Artelys | OPTIMIZATION SOLUTIONS

EUROPE: BENEFITS OF INTEGRATING REGIONS AND ENERGIES TO THE SECURITY OF SUPPLY

GUILLAUME TAREL, PhD

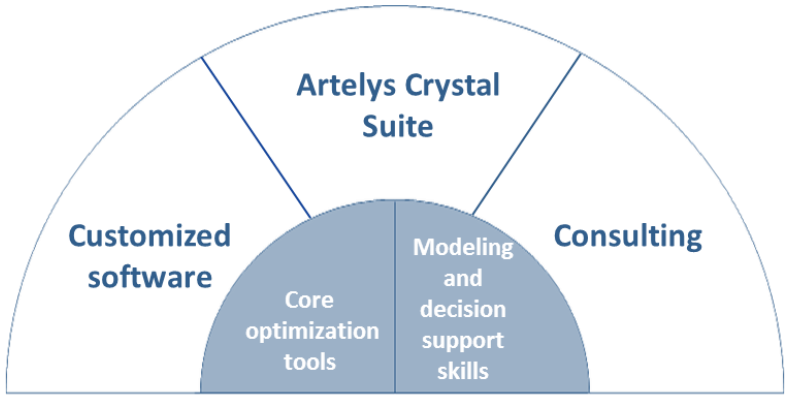
FERC conference on Increasing Market and Planning Efficiency through Improved Software, June 2016

Artelys | OPTIMIZATION SOLUTIONS

ARTELYS

COMPANY OVERVIEW

- **Independent company founded in 2000**
  - 60+ consultants specialized in advanced analytics & software development
    - Numerical optimization, forecast, simulation
    - Power/oil/gas sectors
  - Locations
    - Paris, France
    - Chicago, USA
    - Montréal, Canada
    - London, UK



- **Main assignments**
  - Service
    - Consulting (audit, quantitative analysis)
    - Training, maintenance, support
  - Software
    - Development and delivery of decision-support and forecast algorithms
    - Software development and implementation

THE MOST EFFICIENT OPTIMIZATION TOOLS

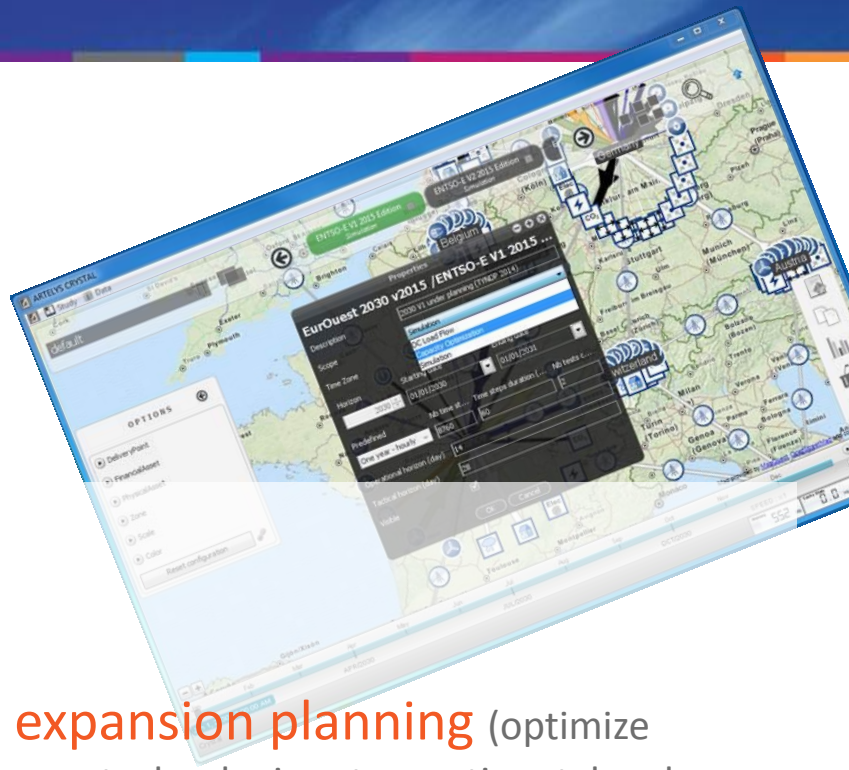
- Artelys KNITRO
  - **Nonlinear programming**
  - industry leading solver for very large, difficult nonlinear optimization problems

- FICO Xpress Optimization Suite
  - **Linear programming**
  - Large range of modeling and numerical optimization tools, solving complex operational problems

- Artelys Kalis
  - **Constraint programming**
  - Object-oriented environment to model and solve problems with constraints programming techniques

ARTELYS CRYSTAL SUPER GRID FOR POWER SYSTEMS PLANNING

Artelys Crystal SuperGrid



Main features (2016.1.0 commercial version)

- Efficient optimal dispatch on a continental scale
- **Large-scale multi-scenario capacity expansion planning** (optimize investments for tens of generation/transport/storage technologies at a continental scale, taking into account tens of hourly weather scenarios)
- DC load flow option
- User-friendly interface to compare investment values (multi-scale GUI, comparison modes, built-in KPIs)
- Efficient collaboration tools (shareable database, import/export Excel sheets)
- Includes reference data on future energy mixes
- Automatic validation tools for all types of energy-related time series

Artelys | OPTIMIZATION SOLUTIONS

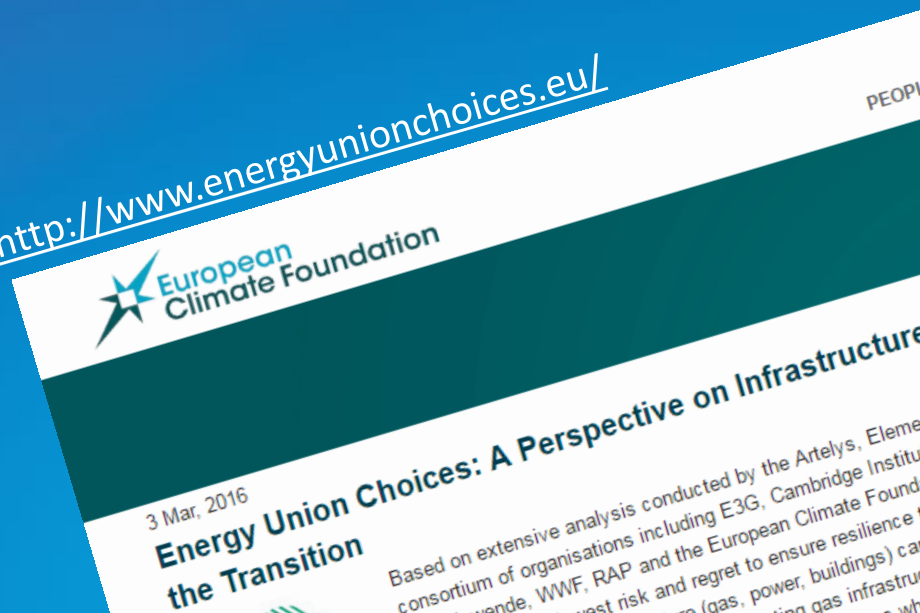
ARTELYS

elementenergy

CLIMACT

"ENERGY UNION CHOICES" REPORT
Focus on gas security of supply

http://www.energyunionchoices.eu/



June 2016

Study presentation

- Main objectives of the study
  - Assess required investments to ensure gas security of supply in Europe
  - Assess how an integrated gas and power approach can help meet these security of supply challenges at lower costs

- Consortium
  - Artelys:
    - *Power and gas system modelling*
    - *Technical coordination*
  - Climact
    - *Project management and supporting narrative*
  - Element Energy
    - *Demand side action modelling*

