Energy Union Choices

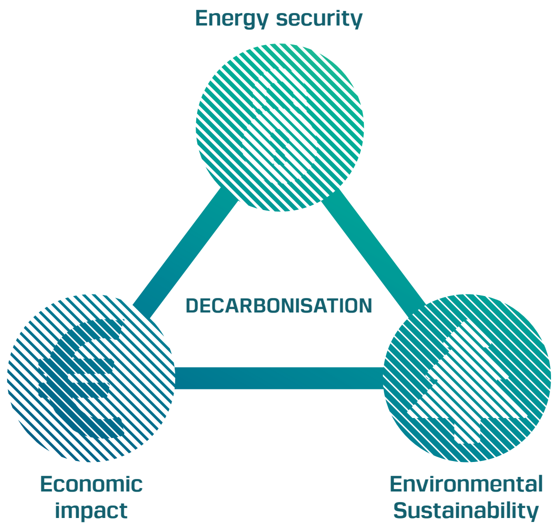
A Perspective on Infrastructure and Energy Security In the Transition

Foreword

The *Energy Union* agenda presents the European Commission and Member States with a unique opportunity to accelerate the transition to a low carbon energy system in Europe. The choices made in the coming years will either lock in high-risk fossil assets, or set the framework for a more flexible and resilient energy system. These decisions will impact Europe's ability to manage the transition in an orderly and timely manner.

In October 2014, the European Council adopted 2030 targets for greenhouse gases (GHG), renewable energy sources (RES) energy efficiency (EE) and electricity interconnections. In parallel, the Commission adopted the *Energy Union with a Forward Looking Climate Policy* as a strategic pillar for the next 5 years.

The new political umbrella is an opportunity to deepen Member States and stakeholders' engagement on energy and climate issues in Europe. That is very important and timely. As the world came together in Paris at the UNFCCC COP21, adopting the Paris Agreement, Europe is no longer alone acting on climate or deploying clean technologies. All countries around the world have committed to taking concrete steps to decarbonise their economies. The international agreement gives further clarity to the direction of travel for Europe. More than ever the low carbon transition should be the



starting point and end goal for every debate on EU's energy policy.

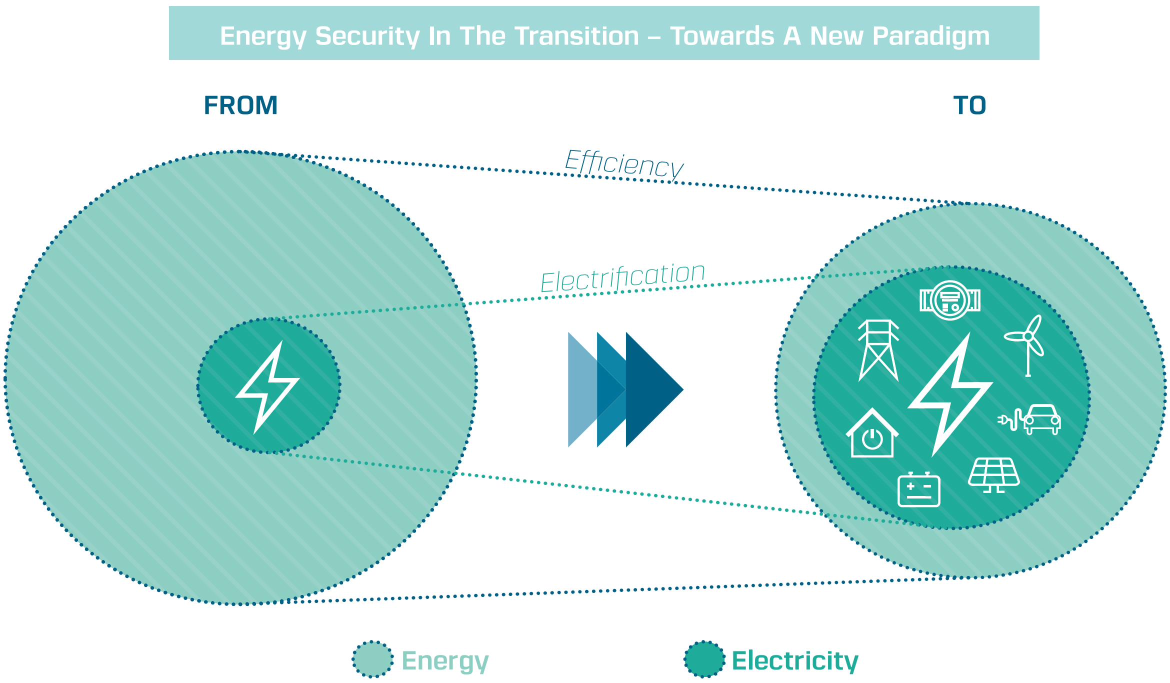
It is within this context of a forward-looking, post-Paris Energy Union agenda that the European

