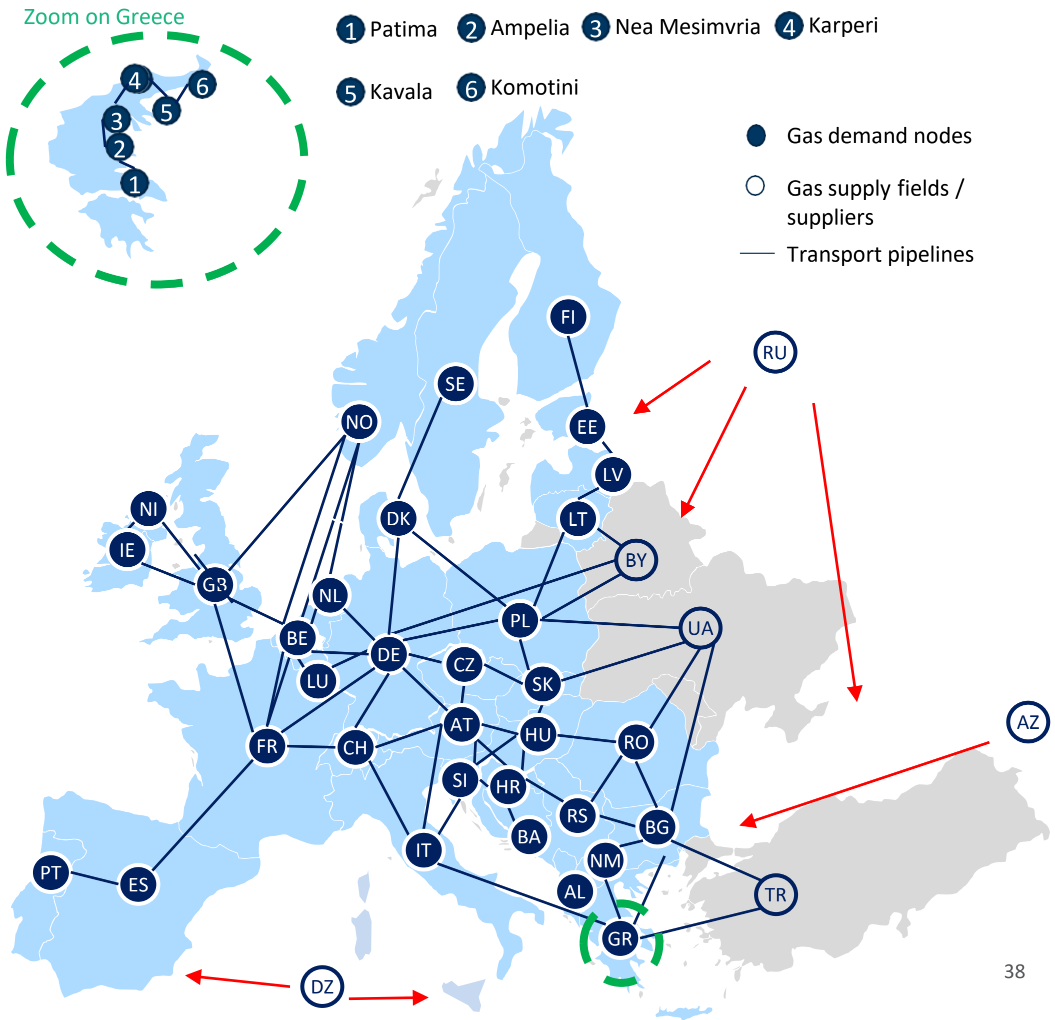
The model accounts for all gas infrastructure, supply and demand across Europe, with additional granularity for the Greek gas system

Focus on gas

Overview

- FTI-CL Energy's gas market model covers the EU-27 countries as well as the UK, Switzerland, Norway and the Balkans.
- The model considers supply stacks of European indigenous gas fields, as well as stacks of Russia, Azerbaijan and Algeria's gas fields.
- The model determines endogenously:
  - The hourly marginal price ensuring demand is served by supply
  - Hourly flows at every gas node across Europe
  - Gas demand for power generation as a result of the gas and power optimisation process
- The model considers cross-border transport constraints across Europe.
- The model also considers Power2Gas and battery capacities as required for power security of supply.

Geographic scope



Source: FTI-CL Energy

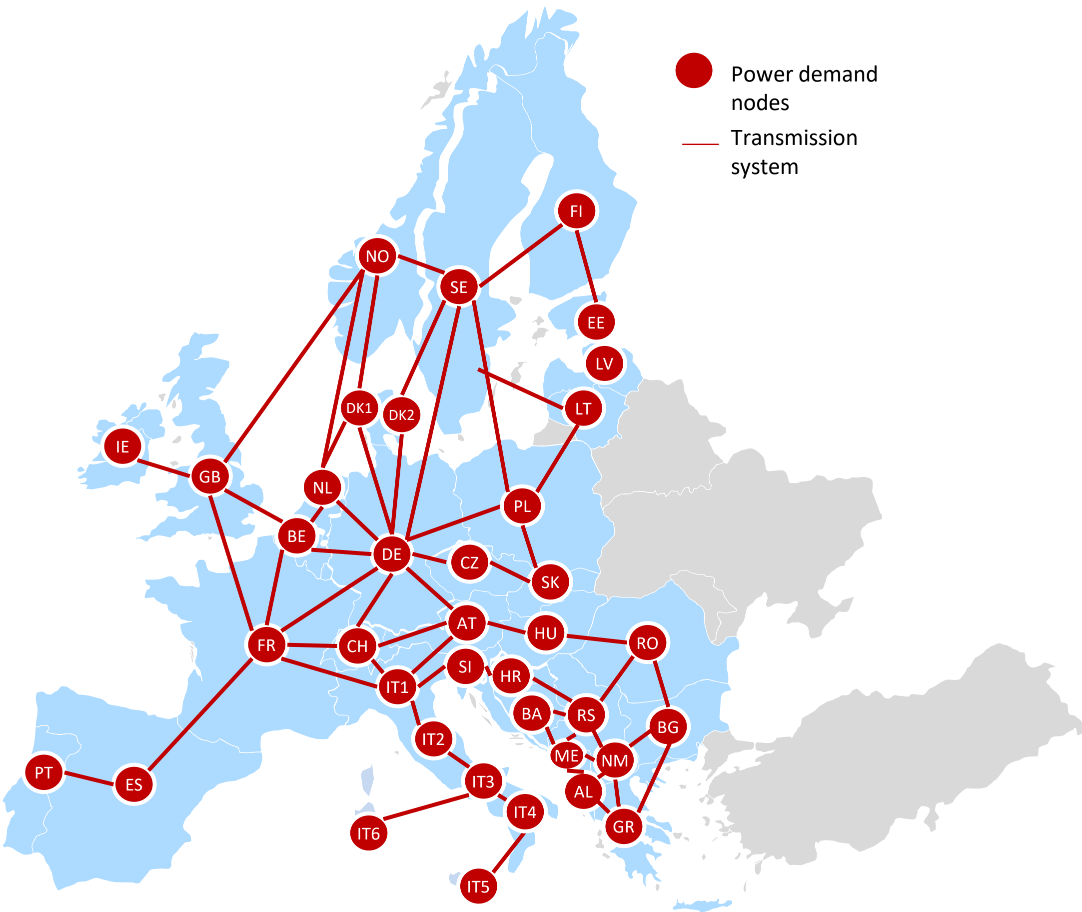
The model accounts for all power infrastructure, supply and demand across Europe

Focus on power

Overview

- FTI-CL Energy's power market model covers the EU-27 countries as well as the UK, Switzerland, Norway and the Balkans.
- FTI-CL Energy's power market model constructs supply in each price zone based on aggregated power plants:
  - Zonal prices are determined as the marginal value of energy accounting for generators' bidding strategies.
  - The model takes into account cross-border transmission and interconnectors, and unit-commitment plant constraints across Europe.
  - The model also provides hourly prices and flows at every power node across Europe.
- FTI-CL Energy's power market model uses ENTSOE Pan-European Climate Database for hourly time series for wind and solar production, hydro inflows and demand pattern.