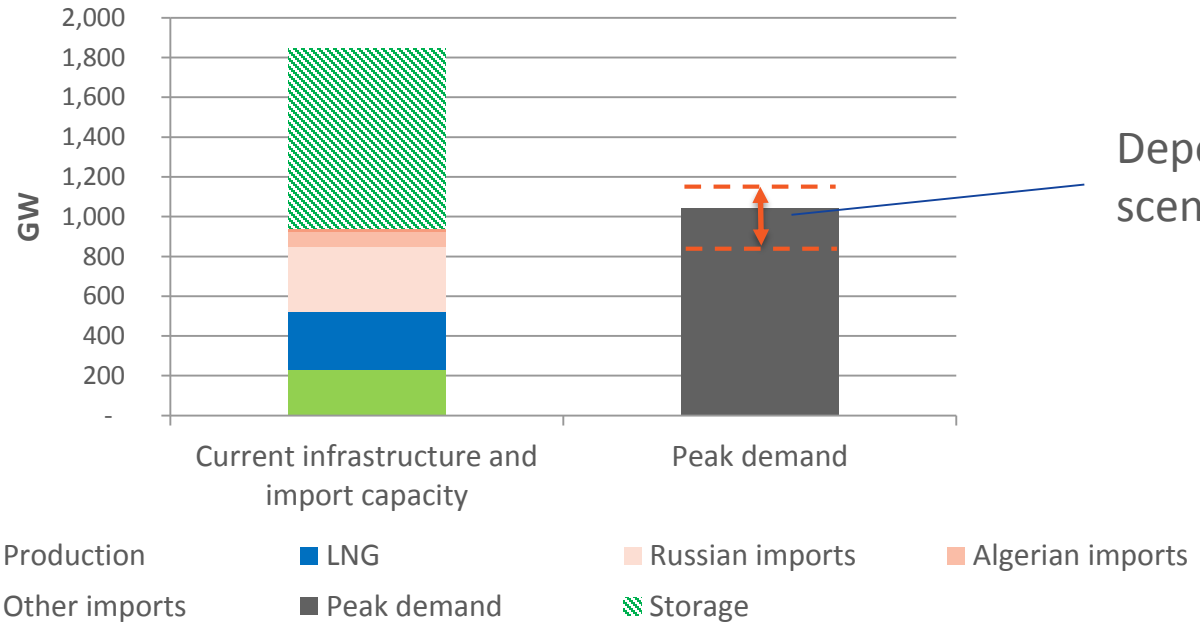
Artelys | OPTIMIZATION SOLUTIONS

CLIMACT

elementenergy

Current gas infrastructure

- Current available capacities (2014) vs 2030 peak demand



- Europe (overall) is robust to any supplier disruption (N-1 rule)

Is it still the case at regional / national level ?
Can storage capacities fully contribute to security of supply ?
Do integrated gas-power strategies help meet these security of supply challenges at lower costs ?

Current gas infrastructure

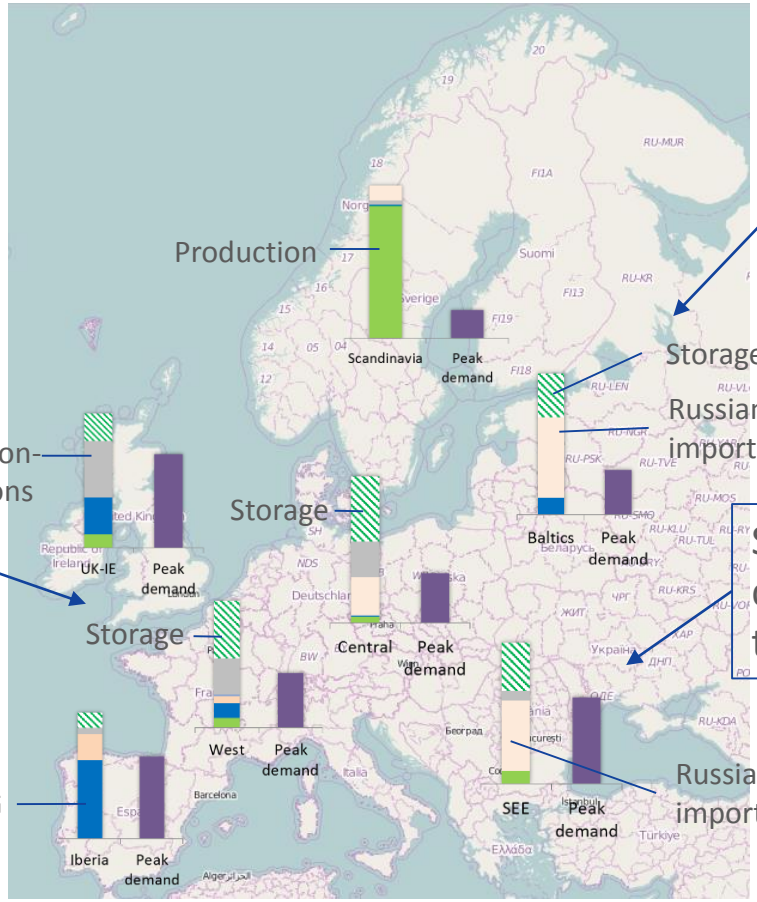
Security of supply stakes are located in South-East Europe

Regional look at Security of Supply (SoS)

Baltics: imports from West Europe (incl. new projects) and LNG are an alternative to Russian imports

West Europe : high diversity of sources (Russia, Norway, LNG, Algeria…)

South-East Europe: highly depends on Russian imports through Ukraine

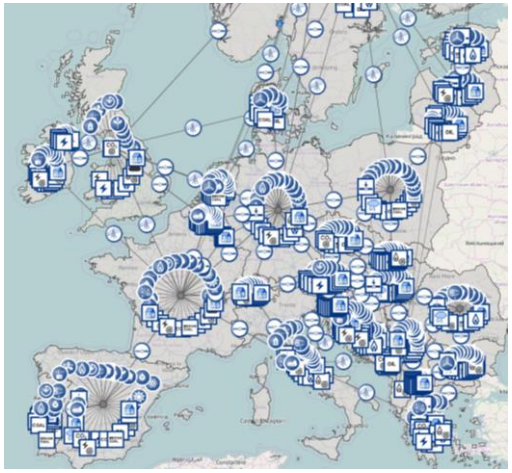


⇒ **More detailed simulations are required to assess how storage and other European countries can contribute to SoS**

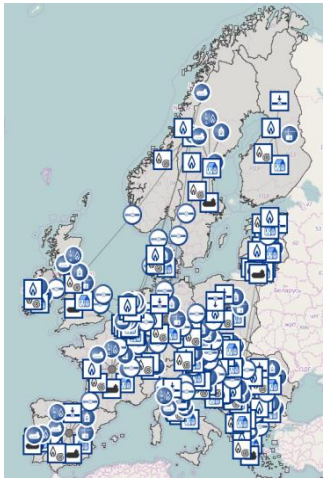
Model used for simulations

A joint gas and power model at Member State level

- Main assumptions
  - Focus on security of supply
  - Infrastructures are aggregated at country scale
  - Simulations are performed at an hourly time granularity over a year for different stress cases
  - Stress case = one-year disruption of a major gas source
    - *Import disruptions (from Ukraine, Norway or Algeria & Libya) and climatic variations (very cold year)*
- Joint gas and power European model
  - LNG terminals, gas production, pipelines, storage and demand response
  - Power generation, interconnections, storage and demand response
- Model based on Artelys Crystal Super Grid
  - Joint optimization of gas and power infrastructure
  - Using High Performance Computing (1280 cores)



Power model



Gas model

Main Findings

- **Europe's existing gas infrastructure is able to face most supply disruptions cases, even under a high gas demand scenario, which includes low efficiency improvements and a coal to gas shift in the power sector.**

- Deep dive on South Eastern Europe
  - The only region which requires reinforcement is South-Eastern Europe to provide optionality to Russian imports via Ukraine, but these investments are relatively small compared to other planned investments in the energy sector
  - A smarter integration of European gas and electricity system can decrease by 45% the infrastructure investments in the region to ensure security of supply, whatever the gas demand scenario (savings of 0,9 to 6,4 bn€)
  - Meeting the 2030 targets for energy efficiency would also significantly decrease the investments required to ensure security of supply in South-Eastern Europe

- Investing in additional gas infrastructure up to 2030 would increase the stranded assets in 2050