[1] Roadmap 2050: A Practical Guide To A Prosperous, Low Carbon Europe, 2010-2014. www.roadmap2050.eu

Climate Foundation and partner organisations E3G, Cambridge Institute for Sustainable Leadership (CISL), the Regulatory Assistance Project (RAP), Agora Energiewende and WWF decided to embark on a new initiative, called *Energy Union Choices*. *Energy Union Choices* builds on the understanding of the long-term implications of the energy transition established in the Roadmap 2050 reports[1]. *Energy Union Choices* aims to take the next step and break new ground. It stands for an inclusive, transparent approach to developing knowledge, and provides an integrated perspective on the infrastructure priorities for the European energy transition.

For the *Energy Union Choices* partners, this is the beginning of a multi-year project. The aim is to gradually build the analytical tools fit to analyse the next level of system integration questions. As efficiency and electrification trends fundamentally change demand profiles and make energy systems interact more closely, it becomes more important to look at gas and electricity systems together, both from a demand and supply angle. A siloed approach will lead to sub-optimal infrastructure choices and priorities and affect the quality of decision-making.

This report is the first output of this new project. Already now, looking at questions around gas security of supply, the benefits of an integrated perspective are clear and compelling. A new energy security picture is emerging – one that is based on the ability to capture and manage flexible demand and supply across a more



efficient and electrified economy. Understanding and embedding these trends in improved analytical tools will be critical to make the right choices in a post-Paris context.

We look forward to your reactions on this report, and invite you for a discussion on future *Energy Union Choices* products.

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Glossary

Bcm: Refers to the energy unit of one billion cubic meter of Natural gas (1 bcm is equivalent to 10.8 TWh GCV). This unit is also used as a capacity unit as Bcm/year or mcm/day.

Gas infrastructure: includes pipelines, LNG terminals, storage capacities and reverse flows upgrade.

Gas only approach: Assessing the gas investments requirements by looking only at the gas system

Integrated approach: Assessing the gas investments requirements by looking simultaneously at gas, power and demand response.

LNG (Liquefied natural gas): Natural gas that has been liquefied by reducing its temperature at atmospheric pressure. LNG is the form used to transport natural gas over long distances.

LNG terminal: is an infrastructure for liquefied natural gas to store. It can comprise special tanks, ships or even building structures.

Loss of load: Loss of load represents the quantity of energy demand that is not met. It is the usual metric used to assess security of supply.

Peak demand / peak load: Refers to a particularly high point in the energy demand, meaning a period in which energy should be provided at a significantly higher level than average supply level.

PRIMES: Partial equilibrium energy model developed by Athens University, mainly used by the European Commission to define its prospective energy scenarios.

Scenario: A scenario describes a possible future for the European Energy context (energy demand, fuel prices, power generation mix ...).

South-Eastern Europe (SEE): In this report, this denotation includes Bosnia, Bulgaria, Croatia, Hungary, Macedonia, Romania and Serbia.

Stress case: a stress case simulates a shock affecting gas supply (a main supplier disruption) or demand (extreme weather conditions)

Executive Summary

Energy underpins our economy and society. European citizens need warm homes, functioning infrastructure, and thriving businesses and industry. Unexpected disruptions can have both an economic and social cost. As a result, energy security has become a key theme in the EU's Energy Union strategy.

As the European Union strives to reach its climate and energy targets for 2020 and beyond, the nature of the energy security challenge is changing. There are significant uncertainties surrounding the EU energy system, around future demand, demand profiles and flexibility, as well as the impact of new technologies and the location of generation. As European policies make the economy more energy efficient and electricity-based, the integration of energy systems and the reliability of renewable energy sources become more important in the system.