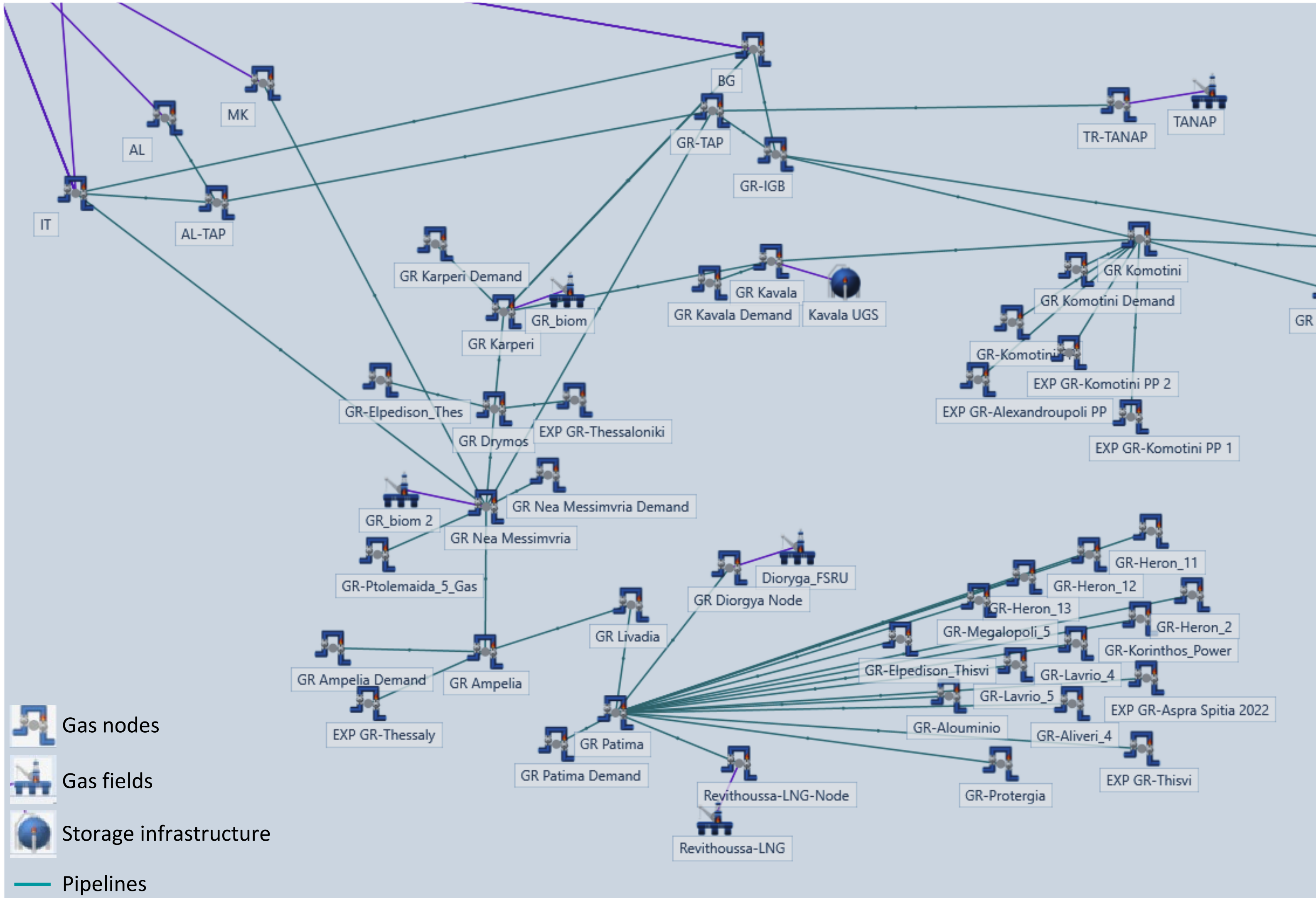
Geographic scope



Source: FTI-CL Energy

Our integrated gas & power model considers a granular mapping of Greece

Map of Greece and neighbouring countries gas and power main infrastructures – From Plexos model



Comments:

- All import/export infrastructure specifically modelled
- All CCGTs individually modelled

Source: Plexos and FTI-CL

Our model relies primarily on ENTSOG & ENTSOE data, with specific complements from DESFA for Greece

Main sources used

	Demand	Supply	Infrastructure
Gas	1 ▪ **Annual demand** DESFA's Development Study and ENTSOG's TYNDP. ▪ **Daily demand profile** University College Cork Plexos' gas model ("UCC").	2 **Volume and prices** ▪ Volume and cost of indigenous gas supply in Europe by Rystad. ▪ Russian export prices based on expected strategy to be competitive in major European markets vs. LNG. ▪ LNG price based on IEA and ICIS data.	3 **Pipelines' capacity** ▪ DESFA's Development Study 2021-2030; and ▪ ENTSOG TYNDP 2020 Low Scenario (includes existing infrastructure and post-FID infrastructure).
Power	4 ▪ **Annual demand** ▪ National Energy and Climate Plan (NECP) demand scenarios. ▪ EU Commission Energy Roadmap 2050. ▪ **Daily demand profile** ▪ ENTSOE'S TYNDP data.	5 **Long term capacity scenarios derived from:** ▪ Dynamic long-term optimization; combined with ▪ Long term capacity scenarios based on energy policies and regulation. **Short term capacity scenarios derived from:** ▪ Hourly supply in each price zone based on aggregated plants constraints.	6 **Transmission' lines capacity** ▪ Based on the ENTSO-E and FTI-CL Energy's expertise.

For Gas Demand inputs, we rely primarily on DESFA's Development Study and ENTSOG's TYNDP data

Gas demand - Sources and assumptions

	Annual demand	Daily demand profiles

Greece	▪ **DESFA's Development Study 2021-2030.**
	▪ **ENTSOG'S TYNDP data** (2040 Global Ambition scenario).
	  ▪ Interpolation for each year between each five year data point.
	  ▪ Similar growth rate from 2040-2050 than from 2030-2040.
	  ▪ Demand is split at each demand point proportionate to exit capacity.
		▪ Daily profile taken from the **UCC** which provides daily profiles for each country 2025, 2030 and 2040.

Albania	▪ Grant Thornton's average demand for 2021-2030; growth rate assumed to continue up to 2050.	▪ Daily profile from **UCC**.
Rest of Europe	▪ **ENTSOG'S TYNDP data** (National Trends scenario for 2025; Global Ambition scenario for 2030 and 2040). ▪ Interpolation for each year between each five year data point.	▪ Daily profile from **UCC**.

For Gas Supply inputs, sources differ depending on indigenous production and imports

Gas supply - Sources and assumptions

Europe indigenous production

Fossil Methane

- Current and forecasted volume and production cost of each gas field taken from **Rystad for GB, IT, DE, RO, NO, NL** and other EU countries

Biomethane

- Eurostat for 2020 data.
- **ENTSOG'S TYNDP** (Global Ambition scenario).
- Daily production profile taken from UCC.
- Cost expected to be **covered by out of market payment** (i.e. bid at 0 EUR/MWh).

Hydrogen

- ENTSOG'S TYNDP data: median scenario between ENTSOE TYNDP 2020 Global Ambition and Distributed Generation scenarios.
- Cost expected to be **covered by out of market payment** (i.e. bid at 0 EUR/MWh).
- H2 production as mixture of baseload and flexible production.

Pipeline imports to Europe

Contracted volumes

- Contracted volumes from **Cedigaz** Long-Term contracts database for RU, DZ, AZ and TR.
- Price for DZ and AZ based on estimates of **Long-Run Marginal Cost** from the IEA.
- **Price for RU** based on expected strategy to be competitive in major European markets vs. LNG imports (**85% of LNG prices**).
- Price for TR based on (and more expensive than) RU's prices.

Uncontracted volumes

- **RU:** S&P Platts Russian production / exports forecasts.
- **DZ:** CREG gas exports forecast.

LNG imports to Europe

Volumes

- LNG terminals capacity (existing or planned) in all Europe as per Gas Infrastructure Europe data.

Prices

- Annual price computed as average of (1) variable cost of US liquefaction and of (2) a standard Asian oil-based price formula for annual price, from IEA
- Daily price computed using average daily prices for East Asian spot LNG over 2013-2021, from ICIS, applied to annual price

We use DESFA’s current and Investment gas transport capacity in Greece and ENTSOG’s current and forecasted transport data capacity for Europe

Gas infrastructure - Sources and snapshot

Transport pipelines in 2027 and 2050

Greece

Source: DESFA

	Current pipelines capacity		Investment – CAPEX 422 M€		Investment – CAPEX 750 M€	
HP Pipelines	**Max Daily Flow**	**Max Daily Flow Back**	**Max Daily Flow**	**Max Daily Flow Back**	**Max Daily Flow**	**Max Daily Flow Back**
Kipi → Komotini	60	63.6	60	172	268	267
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Livadia → Patima	238.8	244.2	348	245	448	373

Rest of Europe

Source: ENTSOG TYNDP Low Scenario (existing and approved FID infrastructures)

Note: 70 pipelines with a daily max capacity of less than 300 GWh/day not represented here.

Year	2027	2050
RU-DE	3,533	3,533
DE-CZ	2,526	2,526
RU-SK	2,278	2,278
SK-AT	1,570	1,570
NO-GB	1,499	1,499
UA-BG	1,472	1,472
NL-BE	1,437	1,437
CZ-DE	1,414	1,414
NO-DE	1,247	1,247
CZ-SK	1,247	1,247
DZ-IT	1,150	1,150
AT-IT	1,149	1,149
RU-BY	1,024	1,024
NL-DE	977	657

Year	2027	2050
NO-NL	964	964
BY-DE	932	932
BE-FR	870	870
BE-GB	803	803
DZ-ES	732	732
GB-BE	652	652
CH-IT	635	635
DE-FR	620	620
FR-DE	620	620
NO-FR	590	590
AT-DE	548	548
UA-HU	517	517
DE-NL	503	503
NL-GB	494	494

Year	2027	2050
NO-BE	488	488
BY-PL	452	452
IT-CH	441	441
LY-IT	440	440
DE-BE	439	439
SK-UA	416	416
BG-RS	415	415
SK-CZ	400	400
GB-IE	387	387
DE-AT	383	383
UA-RO	371	371
BG-BG	344	344
BY-LT	325	325
DE-CH	318	318

For Power Demand inputs, we rely primarily on ENTSOE’s TYNDP data, which includes EU net zero by 2050, and high electric renewable penetration

Power demand – Sources and assumptions

Annual demand

Greece

- **National Energy and Climate Plan** (NECP) demand scenarios (from 2021 to 2030);
- European Commission Energy Roadmap 2050 (from 2030 to 2050).