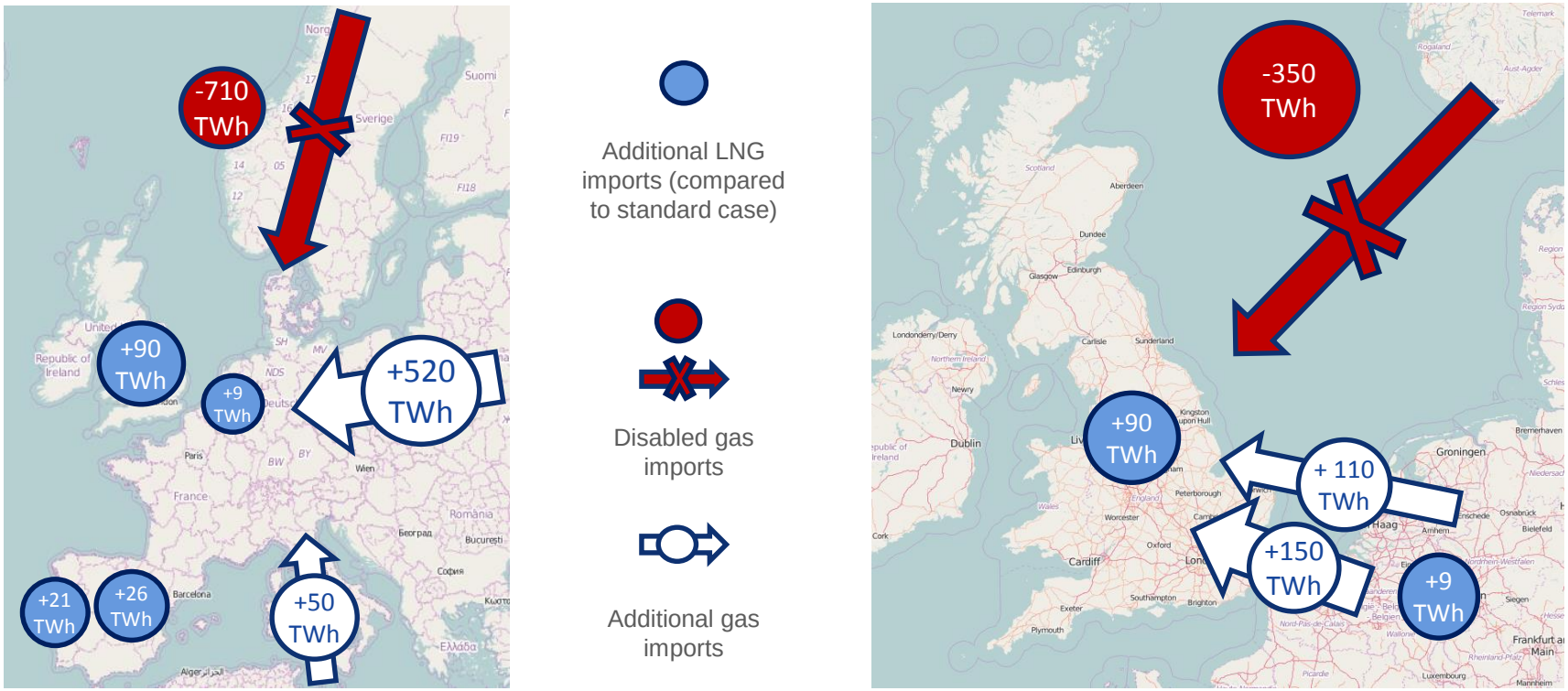
Current trends 2030 – Gas only

Europe is resilient to a Norwegian imports disruption

- **Norway imports disruption**: Russian gas is transported from the east and LNG from the south to substitute Norwegian gas
  - **No loss of load all over Europe**

Norway imports disruption

Sources of gas supply compared to the standard case

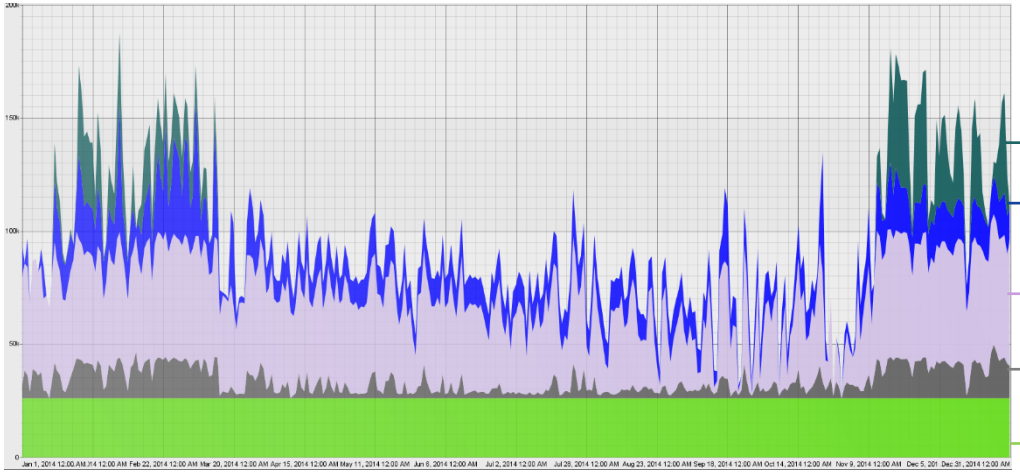


Additional LNG demand: 150 TWh (4% of traded volume worldwide)

Current trends 2030 – Gas only

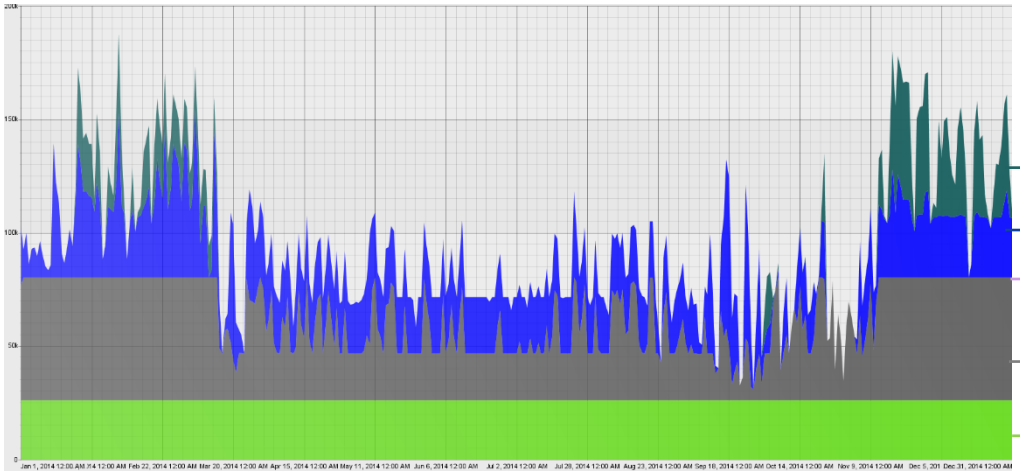
Europe is resilient to a Norwegian imports disruption

Gas supply sources in UK
Standard simulation
(No disruption)



Storage
LNG
Import from Norway
Imports from Belgium and the Netherlands
National production

Gas supply sources in UK
Norway imports disruption



Storage
LNG
Import from Norway
Imports from Belgium and the Netherlands
National production

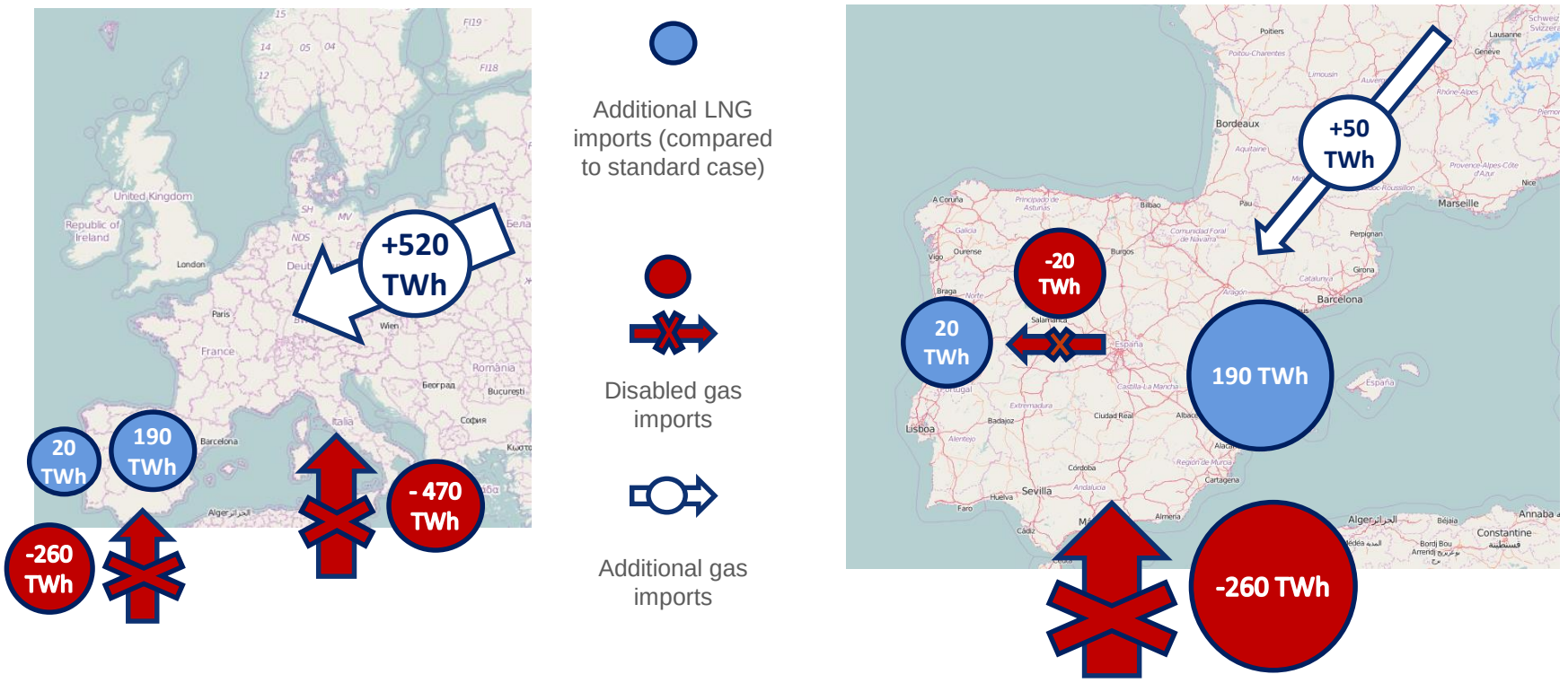
Current trends 2030 – Gas only

Europe is resilient to an imports disruption from North Africa

- **North African imports disruption**: Russian gas is transported from the east to the south. Iberian LNG imports also increase
  - **No loss of load**