Energy security is often quoted as the reason for new infrastructure projects. Most energy related infrastructure investments are capital-heavy and long-lived (40 years and more), which means infrastructure built today will be part of EU energy system in 2050. Any assessment of energy security and infrastructure investments should, therefore, take into account the long-term energy trends and climate goals and have deep decarbonisaton at its core.

The *Energy Union Choices* project aims to bring a wider perspective to the question of energy security and infrastructure in the transition, using the latest analytical tools to support key stakeholders in making the most resilient choices. Energy security and infrastructure investments are often assessed in isolation leading to sub-optimal, if not contradictory, outcomes. It is therefore important that analytical tools and methodologies bring an integrated energy system perspective, particularly looking at the gas and electricity systems together.

This report provides a perspective on the resilience of the EU gas system and the adequacy of existing capacity under a set of different possible futures and scenarios. The scenarios represent a wide range of energy demand projections and looks at a set of extreme disruption cases. It seeks to answer the questions: Which infrastructure investments are lowest

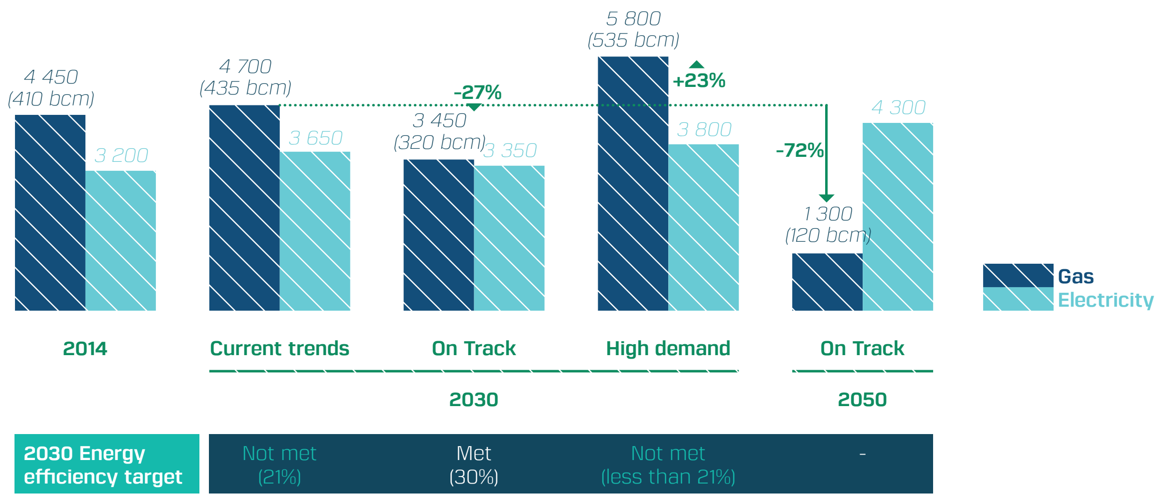


Figure 1: Gas and power demand in Europe, for the scenarios considered (in TWh)

risk and regret to ensure resilience throughout the transition? Can an integrated view of infrastructure investments (across electricity, gas, heat, demand-side and storage) help meet security of supply challenges at a lower cost?

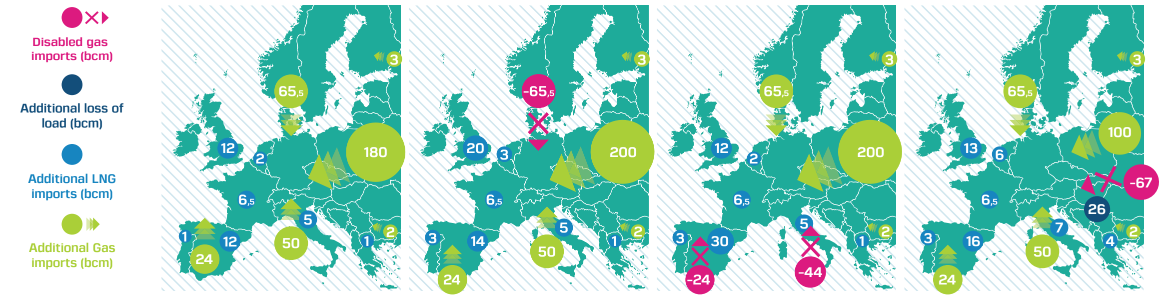
The study looks primarily at the 2030 horizon but also tests implications in a 2050 perspective in line with the EU's longer-term decarbonisation goals.