Rest of Europe

- FTI analysis and benchmark based on the **European Commission Energy Roadmap 2050.**

Daily demand profiles

All countries

- **ENTSOE’S TYNDP data** (National Trends load profile);
- We apply these daily profile to annual total demand through 2050 in all countries.

Our power market model relies on a dispatch optimisation applied to long term capacity scenarios

Power supply - Sources and assumptions

Long term capacity scenarios

Long term capacity scenarios can be derived from two distinct approaches:

- **Dynamic long-term optimisation**: Based on cost reduction assumptions, the capacity mix is optimized to minimise the cost of the system while meeting a number of constraints such as security of supply or CO2 emission reduction target.
- **Long term capacity scenarios based on energy policies and regulation**: Capacity projections are based on national and European energy policies and regulation which would structure the evolution of the capacity mix (coal closure policies, nuclear policies, renewable policies, etc.)

Our modelling approach combines both long-term capacity scenarios based on energy policies and regulation and dynamic long-term optimisation through:

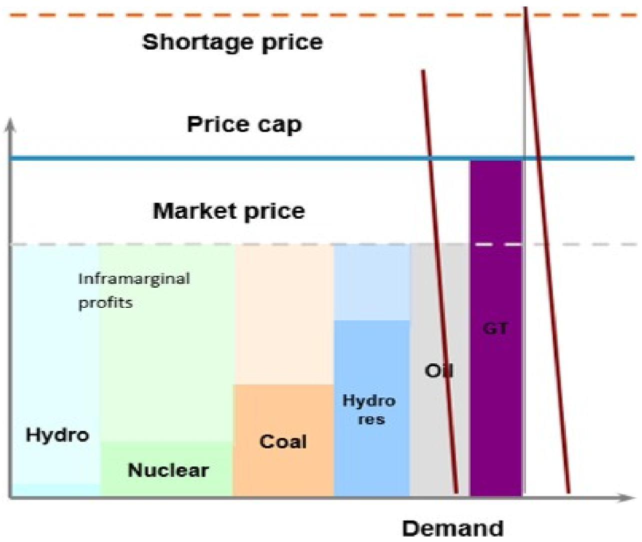
- **National energy and climate plans renewable development** until 2030.
- **Coal and nuclear phase-down plan** through 2050.
- **European emission reduction** to net zero by 2050.
- National **power system reliability** through minimum margin.

Short term dispatch optimization

We constructed hourly supply in each price zone based on aggregated plants unit commitment constraints:

- European power plants database containing technical parameters of all thermal European plants.
- Zonal prices are found as the marginal value of energy accounting for generators' bidding strategies.
- Model takes into account cross-border transmission and interconnectors.

Illustrative example of a supply cost curve



We created a transmission database referencing historic NTCs and future interconnection projects based on the ENTSO-E data and our expertise

Power infrastructure - Sources and snapshot

Transmission lines in 2027 and 2050

Greece and Rest of Europe

Source: ENTSO-E data and FTI-CL Energy.

Note: 43 pipelines with a daily max capacity of less than 840 MW/day not represented here.

Year	2027	2050
AT-DE	7,500	8,500
ES-FR	5,000	9,000
CH-DE	4,600	8,600
DE-FR	4,500	7,000
DE-NL	4,400	6,000
ITN-ITCN	4,400	8,400
FR-ITN	4,350	6,000
ES-PT	4,200	5,800
FR-GB	4,000	7,400
NO-SE	3,595	4,095
DE-DKW	3,500	3,500
BE-NL	3,400	6,400
FI-SE	3,200	6,500
FR-CH	3,200	5,700
ITCA-ITS	2,850	4,850
BE-FR	2,800	4,800
CZ-DE	2,600	4,100

Year	2027	2050
LUG-DE	2,300	2,300
CZ-SK	2,000	3,000
DE-PLI	2,000	4,000
ITCN-ITCS	2,000	6,150
SI-HR	2,000	2,500
ITN-CH	1,910	4,100
HU-SK	1,800	2,800
DKE-SE	1,700	3,100
HU-HR	1,700	1,700
DKW-NO	1,632	3,700
ITCA-ITSIC	1,500	1,500
DE-NO	1,400	1,400
GB-DE	1,400	1,400
GB-DKW	1,400	1,400
GB-NO	1,400	2,800
BG-GR	1,350	3,250
HU-RO	1,300	2,200

Year	2027	2050
IE-NI	1,250	2,900
AT-CH	1,200	1,700
HU-SI	1,200	1,200
ITCS-ME	1,200	1,200
EE-LV	1,100	1,850
RO-BG	1,100	2,300
EE-FI	1,015	2,015
BE-DE	1,000	2,000
DE-DKE	1,000	2,000
GB-BE	1,000	1,000
GB-NL	1,000	1,000
PLE-SK	1,000	1,000
AT-SI	952	2,650
IE-GB	950	950
LT-LV	950	1900
AT-CZ	900	900
MK-GR	850	1300

NTCs: Net Transfer Capacities

3. Methodology for welfare quantification

The Investment brings welfare through wholesale gas and power externalities and private trading benefits

Section summary

A **Quantified welfare benefits in normal conditions**

i. We quantified the increase in Greek welfare as a result of the Investment following ENTSOG's CBA methodological guidelines.

ii. Namely, we quantified:

- The impact on gas wholesale prices.
- The impact on power wholesale prices.
- The storage margin created for storage operator and storage users.

iii. We quantified Greek welfare benefits of the Investment based on modelled gas and power prices in a central normal conditions scenario, comparing results with and without the Investment.

B **Quantified welfare benefits in stress conditions**

i. To capture **security of supply value**, we quantified the Greek welfare benefits based on modelled gas and power prices in stress conditions, comparing results with and without the Investment, and identifying the additional welfare benefits thus produced compared to normal conditions.

From 2027 to 2050, we explicitly model the power and gas markets to assess welfare creation

Overview of approach used to quantify the welfare impact of the Investment, through its main monetized benefits

ENTSOG

ENTSOG:

Recommended Methodology for CBA for Gas Infrastructure Projects (2018, 2nd version).

Approach developed for gas pipelines, used here as guiding principle.

No specific ENTSOG methodology available to measure value of storage in Energy Transition.

Period	Approach	Metrics used
From 2027 (Expected commissioning); **to 2050** (End of ENTSOG & ENTSOE forecasts).	**Modelling of welfare impacts** of Investment in the power and gas markets across Europe, hour by hour.	α **Greek gas consumers externality** based on wholesale market price change. β **Greek power consumers externality** based on wholesale market price change. γ **Greek storage margin created** for storage operator and users.
2051 to decom-missioning	**Residual value** of Investment until end of technical life of the Investment.	δ **Annual depreciation** of the Investment in Greece, used a measure of benefits (as recommended in ENTSOG CBA Methodology)

Focus of this section

Combination

Annual benefits are discounted to decision time (2021) using a 4% annual real social discount rate (Recommended value of ENTSOG CBA Methodology).

Reminder: We relied on a central case reflecting normal conditions, and six stress cases to measure the security of supply value on top of these normal conditions

Principles of modelling for central case and security of supply cases

Central case – Normal conditions

- Full availability of import pipeline and LNG terminals.
- Full availability of import power lines and standard availability of power plants.
- Likely weather condition: based on most likely weather conditions based on past 34 years, as measured in the TYNDP.
- Historic gas supply cost profile from the last decade replicated in the future.