North African imports disruption

Sources of gas supply compared to the standard case

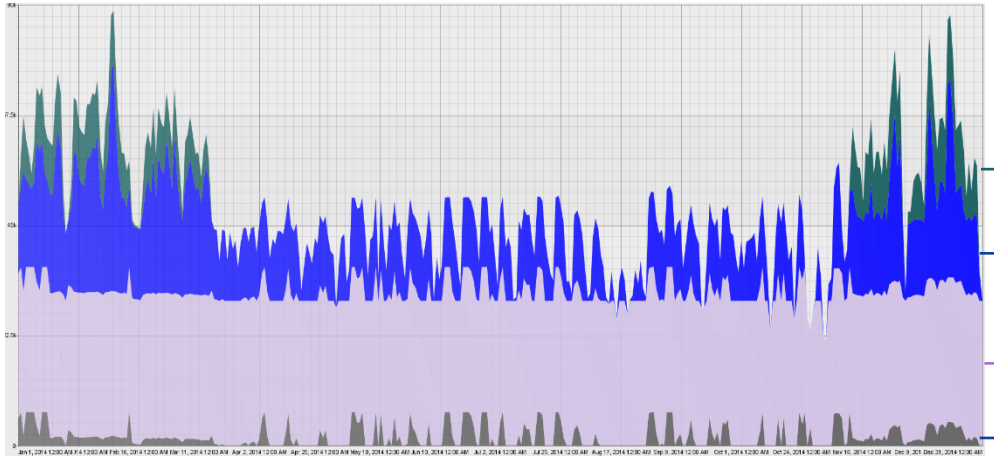


Additional LNG demand: 210 TWh (6% of traded volume worldwide)

Current trends 2030 – Gas only

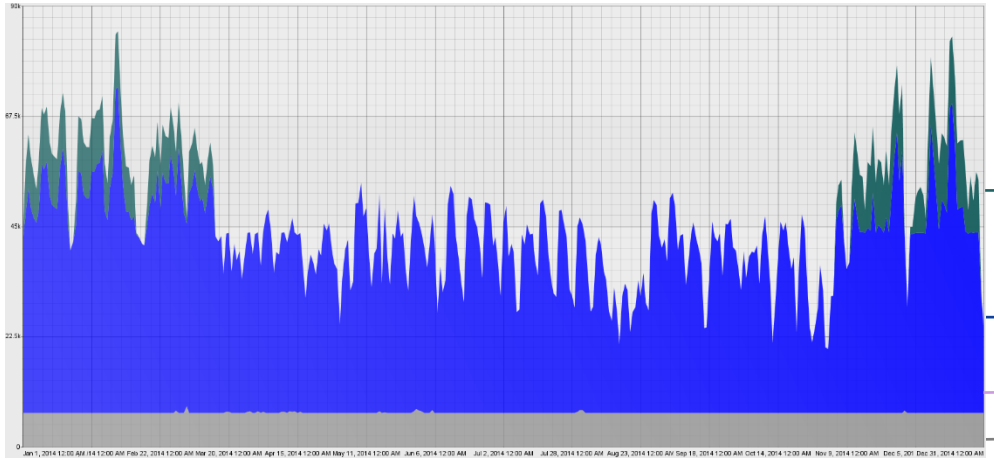
Europe is resilient to an imports disruption from North Africa

Gas supply sources in Spain
Standard simulation
(No disruption)



Storage
LNG
Import from Algeria
Imports from France

Gas supply sources in Spain
North African imports disruption



Storage
LNG
Import from Algeria
Imports from France

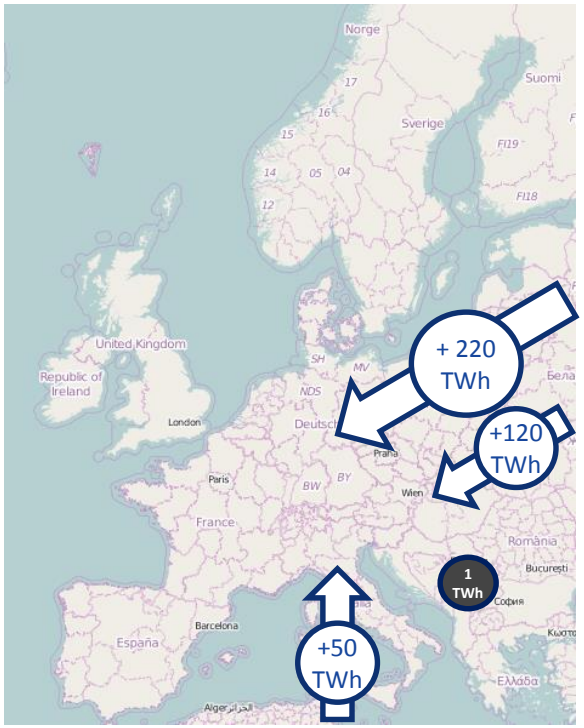
Current trends 2030 – Gas only

European gas system is resilient to a very cold year

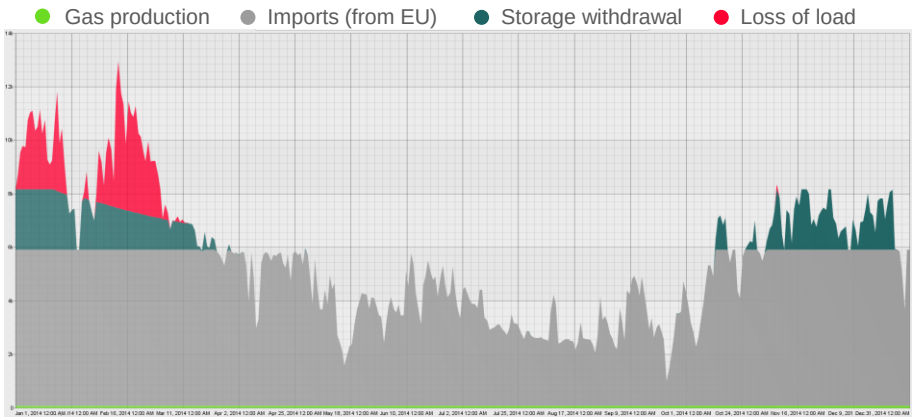
- **Cold year stress case:** Security of supply issues are located in South Eastern non-EU countries
  - **Supply issues in non-EU Balkan countries** due to limited transmission capacities

Additional gas imports

Loss of load due to cold events



Loss of load in the cold case
(compared to the standard case)