Finding 1: Europe's current gas infrastructure is largely resilient to a wide range of demand futures and extreme supply disruption cases, with the exception of some countries mostly in South-Eastern Europe under specific circumstances

Under normal market conditions, Europe does not need any new import capacities into Europe or cross-border gas infrastructure between Member States to secure supplies. Extrapolating current trends and policies in the European energy market to 2030, gas demand remains at similar levels as today prompting no supply shortages or new infrastructure needs. The situation improves substantially in the case of full implementation of 2030 targets, as demand reduces to 320 bcm (from 410 bcm today).

Even in a scenario where gas demand increases towards 2030 (to 535 bcm), the analysis shows that the diversity of existing gas routes and infrastructure is sufficient to avoid loss of load in the European Union. While this scenario represents a real failure to meet the 2030 targets, it indicates that the continent's existing gas infrastructure has a good margin to secure supplies. Also, it should give policy makers the confidence that the existing gas system can handle an accelerated coal phase-out in the power sector without significant new infrastructure investments.

Also under extreme cold weather conditions, with an 8% increase in average consumption, existing



Scenario	Extreme cold	Norway disruption	North Africa disruption	Ukraine disruption
Finding	Little or no disruption in any demand scenario	Little or no disruption in any demand scenario	Little or no disruption in any demand scenario	Significant disruption in South East Europe; little or no disruption elsewhere

Figure 2: Gas imports and loss of load under extreme conditions (Current Trends, 2030).

infrastructures can ensure gas security of supply for most of Europe. Only in a few countries, like Serbia and Finland, the margins are rather tight and cold weather conditions in combination with high demand can lead to some security of supply concerns[2].

It is common practice at national and EU level to assess system resilience against a range of disruption scenarios that are considered likely and impactful. Infrastructure investments are then prioritized accordingly. This report finds that current gas infrastructure in Europe provides sufficient optionality to face major and unprecedented stress and supply disruptions cases.

For example, if imports from North Africa were interrupted for an entire year, EU countries could rely on more Russian gas (+ 48 bcm, adding up to a total of 201 bcm) as well as more Iberian LNG imports (+ 19.5 bcm, adding up to a total of 32.5 bcm), transported across the continent via existing pipelines. In case Norwegian supplies become unavailable[3], more Russian gas is transported from the east (+ 48 bcm, adding up to a total of 201bcm) and LNG coming in from the south (+ 4 bcm, adding up to a total of 17 bcm).

The extreme case of a yearlong Ukrainian transit shutdown does not result in any loss of load in most of the European continent, with the exception of some countries in South Eastern Europe, which are strongly affected (loss of load up to 26 bcm). This is due to constraints in the pipelines between Western and South Eastern Europe, unable to sustain a sufficient flow of gas from the (largely underutilised) LNG terminals in Western and Northern Europe.

The report identifies South Eastern Europe as the region in Europe where a real gas security of supply issue occurs. The question is to what extent that means new investments in gas infrastructure assets – gas

[2] The Finnish National Energy Security Agency (NESA) developed a specific Gas Emergency Response Plan, which includes gas demand reduction measures, control of gas deliveries, alternatives fuel stock for fuel switching and cut back of contractual supplies (see "Provisions for and actions in a potential disturbance in the Natural Gas supply, NESA, Oil pool committee, 2013")

[3] The Campbell's Atlas of Oil and Gas Depletion (2013) projects that Norwegian gas production could peak in 2018, and that their total fossil fuel production (oil and gas) would decrease by two thirds by 2030.

solution to gas problems –, or whether an integrated perspective on gas, electricity and building infrastructure together can help meet supply security standards at lower costs.

Finding 2: An integrated and regional perspective on gas and electricity systems together helps meet supply security standards at significantly lower costs

In case of gas supply concerns, the tendency is to solely look at gas supply solutions. This report finds that, under current gas demand trends, investments of up to 6.9bn EUR in a mix of new LNG terminals, pipelines and gas storage facilities are required to provide the necessary options to deal with a Ukraine transit disruption case. Under a high gas demand scenario, this number increases to 14.1bn EUR.