Expected to measure the central case impact of the Investment in **normal system conditions**

Focus of next slides

Security of supply cases – Stress conditions

Combinations of stress conditions on gas and power system:

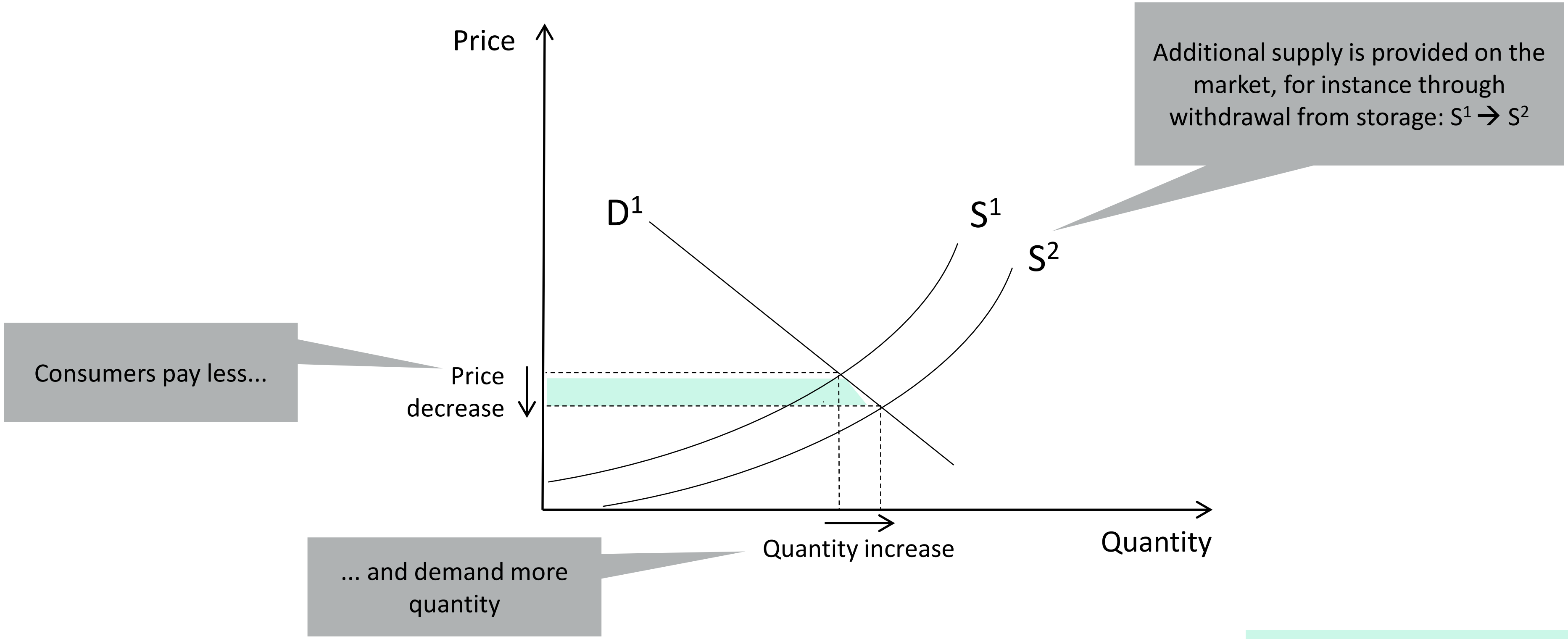
- Gas supply interruptions (TANAP, LNG…).
- Partial gas infrastructure unavailability (interconnections, DESFA system…).
- Partial power infrastructure unavailability (interconnections, power plants…).
- Extreme climatic conditions (heat wave, low wind…).
- Upper bound of gas market price dynamics (high prices, high volatility…).

Expected to measure additional impacts of the Investment in **stress system conditions**

Note: TYNDP always refers to Ten-Year Network Development Plan 2020 (latest available) published by ENTSOE and ENTSOG. Next TYNDP expected in 2022.

The pipeline investment brings welfare through wholesale gas and power market price reduction (externalities)

Focus on a typical externality impact - Illustrative α β



Welfare gain is created for all consumers, as measured in the green area

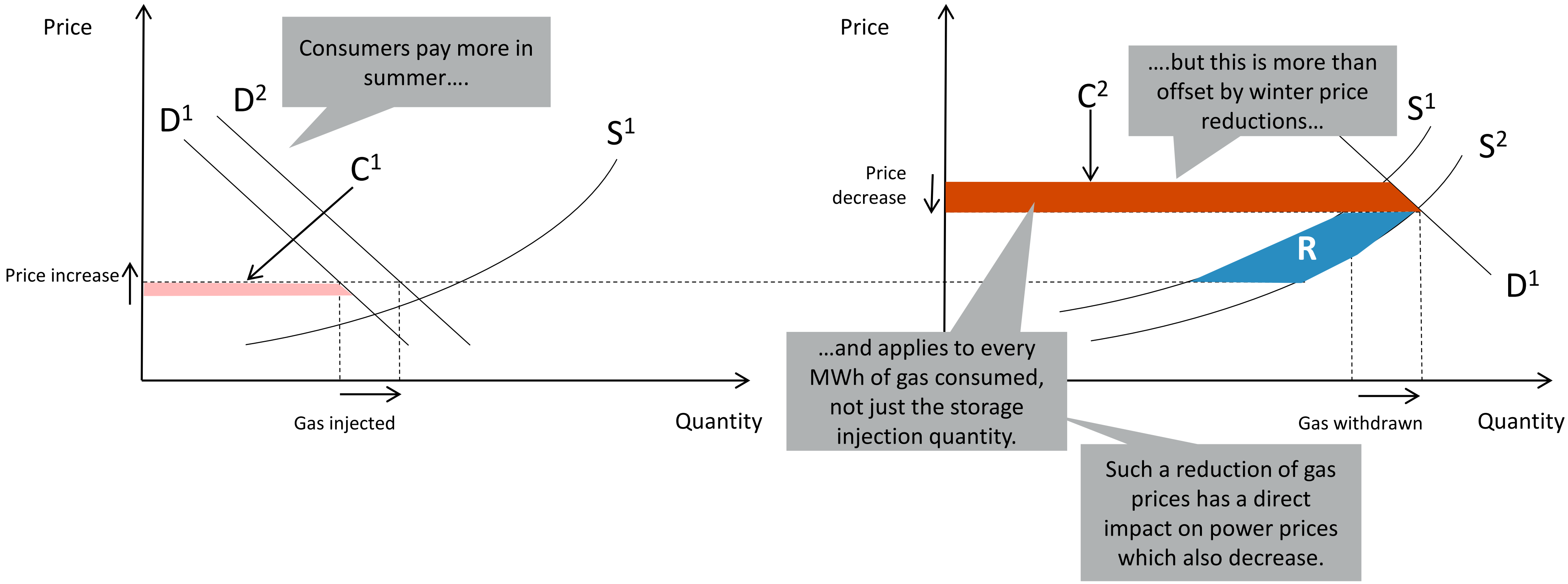
Note: Power externalities are created in a similar fashion.

Storage brings welfare through wholesale gas and power market price reduction (externalities) and private trading benefits

Focus on a typical storage impact - Illustrative

Summer

Winter



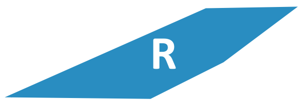
Externalities – Impact for all gas consumers α

ΔPrice <0

ΔPrice >0

Private impact – Storage margin shared between storage operator and storage clients γ

Revenues >0



Reminder: We relied on a central case reflecting normal conditions, and six stress cases to measure the security of supply value on top of these normal conditions

Principles of modelling for central case and security of supply cases

Central case – Normal conditions

- Full availability of import pipeline and LNG terminals.
- Full availability of import power lines and standard availability of power plants.
- Likely weather condition: based on most likely weather conditions based on past 34 years, as measured in the TYNDP.
- Historic gas supply cost profile from the last decade replicated in the future.

Expected to measure the central case impact of the Investment in **normal system conditions**

Security of supply cases – Stress conditions

Combinations of stress conditions on gas and power system:

- Gas supply interruptions (TANAP, LNG…).
- Partial gas infrastructure unavailability (interconnections, DESFA system…).
- Partial power infrastructure unavailability (interconnections, power plants…).
- Extreme climatic conditions (heat wave, low wind…).
- Upper bound of gas market price dynamics (high prices, high volatility…).

Expected to measure additional impacts of the Investment in **stress system conditions**

Focus of next slides

Note: TYNDP always refers to Ten-Year Network Development Plan 2020 (latest available) published by ENTSOE and ENTSOG. Next TYNDP expected in 2022.

We have considered six stress scenarios to cover some of the expected variations around normal market conditions

Overview of stress tests conducted

	European Demand				European Supply					Extra Europe prices	
	Climate event		Infra. outage	Loss of demand	Climate event	Infra. outage		Loss of supply		Price level	Price volatility
	Cold spell	Heat wave			Low wind	NMK+BG interco. outage	Reduced pipe supply to Greece	TAP & Kipi interruption	No LNG for a short period	2021 TTF prices for LNG&RU	2021 TTF peak price
A Gas price volatility as in 2021										✓	
B Pronounced pan-European 2-week cold spell	✓										✓
C Pronounced pan-European 2-week cold spell & part power line outage	✓					✓					✓
D Pronounced heat wave as in 2021 & part power lines outage		✓			✓	✓					
E **Azeri interruption** (based on scenario Γ2b from RAE's 2020 National Risk Assessment Study)								✓			
F **Reduced pipeline supply to Greece & no LNG** (based on scenario B5b from RAE's 2020 National Risk Assessment Study)							✓		✓		

Based on RAE's 2020 National Risk Assessment Study

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Stress cases "A" to "D" have been constructed based on historical precedents

Description of stress tests

Stress scenario	Storyline	Parameters
A **Gas price volatility as in 2021**	**European gas prices experience unusually high volatility, fuelled by energy transition uncertainty.**	Marginal European supplies (LNG & Russian pipeline imports) are priced following the same volatility as witnessed in 2021 European gas prices: import prices are set following TTF spot prices of 2021.
B **Pronounced pan-European 2-week cold spell**	**A two week cold spell event is observed in February.**	Based on historic data, ENTSOE developed a climate database based on: precipitations, wind, temperatures, sun exposition, etc. As a result, ENTSOE defined three representative climate years: cold (1984), average (1982) and warm (2007). We use here the 1982 weather conditions as they shows the strongest 2-week power demand in Greece due to the cold spell: Feb 2 to Feb 15. LNG and Russian gas priced during this period at the highest TTF prices observed in 2021 to reflect energy system tensions.
C **Pronounced pan-European 2-week cold spell & part power line outage**	**Same as scenario "B" but together with a power infrastructure outage.**	We consider an outage of the power lines connecting Greece with Bulgaria and North Macedonia on top of cold spell conditions.
D **Pronounced heat wave as in 2021 & part power lines outage**	**A two week heatwave is observed in June/July in line with 2021 events in Greece together with limited availability of wind capacity.**	Out of the ENTSOE representative years, we use 2007 power profile (the warm year reference). This year displays the highest heat-related power demand in Greece. The peak demand occurs from Jun 20 to Jul 3. On top of these heat wave conditions, we curtail (i) wind at 5% of its total capacity and (ii) Greece's power connection with Bulgaria and North Macedonia.