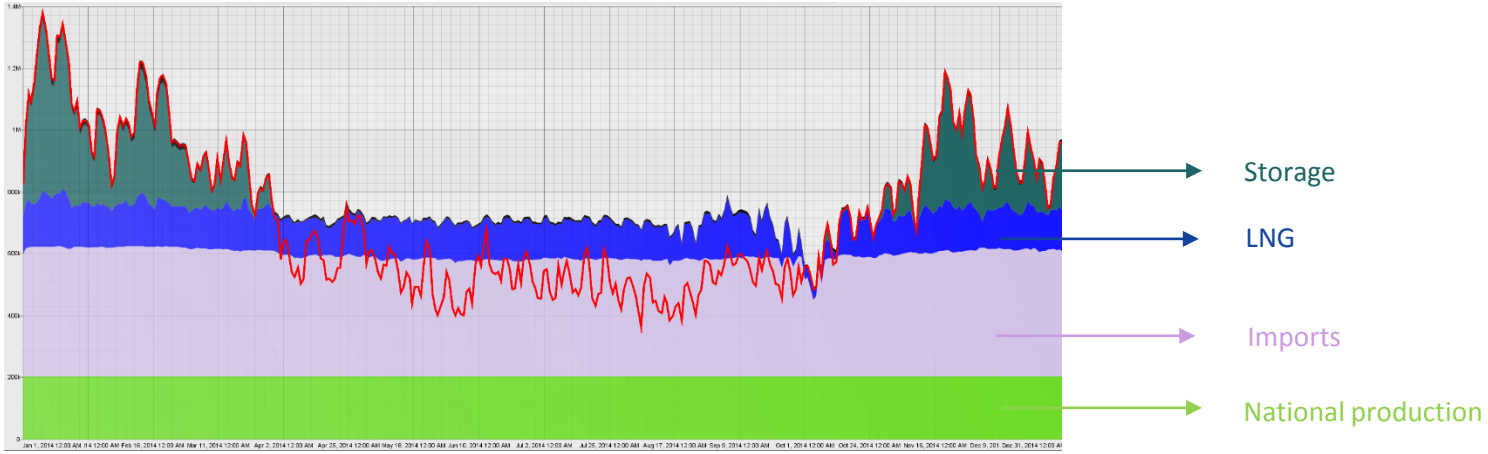
Gas supply and loss of load in Serbia in the cold case

High demand 2030 – Gas only

In a high demand scenario, the system remains robust to standard condition

- High demand scenario (from ENTSO-G TYNDP 2014 Green scenario)
  - Higher gas consumption 5800 TWh (*ENTSO-G 2030*) vs 4700 TWh (*Current trends 2030*)
  - Switch in the merit order due to high CO2 cost
    - *+70GW of CCGT in the power mix to replace coal fleet*
    - *+ 400 TWh for gas to power compared to PRIMES*
  - + 700 TWh for other gas usages

- At a European level, gas security of supply is ensured in standard conditions

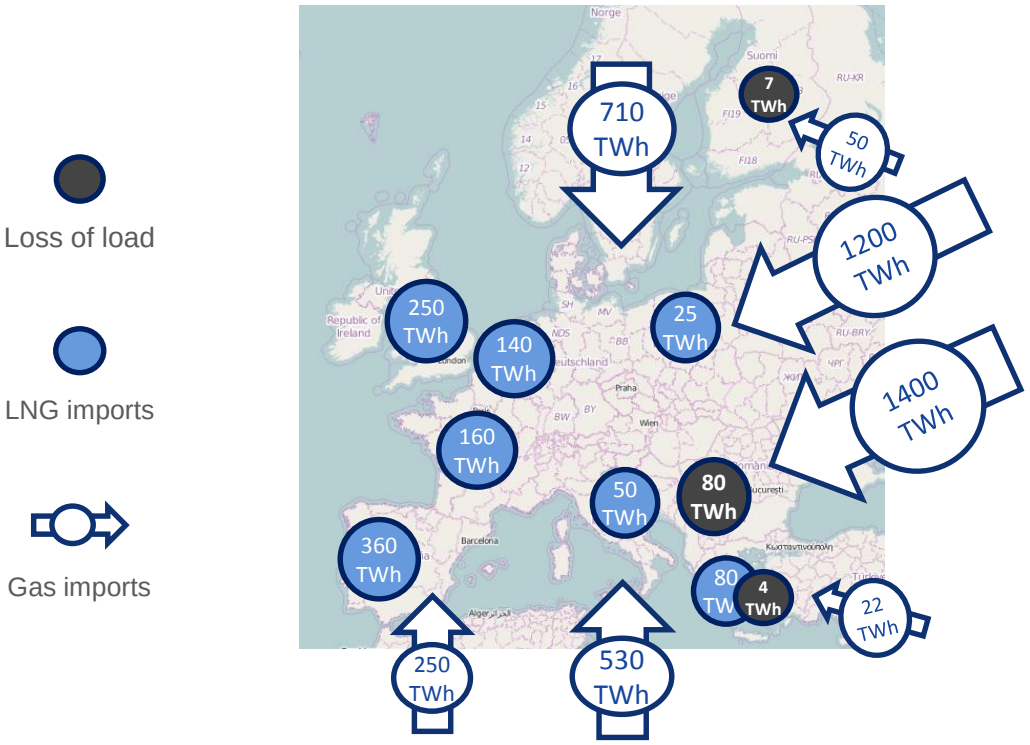


High demand scenario – EU gas supply in standard conditions

High demand 2030 – Gas only

Under a very cold year, the system remains relatively robust

- Under poor weather conditions, current infrastructures guarantee security of supply for most of Europe, but **supply is weakened in South Eastern countries (mostly non-EU countries) and Finland**



Loss of load in the cold case
(High Demand scenario)

Current trends 2030 – Gas only

Europe can mostly handle a Ukraine disruption, the only area with security of supply issues is South Eastern Europe

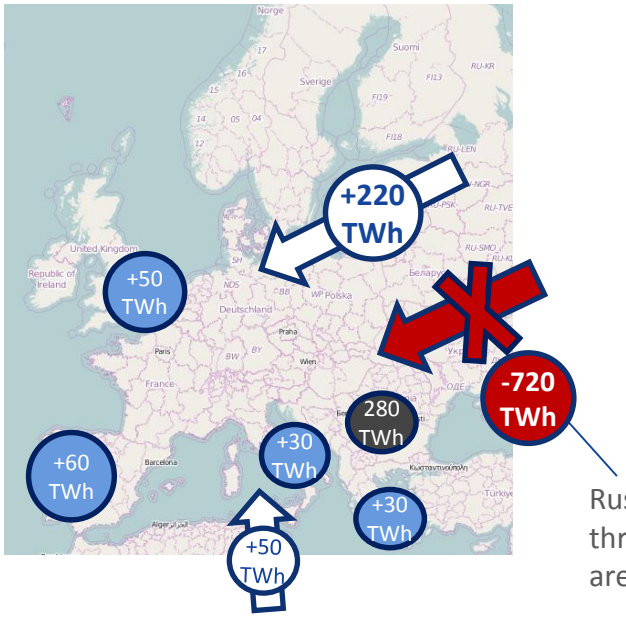
- **Ukraine transit disruption:** Security of supply issues are located in SEE
  - **EU (BG, RO, HU, HR) and non-EU Balkan countries (RS,BA,MK) are strongly affected**
    - *289 TWh of loss of load: 60% of the demand in these countries*
  - In Western Europe, Russian imports are replaced by LNG

Additional LNG imports (compared to standard case)

Loss of load

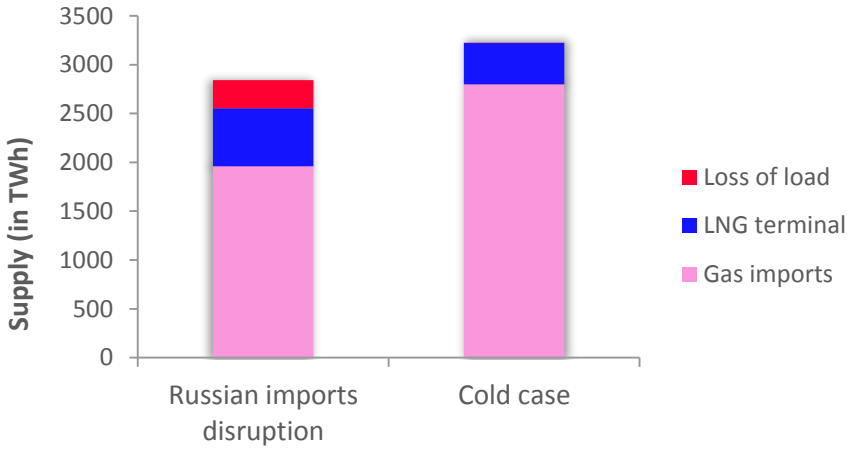
Disabled gas imports

Additional gas imports



Russian exports through Ukraine are cut all year

Loss of load in the Ukraine transit disruption case
(of which 48 TWh for non-EU countries)



European gas supply in the most impactful stress cases

Main Findings

- Europe's existing gas infrastructure is able to face most supply disruptions cases, even under a high gas demand scenario, which includes low efficiency improvements and a coal to gas shift in the power sector.