A smarter integration of European gas and electricity systems and demand-side management, however, changes the picture and can significantly decrease investments in gas infrastructure. In both demand cases, investment needs are cut in half (to 3.7bn EUR in Current trends scenario and 7.7bn EUR in High demand scenario). This cost reduction comes from an optimal leveraging of the synergies between gas and power systems, by displacing the use (and, to a lesser extent, the location) of gas-based generation in areas with less congestion risks and re-importing the electricity using existing electricity transmissions. Because gas-for-power has the tendency to be peaky, leveraging the power system from other regions has the additional benefits of reducing peak demand in the regions having issues. On the demand side, the use of already existing oil back-up capacities in gas-heavy industries would also contribute significantly to this reduction. Both these aspects help decrease the overall gas demand during crisis situations, which avoids oversizing those new

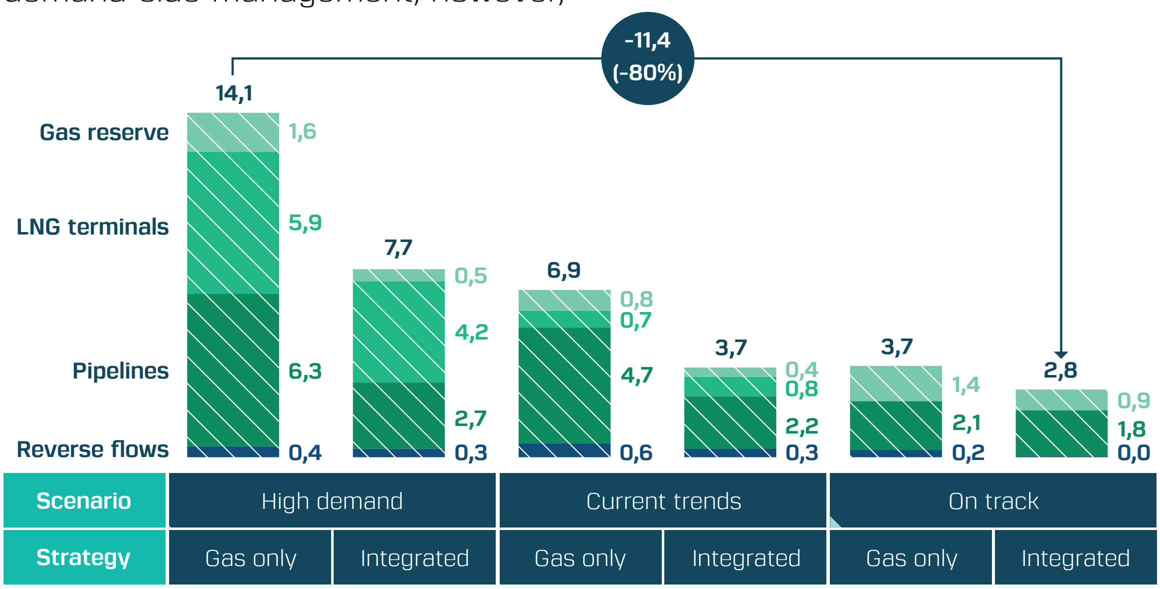


Figure 3: Overview of costs (investments and maintenance) in billion € to ensure security of supply across scenarios and strategies

gas infrastructure assets that are still needed.

Finding 3: Demand reduction as a priority; buildings efficiency significantly reduces investment needs

Buildings are an integral part of the EU's energy system. The report finds that implementing demand side measures, in line with a 2030 efficiency targets[4], can significantly reduce gas demand and infrastructure investments requirements.

This report shows that an integrated perspective on energy security, looking at gas, electricity and buildings efficiency together, has the potential to reduce gas infrastructure investments by 80%, equivalent to 2.8bn (from 14.1bn).

Finding 4: Delivering the EU's 2030 targets can significantly reduce gas imports into Europe

The European Union is currently highly dependent on energy imports. This report finds that, if the EU continues on a low carbon pathway in line with its 2030 climate and energy targets, it can reduce imports with 95bcm (-29%), compared to a scenario that fails to meet these targets.