Stress cases "E" and "F" have been constructed based on RAE's 2020 National Risk Assessment Study

Description of stress tests

Stress scenario	Storyline	Parameters
E **Azeri interruption**	**Azeri transit (TANAP) is interrupted leading also to a full curtailment at Kipi.** This scenario is based on Γ2b scenario from RAE 2020 National Risk Assessment Study.	The scenario applies to the month with the highest non-power gas demand in Greece (Jan 3 – Feb 2).
F **Reduced pipeline supply to GR & no LNG**	**Pipeline import capacity is significantly reduced in Greece, reflecting severe network outages.** This scenario is based on B5b scenario from RAE 2020 National Risk Assessment Study.	We apply this scenario to the month with the highest non-power gas demand in Greece (Jan 3 – Feb 2). Such a scenario considers, through the whole month: i. Reduced import flow through Kipi, Nea Messimvria and Sidirokastro to 14.6 M m3/day; and ii. Full curtailment of LNG flows at all terminals.

We have estimated a high-level likelihood for stress tests “A” to “D”

High-level likelihood estimates of the stress tests

Stress scenario	High-level annual likelihood	Source of likelihood estimate
A Gas price volatility as in 2021	~10%	Two main events had a significant impact on gas prices volatility over the past 20 years: Fukushima in 2011 and the recent gas price spike in 2021: we assume price spikes are **a one in ten year event = 10%.**
B Pronounced pan-European 2-week cold spell	23%	ENTSOE calculates that, since 1981, 23.5% of years have been cold years. We assume similar occurrence in the future and adjust from 23.5% to 23% to account for stress scenario C which is also built on a cold year.
C Pronounced pan-European 2-week cold spell & part power line outage	0.5%	We rely on the same weather likelihood as in stress scenario B (23.5%) based on historic ENTSOE analysis. We multiply this figure by an estimate of the high-level likelihood of joint outage on BG-GR and NMK-GR power interconnections: ▪ We identified reliable historic data only for the BG-GR interconnection, with full unavailability evidenced on 4% of historic days. ▪ In the absence of reliable data for the NMK-GR interconnection, we assume some dependence between the two interconnections, and make a qualitative assumption of a halving of the likelihood of both interconnections being unavailable compared to only BG-GR unavailable, therefore assuming a **2%** likelihood for both BG-GR and NMK-GR power interconnection unavailable. ▪ This leads to a total likelihood of **23.5%*2%=0.5%**
D Pronounced heat wave as in 2021 & part power lines outage	1%	ENTSOE calculates that, since 1981, 50% of years have been warm years. We assume similar occurrence in the future. We multiply this figure by the high-level likelihood of BG-GR & NMK-GR power interconnections being both fully unavailable **as in scenario “C”. High-level likelihood = 50% * 2% = 1%.**

We have also estimated a high level qualitative likelihood for stress tests "E" and "F"

High level qualitative likelihood estimates of the stress tests

Stress scenario	High level qualitative annual likelihood	Source of likelihood estimate
E **Azeri interruption**	5%	In RAE's 2020 National Risk Assessment Study, scenario Γ2b has a 5% probability. Scenario Γ2b is similar to Scenario E, but scenario Γ2b assumes a partial unavailability of LNG imports. On the contrary, scenario E assumes full LNG availability. Scenario E is therefore more likely than scenario Γ2b, as it is less extreme, with LNG infrastructure unaffected in scenario E. We therefore use scenario Γ2b's probability as lower bound estimate for scenario E's high-level likelihood.
F **Reduced pipeline supply to GR & no LNG**	2%	In RAE's 2020 National Risk Assessment Study, scenario B5b has a 2% probability. Scenario B5b is similar to Scenario F, but scenario B5b assumes an outage that lasts a full winter (6 months duration), while scenario F only assumes an outage for 1 month. Both scenarios assume an outage of reduced pipeline supply and no LNG, but scenario F assumes this for a period that is shorter and included in the longer period of scenario B5b: scenario F is thus less extreme than scenario B5b. We therefore use scenario B5b's probability as lower bound estimate for scenario F's high-level likelihood.

4. 750 €m investment scenario results

Normal conditions lead to EUR 481m of benefits, with stress conditions bringing additional value of EUR 293m, below costs at EUR 913m

Section summary

A Normal conditions

Total normal condition = EUR 481 m, out of which:

- Total externalities = EUR 171m
- Margin created from storage = EUR 214m
- Residual value = EUR 97m

B Stress tests

Total stress tests = EUR 293 m, of additional benefits to normal conditions, out of which:

- Scenario A. Gas price volatility as in 2021 = EUR 77m
- Scenario B. Pronounced 2-week cold spell = EUR 144m
- Scenario C. Pronounced 2-week cold spell with part power lines outage = EUR 5m
- Scenario D. Pronounced heat wave as in 2021 and part power lines outage = EUR 1m
- Scenario E. Azeri interruption = EUR 7m
- Scenario F. Reduced pipeline supply to Greece & no LNG = EUR 59m

C CAPEX and OPEX

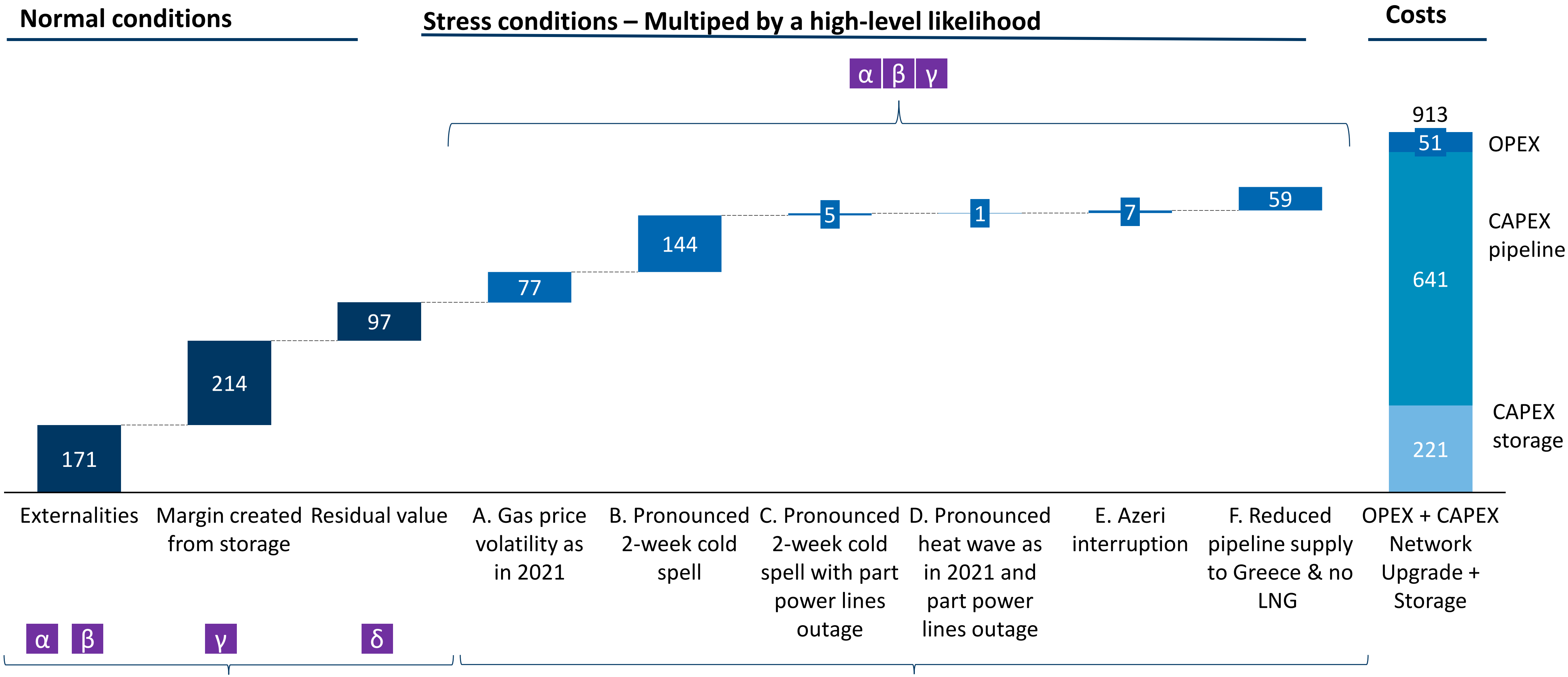
Total CAPEX + OPEX = EUR 913m, out of which:

- CAPEX pipelines = EUR 641m
- CAPEX storage = EUR 221m
- OPEX = EUR 51m

Note: All discounted values in million EUR_{2021}. Some totals may not add up due to rounding.