- Deep dive on South Eastern Europe
  - The only region which requires reinforcement is South-Eastern Europe to provide optionality to Russian imports via Ukraine, but these investments are relatively small compared to other planned investments in the energy sector

  - A smarter integration of European gas and electricity system can decrease by 45% the infrastructure investments in the region to ensure security of supply, whatever the gas demand scenario (savings of 0,9 to 6,4 bn€)

  - Meeting the 2030 targets for energy efficiency would also significantly decrease the investments required to ensure security of supply in South-Eastern Europe

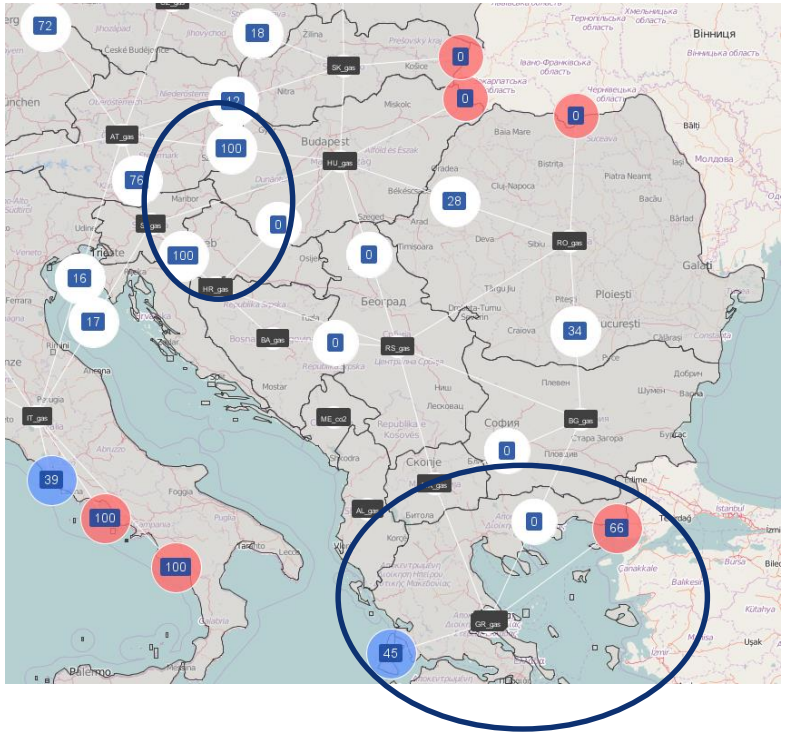
- Investing in additional gas infrastructure up to 2030 would increase the stranded assets in 2050

Current trends 2030 – Gas only

Security of supply issues are located in South Eastern Europe

- **Ukraine transit disruption :** Due to transmission constraints, South Eastern Europe suffers security of supply issues while LNG terminals in Europe remain underutilized (28% load factor).
  - **Congestions** in the pipelines that connect Western Europe to South Eastern Europe (AT -> HU and SI -> HR)
  - **Unidirectional pipelines:** LNG and gas from Greece cannot be transported to other South Eastern ern countries.

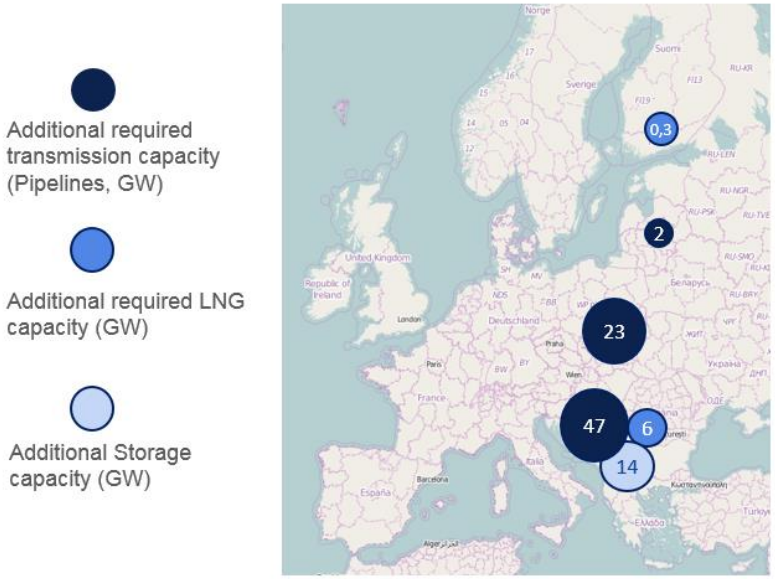
Load factors of pipelines and LNG terminals in South Eastern Europe in the Ukraine transit disruption case



Current trends 2030 – Gas only

New infrastructures are required to ensure SoS in South Eastern Europe

- To provide resilience under Ukraine transit disruption
  - Installation of **6 GW of LNG** (one or two terminals) and of **14 GW of gas reserve** in the zone at risk
  - **Reinforcement of the gas network,** particularly in
    - Central Europe, to create and decongest entry pipelines to the South East
    - South-East Europe, to transport Greek LNG and new LNG resources.

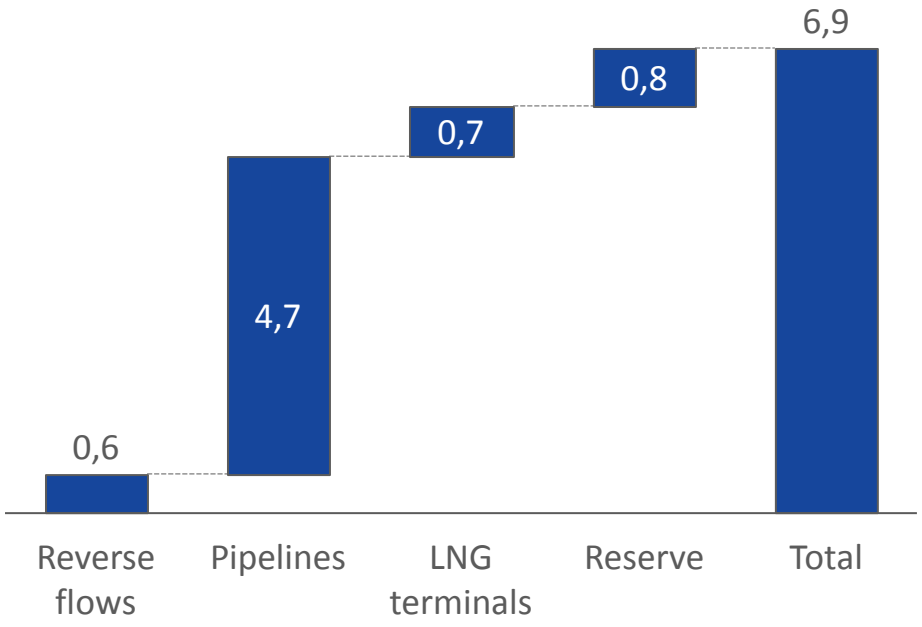


Scenario	Current Trends

Current trends 2030 – Gas only

A mix of new LNG terminals, pipelines and strategic reserve

- Option cost of 6.9 billion euros to avoid the 290 TWh of loss of load in SEE under Ukraine transit disruption



Investment and maintenance costs (bn€)

- All proposed pipelines are included in the 2nd PCI list

High demand 2030 – Gas only

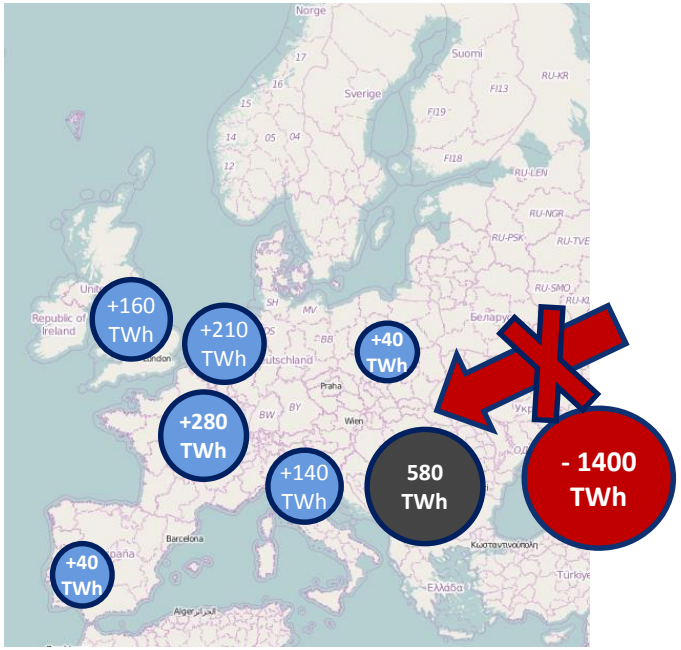
In case of high demand, LoL increases in SEE, but no other region is affected

- **Ukraine transit disruption:** Security of supply issues are located in SEE
  - **EU (BG, RO, HU, HR) and non-EU Balkan countries (RS,BA,MK) are strongly affected**
    - *580 TWh of loss of load: 80% of the demand in these countries*
  - Russian imports are partly compensated by LNG
  - Other gas imports have no margin left

Additional LNG imports (compared to standard case)

Loss of load

Disabled gas imports



Russian exports through Ukraine are cut all year

Loss of load in the Ukraine gas supply disruption case
(of which 140 TWh for non-EU countries)

Main Findings

- Europe's existing gas infrastructure is able to face most supply disruptions cases, even under a high gas demand scenario, which includes low efficiency improvements and a coal to gas shift in the power sector.