Finding 5: New gas infrastructure assets will be superfluous by 2050

Large infrastructure assets have a lifetime much beyond the next 15

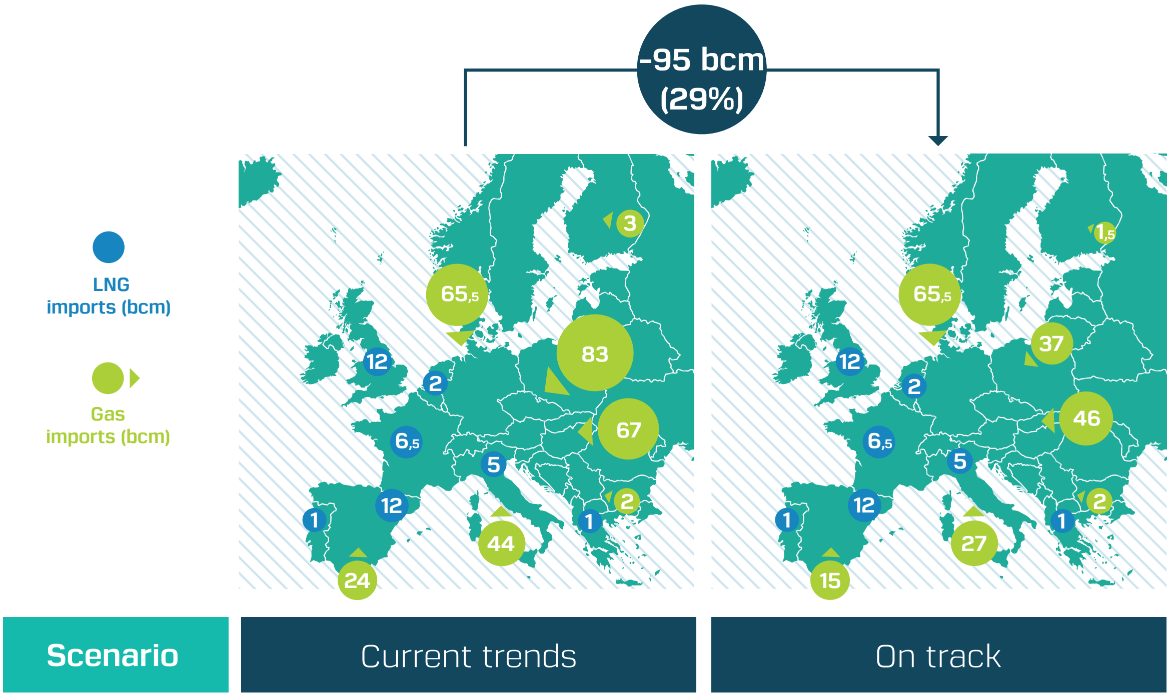


Figure 4: Gas and LNG imports to Europe in the standard case without disruption in 2030, in the Current trends and the On track scenarios

[4]The On track scenario assumes 30% primary energy savings, which is consistent with the upper end of the 2030 target for efficiency adopted at the October 2014 European Council.

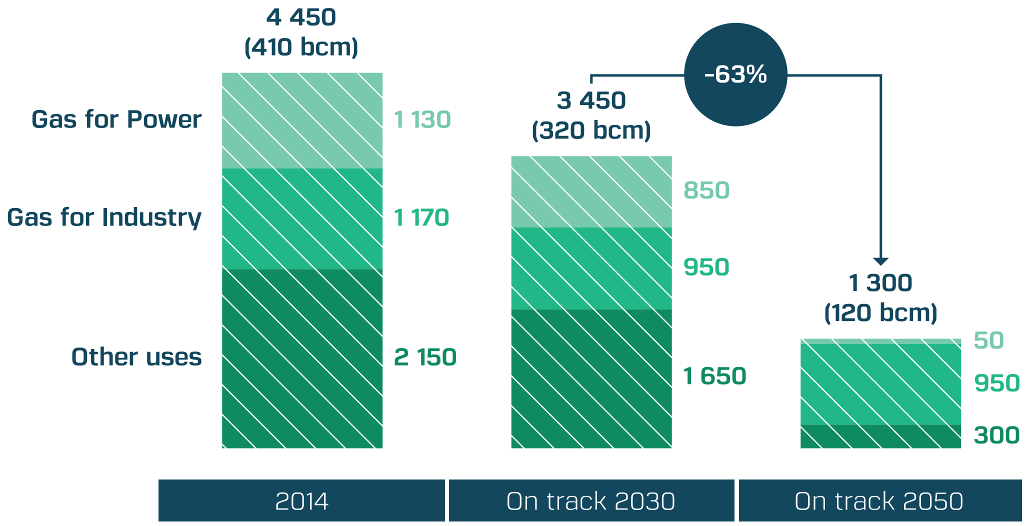


Figure 5: Gas consumption per sector in Europe (TWh and bcm)