Margin created from storage and externalities in normal conditions bring more than half of the measured benefits

Welfare benefits and costs of the Full Investment in Greece – Discounted values in million EUR$_{2021}$



Normal conditions - Computed over 2027-2050

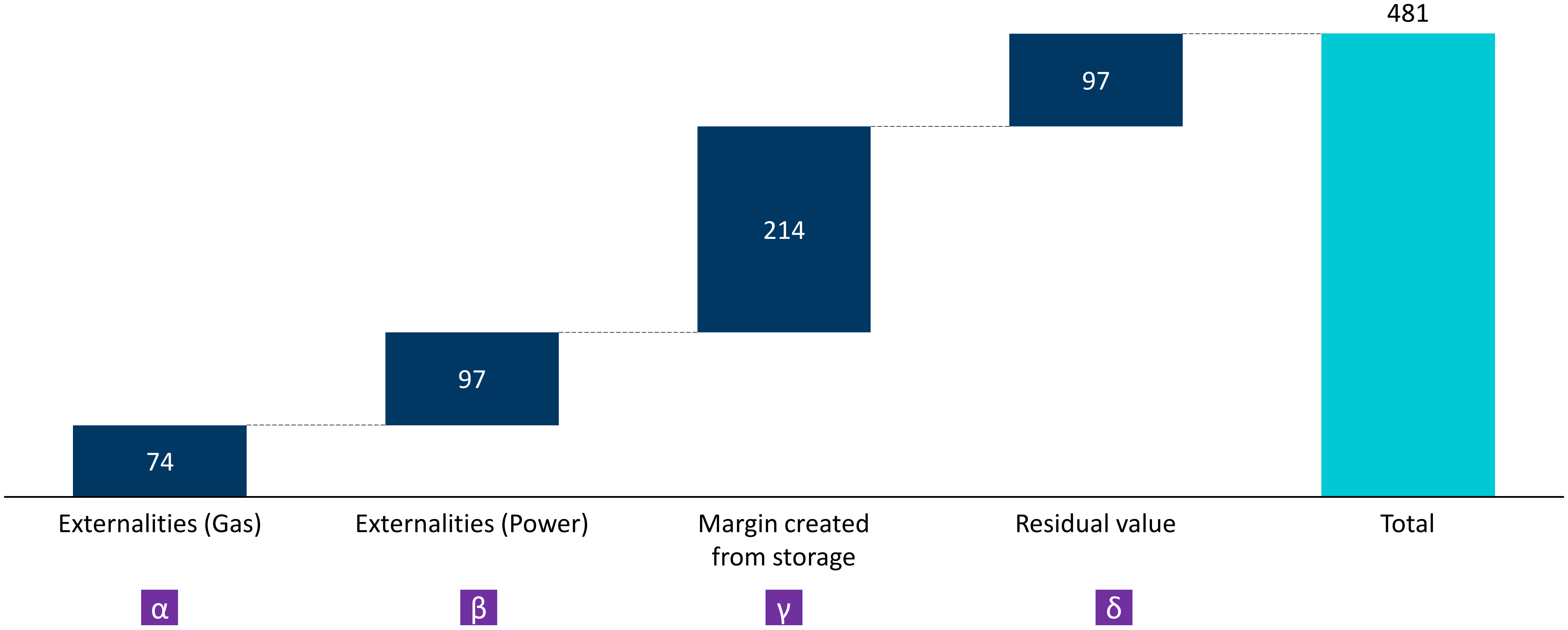
Stress conditions - Additional value vs. normal conditions – Approximated over 2027-2050, and multiplied by annual high-level likelihood

1) Stress case benefits are calculated and compared to normal conditions benefits to present here only the additional welfare creation in the stress case.
2) We have estimated annual stress case results by assuming that the values computed for 2027 with Plexos would decrease linearly to zero by 2050. 2027 could be expected to be most impactful year due to the generally declining role of gas imports over time.
3) We assume that the OPEX of DESFA's pipelines pre and post Investment are the same because volumes flown are very similar: only storage OPEX have been included them in this analysis as extra costs.
4) The realisation of the Investment could also bring non-monetised benefits as discussed in Section 1 of this deck.

Under normal conditions, total welfare benefit of the Full Investment is 481m EUR over 2027-2050

Externalities and private benefits in Greece – Full Investment - 2027 to 2050 – Discounted values in EUR_{2021}

- Values discounted to 2021, using an annual discount rate of 4% (Recommended value of ENTSOG CBA Methodology).
- The benefit in gas and power is calculated as the delta of the wholesale price pre and post investment multiplied by the demand in both segments separately.
- Based on yearly independent modelling runs from 2027 to 2050.



Notes:
*Conservatively, the surplus linked to a variation in quantities of **power** is not included here, only surplus linked to a variation in prices is accounted for at this stage, taking into account the minimum demand volume.*

Following ENTSOG's methodology, the Investment's welfare post 2050 is estimated as the discounted depreciation of the residual value at end-2050

Quantification of externalities post 2050 – Full Investment

- As we model power and gas markets only until 2050, the end of the ENTSO-E/ENTOS-G TYNDP horizon, assets commissioned in 2027 will not have reached the end of their technical life, but they will provide value to the energy system, at least as options
- ENTSOG CBA guidelines recommend that beyond the simulation period benefits should be assumed equal to the residual accounting value of the Investment.
- We therefore computed the residual values of South Kavala UGS and related network upgrades investments using a linear accounting depreciation over the assets' technical life.
- Annual depreciation post 2050 is discounted back to 2021 using the ENTSOG recommended rate (4%)

Key assumptions we used in calculating residual value		Source
CAPEX for Network upgrade	**641m EUR_{2021}** (750m EUR cash out over 2024-2026)	DESFA
CAPEX for Storage creation	**221m EUR_{2021}** (258m EUR cash out over 2024-2026)	HRADF study by Frontier Economics (2020)[1)], adjusted to EUR_{2021}
Commissioning year	2027	DESFA
Modelled life of the assets	Until 2050	ENTSOG/ENTSOE TYNDP (2020)
Technical life of the assets	**40 years** (network upgrade) **50 years** (storage)	DESFA
Social discount rate	4%	ENTSOG 2nd CBA Methodology

δ Residual values after 2050

- Network upgrade = 70 EUR_{2021} m
- Storage creation = 26 EUR_{2021} m
- **Total = 97 EUR_{2021} m**

1) Frontier Economics mentions an uncertainty of +/-25% on Storage CAPEX in its report for HRADF.

Externalities and storage margins both contribute to Security of Supply benefits

Summary of stress conditions results – 750 EUR m network upgrade – Additional welfare benefits multiplied by high-level likelihood – EUR_{2021} m

Stress conditions	α Gas externalities	α Avoided gas shortages	β Power externalities	γ Margin created by storage	Total
A. Gas price volatility as in 2021	10		22	46	**77**
B. Pronounced pan-European 2-week cold spell	15		26	103	**144**
C. Pronounced pan-European 2-week cold spell & part power line outage	1		2	2	**5**
D. Pronounced heat wave as in 2021 & part power lines outage	0		0	0	**1**
E. Azeri interruption	0		2	5	**7**
F. Reduced pipeline supply to Greece & no LNG	7	45	7	1	**59**

$\underbrace{\text{Gas externalities + Avoided gas shortages + Power externalities}}_{\sum = 136}$ ∑ = 157 **∑ = 293**

Notes on computation:

1) Stress case benefits are calculated and compared to normal conditions benefits to present here only the additional welfare creation in the stress case. We assume these additional benefits are realized in the middle of the year.
2) We have estimated annual stress case results by assuming that the values computed for 2027 with Plexos would decrease linearly to zero by 2050. 2027 could be expected to be most impactful year due to the generally declining role of gas imports over time. This estimation may however be conservative in terms of benefits given the expected peak gas consumption in Greece in the early 2030s.