- Deep dive on South Eastern Europe
  - The only region which requires reinforcement is South-Eastern Europe to provide optionality to Russian imports via Ukraine, but these investments are relatively small compared to other planned investments in the energy sector
  - A smarter integration of European gas and electricity system can decrease by 45% the infrastructure investments in the region to ensure security of supply, whatever the gas demand scenario (savings of 0,9 to 6,4 bn€)
  - Meeting the 2030 targets for energy efficiency would also significantly decrease the investments required to ensure security of supply in South-Eastern Europe

- Investing in additional gas infrastructure up to 2030 would increase the stranded assets in 2050

Integrated approach

Synergies between gas and power systems

	Stakes in peak demand	Stakes in yearly consumption
Power System	High (Generation adequacy)	Low (Only for hydro storage management)
Gas System	Medium (Gas storages can efficiently smooth gas demand)	High (Gas storage capacity, take-or-pay obligations)

- Benefits of the integrated approach
  - Displacement (location) of CCGT **use**
    - *From SEE to other countries*
  - Switch to oil to cover part of industry demand during crisis situations
    - *Dual back-up capacities already exist*
    - *No additional investment costs nor construction delay*

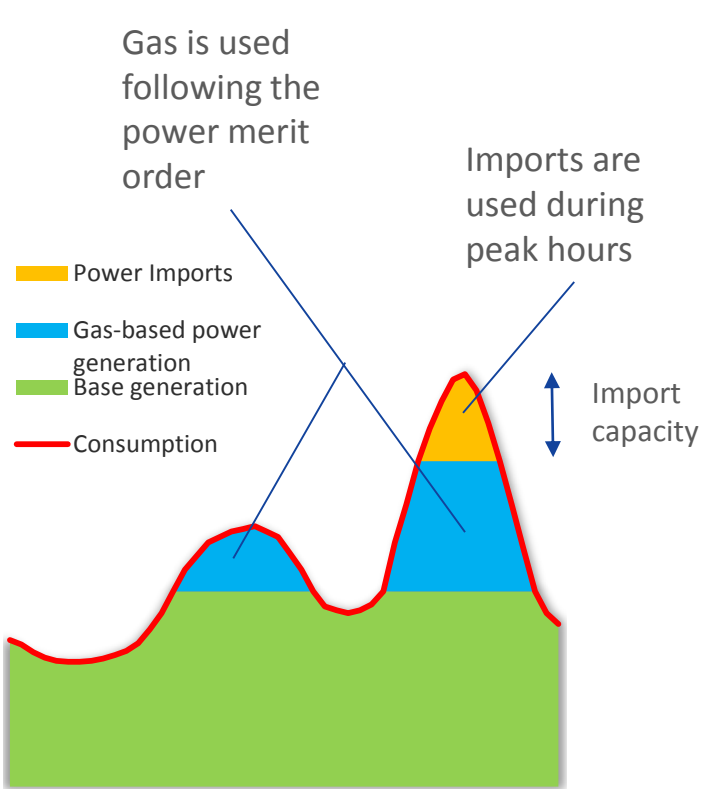
Yearly gas demand is substantially reduced in congested areas

Required investments to cover security of supply are reduced

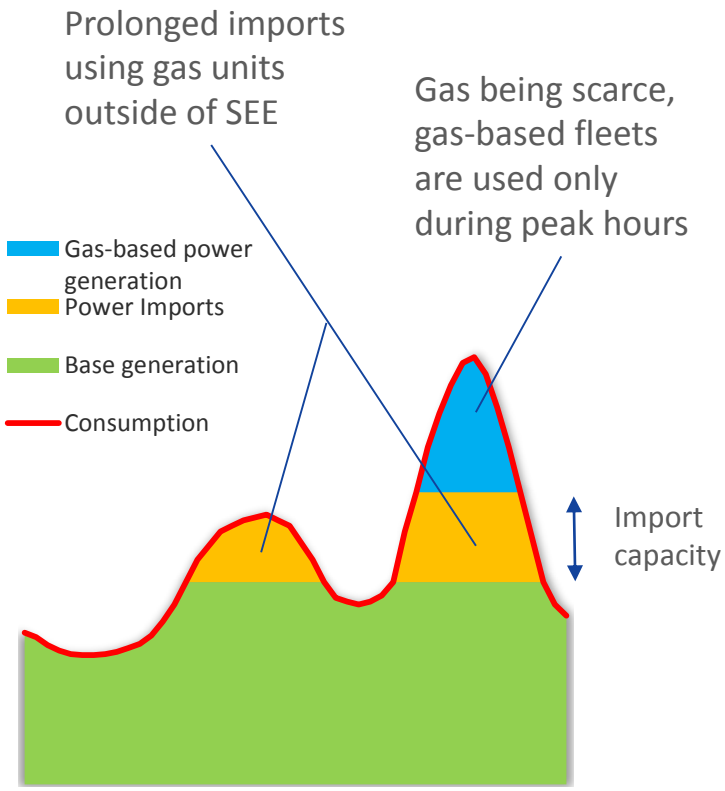
Integrated approach

The gas system benefits from flexibilities of the power system

Power consumption and generation in SEE



Standard approach



Integrated approach

Current trends 2030 – Integrated approach

Investments to ensure security of supply are greatly reduced

- Need for investments to face Ukraine transit disruption are reduced due to the flexibility on gas demand
- Savings of
  - 7 GW of LNG terminals and gas reserves
  - 40% of pipelines (29 GW)

Additional required transmission capacity (Pipelines, GW)

Additional required LNG capacity (GW)

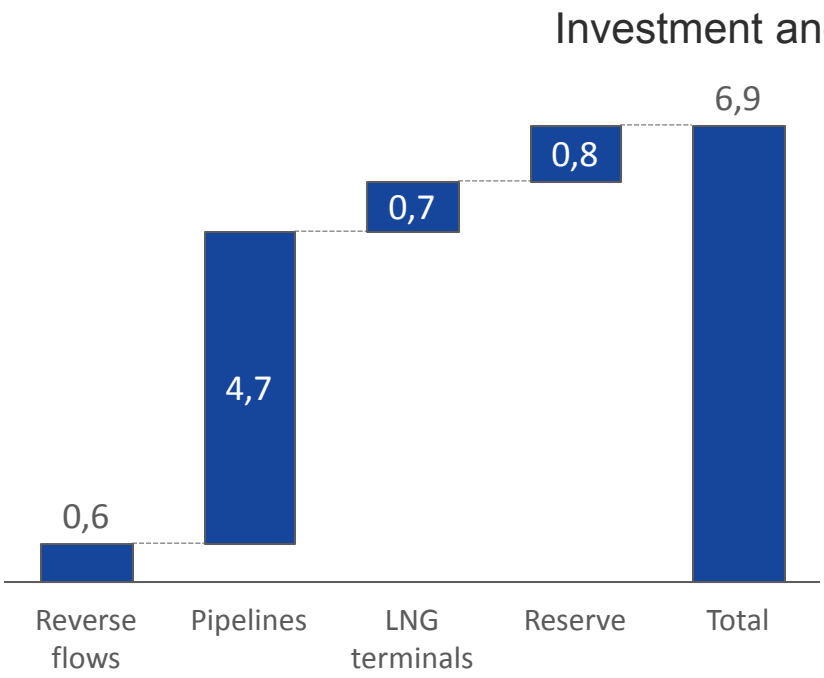
Additional Storage capacity (GW)

Scenario	Current Trends	
Strategy	Gas only	Integrated

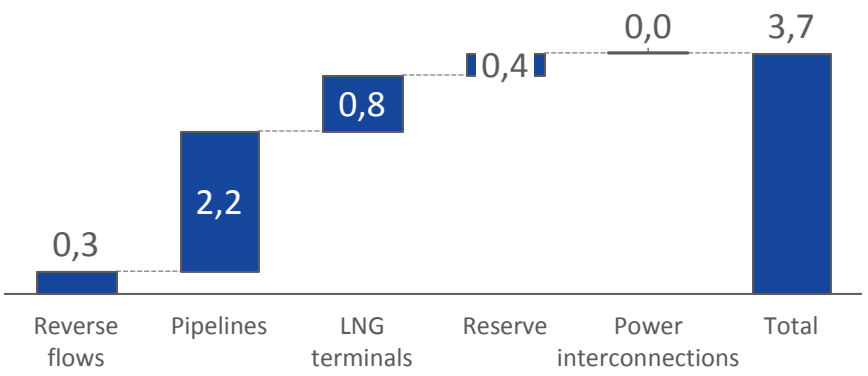
Current trends 2030 – Integrated approach