years. It is important, therefore, to keep a long-term perspective when assessing investment decisions. By 2050, the dual impact of economy-wide efficiency improvements and electrification trends sharply reduce gas demand in Europe. As shown in figure 1 above, gas demand may reduce to 120bcm, down 63% from 410bcm today, while demand for electricity increases with 28% in the same period. These figures are indicative for the changing nature of the energy security challenge.

That means that any new investment in gas infrastructure in the coming years is at serious risk of becoming stranded before the end of its lifetime. The graph below shows the reduction in imports needed to supply the EU's gas demand in 2050.

The report brings compelling evidence on the benefits of an integrated perspective on infrastructure and energy security. The report takes the European Commission 2030 scenarios as the starting point. The fact that the assumptions around efficiency, renewables and electrification in these scenarios are widely perceived as on the conservative side further supports the robustness of the report's findings.

For the *Energy Union Choices* partners, this is the beginning of a multi-year project. The aim is to further build the analytical tools fit to analyse the next level of system integration questions. Looking ahead, *Energy Union Choices* partners are committed to look into other more transparent sources of information as the basis for any further work. ECF and partner organisations strongly recommend and welcome input from other stakeholders to further enrich the debate.

1 Methodology and key assumptions

1.1 Overall approach

The questions in scope were tackled by modelling the European gas and electricity systems with national granularity. This multi-energy model was then tested under different contexts as described below:

| A set of three 2030 scenarios and one 2050 scenario covers a wide range of possible futures (It compares a "Current trends" scenario against scenarios with higher and lower gas demand projections). These scenarios are described in more detail in the appendix available online (energyunionchoices.eu)::

- The "Current trends" scenario takes the latest available PRIMES Reference scenario (published in 2013), undershooting the 2030 targets for greenhouse gases (GHG), renewable energy sources (RES) and energy efficiency (EE, 21%)
- The low energy demand or "On track" scenario takes the recent EE30 PRIMES scenario published by the European Commission (COM) to test the impact of the new 2030 targets (published in 2014). The scenario also includes higher levels of overall electrification of the economy (mainly in heating and transport sectors), compared with "Current trends" scenario and higher energy savings (30%).

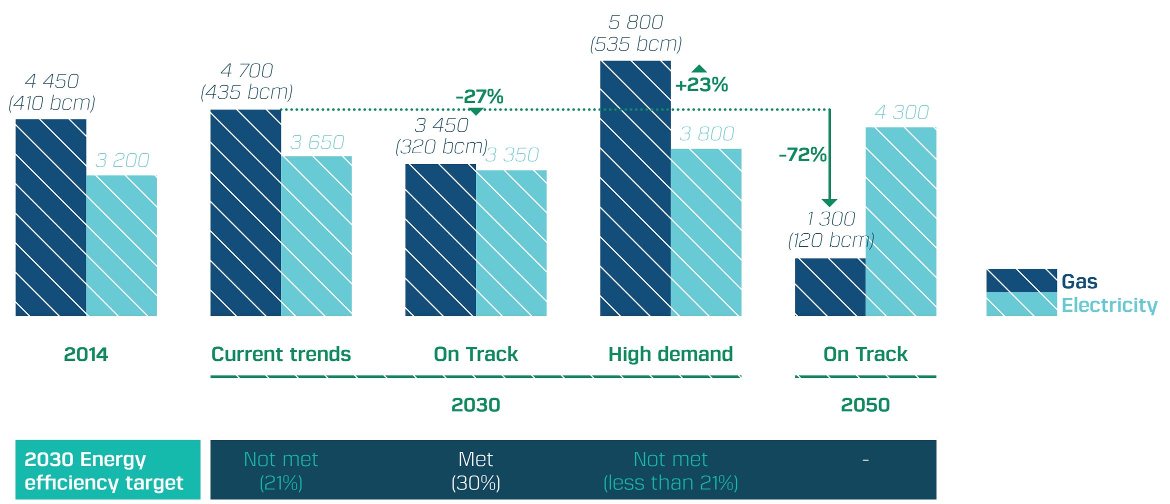


Figure 6: Gas and power demand in Europe, for the scenarios considered (in TWh)