Total CAPEX and OPEX sum EUR 913m

Computation of CAPEX and OPEX for the 750 EUR m network upgrade and Kavala building - EUR_{2021} m

CAPEX over 2024-2026

	CAPEX Network upgrade	CAPEX Storage building
Cash out Yearly cash out	750m EUR[1] = 3 x 250m EUR	258m EUR[2] = 3 x 86m EUR
Annual discounted values Discounted value to EUR_{2021} m at a 4% annual discount rate:	222m EUR_{2021} $= \frac{250m\ EUR_{2024}}{(1+0.04)^{(2024-2021)}}$ 214m EUR_{2021} $= \frac{250m\ EUR_{2025}}{(1+0.04)^{(2025-2021)}}$ 205m EUR_{2021} $= \frac{250m\ EUR_{2026}}{(1+0.04)^{(2026-2021)}}$	77m EUR_{2021} $= \frac{86m\ EUR_{2024}}{(1+0.04)^{(2024-2021)}}$ 74m EUR_{2021} $= \frac{86m\ EUR_{2025}}{(1+0.04)^{(2025-2021)}}$ 71m EUR_{2021} $= \frac{86m\ EUR_{2026}}{(1+0.04)^{(2026-2021)}}$
Total discounted value	**641m EUR_{2021}**	**221m EUR_{2021}**

Annual OPEX computation for 2027-2050

	Unit	Calculation step	Value
Unitary cost[3]	€/MWh	[1]	0.276
Withdrawal + Injection volumes	MWh	[2]	Volume in each year
OPEX in one year	€	[1]*[2]	0.276*Volume in each year

$$Net\ Present\ Value = \sum_{t=1}^{2050-2021} \frac{OPEX_t}{(1+0.04)^t}$$

→ **<u>Total OPEX</u> = 51m EUR_{2021}**

1) Source: DESFA
2) Source: HRADF study by Frontier Economics (2020) ; updated using the Upstream Capital Costs Index (UCCI) from 2020 to 2021 from IHS.
3) Source: HRADF study by Frontier Economics (2020) ; updated using the Upstream Operating Costs Index (UOCI) from 2020 to 2021 from IHS.

5. 422 €m investment scenario results

Normal conditions lead to EUR 446m of benefits, with stress conditions bringing additional value of EUR 274m, above costs at EUR 633m

Section summary

A Normal conditions

Total normal condition = EUR 446 m, out of which:

- Total externalities = EUR 166m
- Margin created from storage = EUR 214m
- Residual value = EUR 66m

B Stress tests

Total stress tests = EUR 274 m, out of which:

- Scenario A. Gas price volatility as in 2021 = EUR 64m
- Scenario B. Pronounced 2-week cold spell = EUR 138m
- Scenario C. Pronounced 2-week cold spell with part power lines outage = EUR 5m
- Scenario D. Pronounced heat wave as in 2021 and part power lines outage = EUR 1m
- Scenario E. Azeri interruption = EUR 7m
- Scenario F. Reduced pipeline supply to Greece & no LNG = EUR 59m

C CAPEX and OPEX

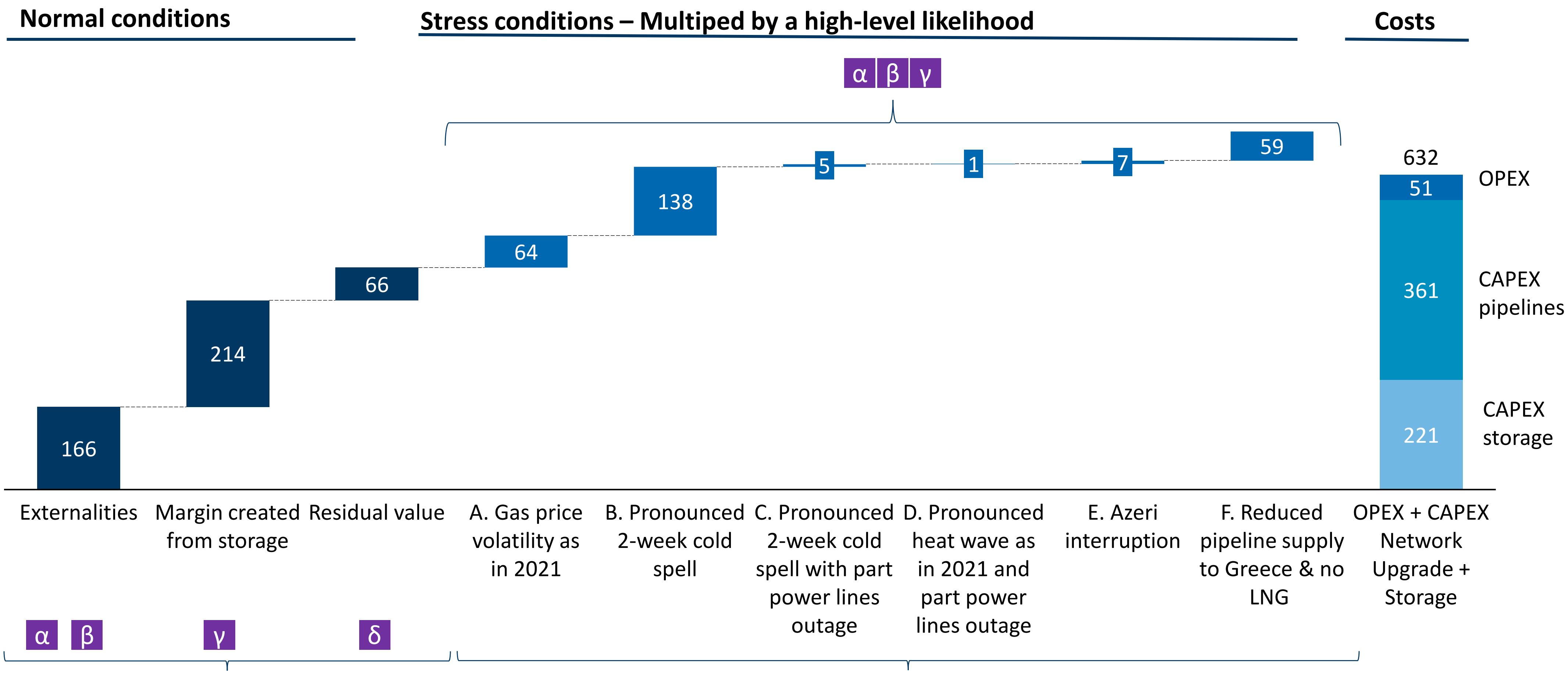
Total CAPEX + OPEX = EUR 632m, out of which:

- CAPEX pipelines = EUR 361m
- CAPEX storage = EUR 221m
- OPEX = EUR 51m

Note: All discounted values in million EUR_{2021}. Some totals may not add up due to rounding.

Margin created from storage and externalities in normal conditions bring more than half of the measured benefits

Welfare benefits and costs of the Partial Investment in Greece – Discounted values in million EUR_{2021}



Normal conditions - Computed over 2027-2050

Stress conditions - Additional value vs. normal conditions – Approximated over 2027-2050, and multiplied by annual high-level likelihood

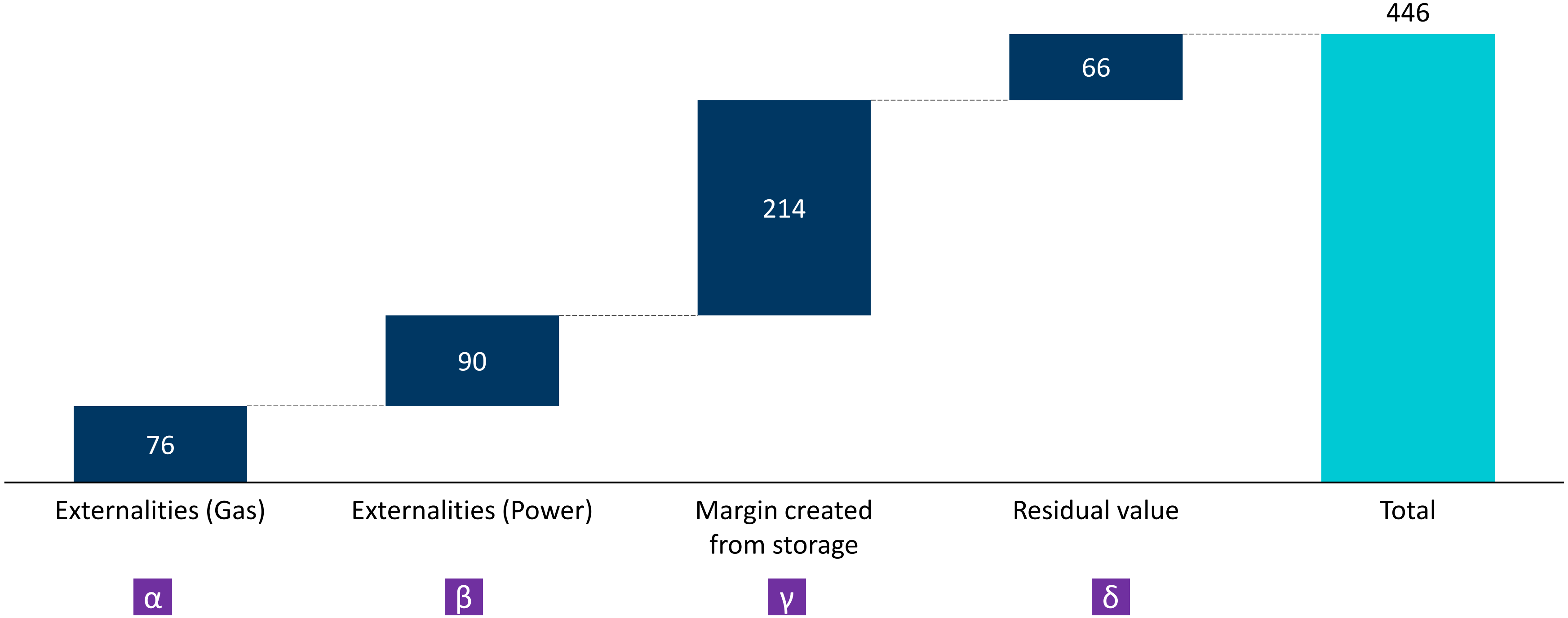
1) Stress case benefits are calculated and compared to normal conditions benefits to present here only the additional welfare creation in the stress case.
2) We have estimated annual stress case results by assuming that the values computed for 2027 with Plexos would decrease linearly to zero by 2050. 2027 could be expected to be most impactful year due to the generally declining role of gas imports over time.
3) We assume that the OPEX of DESFA's pipelines pre and post Investment are the same because volumes flown are very similar: only storage OPEX have been included them in this analysis as extra costs.
4) The realisation of the Investment could also bring non-monetised benefits as discussed in Section 1 of this deck.