Investments to ensure security of supply are greatly reduced

- The integrated approach saves 3.2bn€ of gas investment costs without any additional investments



Gas-Only approach

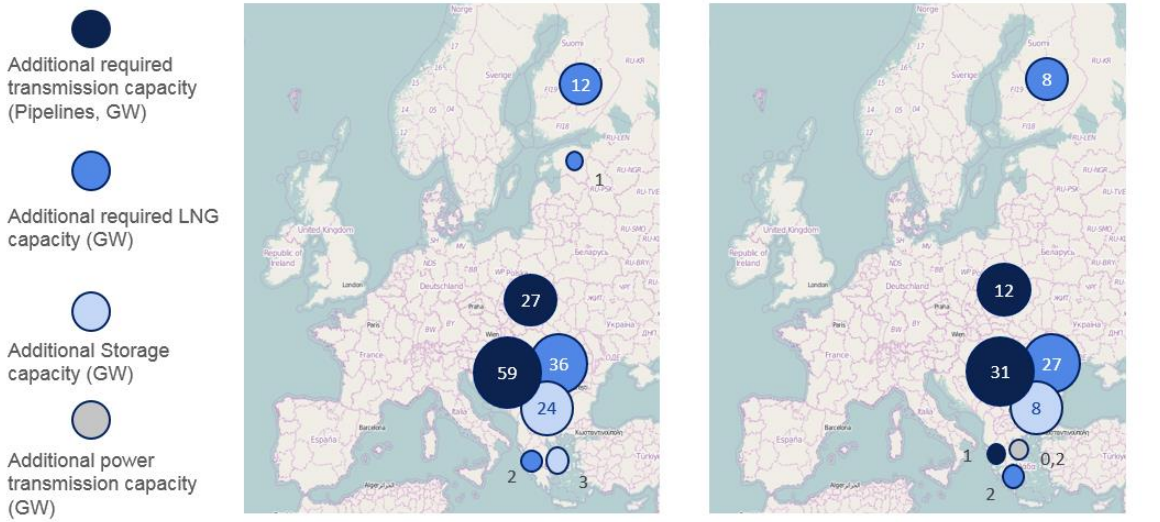


Integrated approach

High demand 2030 – Integrated approach

Savings are even higher in a coal to gas shift scenario

- Gas share in SEE power generation is higher than in Current trends scenario
  - +10 GW of capacity to replace coal fleets in SEE
  - 174 TWh of gas consumption for power (compared to 38 TWh in Current trends)
- Savings of the integrated approach are increased
  - 19 GW of strategic reserve, 14 GW of LNG terminals
  - 48% of additional pipelines (48 GW)

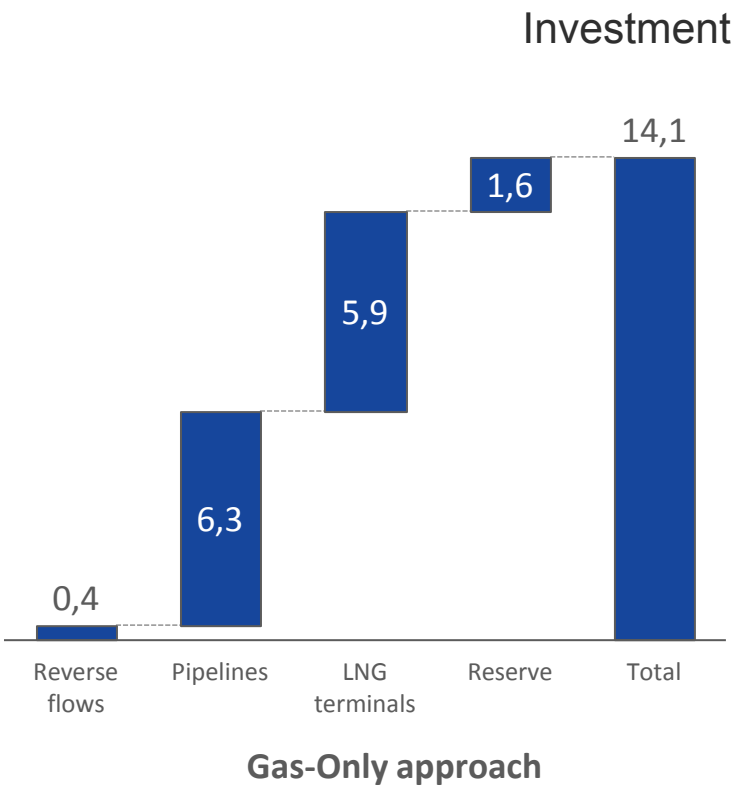


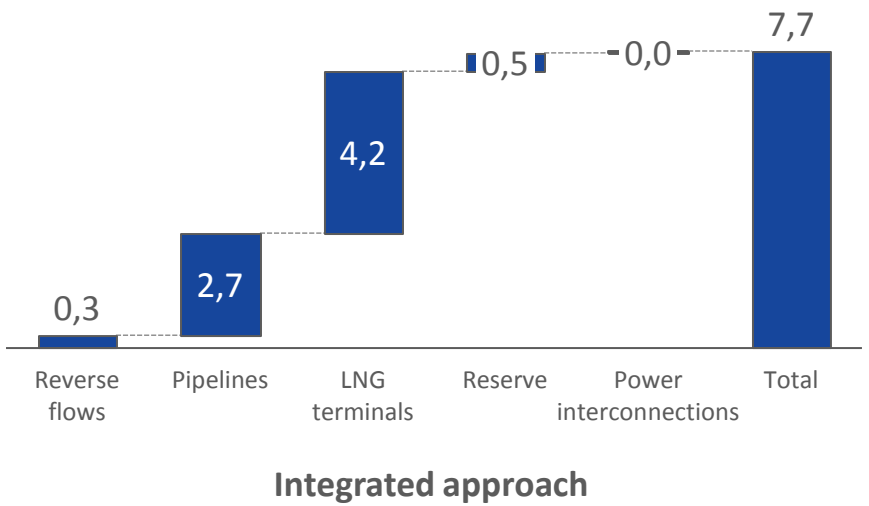
Scenario	High demand	
Strategy	Gas only	Integrated

High demand 2030 – Integrated approach

Savings are even higher in a coal to gas shift scenario

- An integrated approach saves 6.4bn€ of investment costs
  - Higher savings with a shift from coal to gas





Main Findings

- Europe's existing gas infrastructure is able to face most supply disruptions cases, even under a high gas demand scenario, which includes low efficiency improvements and a coal to gas shift in the power sector.

- Deep dive on South Eastern Europe
  - The only region which requires reinforcement is South-Eastern Europe to provide optionality to Russian imports via Ukraine, but these investments are relatively small compared to other planned investments in the energy sector

  - A smarter integration of European gas and electricity system can decrease by 45% the infrastructure investments in the region to ensure security of supply, whatever the gas demand scenario (savings of 0,9 to 6,4 bn€)

  - Meeting the 2030 targets for energy efficiency would also significantly decrease the investments required to ensure security of supply in South-Eastern Europe

- Investing in additional gas infrastructure up to 2030 would increase the stranded assets in 2050

Main Findings

- Europe's existing gas infrastructure is able to face most supply disruptions cases, even under a high gas demand scenario, which includes low efficiency improvements and a coal to gas shift in the power sector.

- Deep dive on South Eastern Europe
  - The only region which requires reinforcement is South-Eastern Europe to provide optionality to Russian imports via Ukraine, but these investments are relatively small compared to other planned investments in the energy sector
  - A smarter integration of European gas and electricity system can decrease by 45% the infrastructure investments in the region to ensure security of supply, whatever the gas demand scenario (savings of 0,9 to 6,4 bn€)
  - Meeting the 2030 targets for energy efficiency would also significantly decrease the investments required to ensure security of supply in South-Eastern Europe

- Investing in additional gas infrastructure up to 2030 would increase the stranded assets in 2050

CONTACT

Artelys France

12 rue du Quatre Septembre
75002 – Paris, FRANCE

Artelys Canada

2001 Bd Robert Bourassa #1700
H3A 2A6 – Montréal, QC, CANADA

Artelys USA

150 N Michigan Avenue, Suite 800
60601 – Chicago, IL, USA

Artelys UK

Aldgate tower, 6th floor, 2 Leman Street
E1 8FA – London, UK