A **Normal conditions**

Under normal conditions, total welfare benefit of the Partial Investment is 446m EUR over 2027-2050

Externalities and private benefits in Greece – Partial Investment - 2027 to 2050 – Discounted values in EUR_{2021}

- Values discounted to 2021, using an annual discount rate of 4% (Recommended value of ENTSOG CBA Methodology).
- The benefit in gas and power is calculated as the delta of the wholesale price pre and post investment multiplied by the demand in both segments separately.
- Based on yearly independent modelling runs from 2027 to 2050.



Notes:
*Conservatively, the surplus linked to a variation in quantities of **power** is not included here, only surplus linked to a variation in prices is accounted for at this stage, taking into account the minimum demand volume.*

Following ENTSOG's methodology, the Investment's welfare post 2050 is estimated as the discounted depreciation of the residual value at end-2050

Quantification of externalities post 2050 – Partial Investment

- As we model power and gas markets only until 2050, the end of the ENTSO-E/ENTOS-G TYNDP horizon, assets commissioned in 2027 will not have reached the end of their technical life, but they will provide value to the energy system, at least as options
- ENTSOG CBA guidelines recommend that beyond the simulation period benefits should be assumed equal to the residual accounting value of the Investment.
- We therefore computed the residual values of South Kavala UGS and related network upgrades investments using a linear accounting depreciation over the assets' technical life.
- Annual depreciation post 2050 is discounted back to 2021 using the ENTSOG recommended rate (4%)

Key assumptions we used in calculating residual value		Source
CAPEX for Network upgrade	**361m EUR$_{2021}$** (422m EUR cash out over 2024-2026)	DESFA
CAPEX for Storage creation	**221m EUR$_{2021}$** (258m EUR cash out over 2024-2026)	HRADF study by Frontier Economics (2020)[1)], adjusted to EUR$_{2021}$
Commissioning year	2027	DESFA
Modelled life of the assets	Until 2050	ENTSOG/ENTSOE TYNDP (2020)
Technical life of the assets	**40 years** (network upgrade) **50 years** (storage)	DESFA
Social discount rate	4%	ENTSOG 2nd CBA Methodology

δ Residual values after 2050

- Network upgrade = 39 EUR$_{2021}$ m
- Storage creation = 26 EUR$_{2021}$ m
- **Total = 66 EUR$_{2021}$ m**

1) Frontier Economics mentions an uncertainty of +/-25% on Storage CAPEX in its report for HRADF.

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Externalities and storage margins both contribute to Security of Supply benefits

Summary of stress conditions results – 422 EUR m network upgrade – Additional welfare benefits multiplied by high-level likelihood – EUR_{2021} m

Stress conditions	α Gas externalities	α Avoided gas shortages	β Power externalities	γ Margin created by storage	Total
A. Gas price volatility as in 2021	6		14	45	**64**
B. Pronounced pan-European 2-week cold spell	14		22	101	**138**
C. Pronounced pan-European 2-week cold spell & part power line outage	1		2	2	**5**
D. Pronounced heat wave as in 2021 & part power lines outage	0		0	0	**1**
E. Azeri interruption	0		2	4	**7**
F. Reduced pipeline supply to Greece & no LNG	7	45	6	1	**59**

$\underbrace{\text{Gas externalities + Avoided gas shortages + Power externalities}}_{\sum = 121}$ ∑ = 153 **∑ = 274**

Notes on computation:

1) Stress case benefits are calculated and compared to normal conditions benefits to present here only the additional welfare creation in the stress case. We assume these additional benefits are realized in the middle of the year.
2) We have estimated annual stress case results by assuming that the values computed for 2027 with Plexos would decrease linearly to zero by 2050. 2027 is generally expected to be most impactful year due to the generally declining role of gas imports over time. This estimation may however be conservative in terms of benefits given the expected peak gas consumption in Greece in the early 2030s.

Total CAPEX and OPEX sum EUR 632m

Computation of CAPEX and OPEX for the 422 EUR m network upgrade and Kavala building - EUR_{2021} m

CAPEX over 2024-2026

	CAPEX Network upgrade		CAPEX Storage building	
Cash out	422m EUR[1]		258m EUR[2]	
Yearly cash out	= 3 x 141m EUR		= 3 x 86m EUR	
Annual discounted values	125m EUR_{2021}	$= \frac{141m\ EUR_{2024}}{(1+0.04)^{(2024-2021)}}$	77m EUR_{2021}	$= \frac{86m\ EUR_{2024}}{(1+0.04)^{(2024-2021)}}$
Discounted value to EUR_{2021} m at a 4% annual discount rate:	120m EUR_{2021}	$= \frac{141m\ EUR_{2025}}{(1+0.04)^{(2025-2021)}}$	74m EUR_{2021}	$= \frac{86m\ EUR_{2025}}{(1+0.04)^{(2025-2021)}}$
	116m EUR_{2021}	$= \frac{141m\ EUR_{2026}}{(1+0.04)^{(2026-2021)}}$	71m EUR_{2021}	$= \frac{86m\ EUR_{2026}}{(1+0.04)^{(2026-2021)}}$
Total discounted value	**361m EUR_{2021}**		**221m EUR_{2021}**	

Annual OPEX computation for 2027-2050

	Unit	Calculation step	Value
Unitary cost[3]	€/MWh	[1]	0.276
Withdrawal + Injection volumes	MWh	[2]	Volume in each year
OPEX in one year	€	[1]*[2]	0.276*Volume in each year

$$Net\ Present\ Value = \sum_{t=1}^{2050-2021} \frac{OPEX_t}{(1+0.04)^t}$$

➡ **Total OPEX = 51m EUR_{2021}**

1) Source: DESFA
2) Source: HRADF study by Frontier Economics (2020) ; updated using the Upstream Capital Costs Index (UCCI) from 2020 to 2021 from IHS.
3) Source: HRADF study by Frontier Economics (2020) ; updated using the Upstream Operating Costs Index (UOCI) from 2020 to 2021 from IHS.

6. Appendix

Gross results for Stress tests in 2027 for Full Investment: undiscounted, no likelihood applied

Summary of stress conditions results – 750 EUR m network upgrade – Additional welfare benefits – EUR_{2027} m

Stress conditions	Gas externalities	Avoided gas shortages	Power externalities	Margin created by storage	Total
A. Gas price volatility as in 2021	13		30	63	**106**
B. Pronounced pan-European 2-week cold spell	9		15	61	**86**
C. Pronounced pan-European 2-week cold spell & part power line outage	21		68	58	**146**
D. Pronounced heat wave as in 2021 & part power lines outage	1		3	4	**8**
E. Azeri interruption	1		5	13	**19**
F. Reduced pipeline supply to Greece & no LNG	46	308	46	8	**409**

$\underbrace{\text{Gas externalities + Avoided gas shortages + Power externalities}}$

∑ = 567 ∑ = 207 **∑ = 774**

Gross results for Stress tests in 2027 for Partial Investment: undiscounted, no likelihood applied

Summary of stress conditions results – 422 EUR m network upgrade – Additional welfare benefits – EUR_{2027} m

Stress conditions	Gas externalities	Avoided gas shortages	Power externalities	Margin created by storage	Total
A. Gas price volatility as in 2021	8		19	62	**89**
B. Pronounced pan-European 2-week cold spell	9		13	61	**83**
C. Pronounced pan-European 2-week cold spell & part power line outage	21		67	61	**149**
D. Pronounced heat wave as in 2021 & part power lines outage	1		3	4	**7**
E. Azeri interruption	1		5	12	**18**
F. Reduced pipeline supply to Greece & no LNG	46	308	43	8	**405**

$\underbrace{\text{Gas externalities + Avoided gas shortages + Power externalities}}_{\sum = 543}$

∑ = 208

∑ = 751

Experts with Impact™

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