Figure 7: Overall approach of the study

- The "High demand" scenario is based on 2030 ENTSO-E vision 3 (2014) and ENTSO-G Green (published in 2015) scenarios which are consistent with each other and cater for the highest demand on the system. Although this scenario assumes a high development of RES in the power system, it does not attain to 2030 energy efficiency targets. It also shows an increase of the gas consumption as it models a significant coal to gas switch in the power sector in the next 15 years.
- For 2050, one "On track" scenario was used to test longer-term security of supply questions and assess the resilience and perspectives for new and existing gas infrastructure. This scenario, based on a TIMES model, was developed by E4SMA for the energy Modelling Forum and simulates an 80% GHG reduction through high energy efficiency and electrification of the energy system.

The European gas system was set under a variety of stress cases to test how resilient the system was to significant disruptions (gas disruptions from Ukraine transit, Norway or North Africa) or to adverse weather events, all assumed to last for one year.

- 2 main investment strategies were considered in order to face the security of supply issues arising under these stress cases:
    - Either purely gas supply related solutions, e.g., increasing pipeline connectivity, gas storage or adding new LNG capacity;
    - Or, integrated energy solutions, such as leveraging power lines instead of building new gas pipelines, or gas demand response in the industry (on top of gas supply solutions)

1.2 Model and simulations

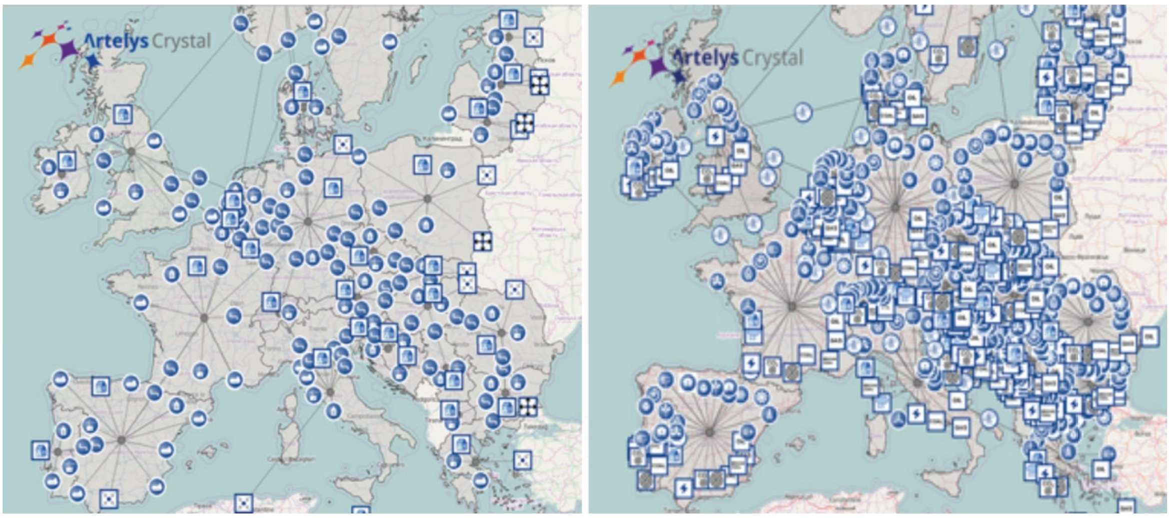


Figure 8: European gas (left) and electricity (right) systems

The main findings presented in section 2 rely on a European multi-energy model, with granularity on Member State level, representing both the gas and power systems, and includes non-EU ENTSO-G countries (Norway, Swiss, Serbia, Bosnia, Macedonia). This model is based on Artelys Crystal Super Grid and takes into account the following assets, aggregated at the national level:

- Gas system: LNG terminals, gas production, pipelines, storage and demand response
- Power system: Power generation (including gas-based generation), interconnections and storage
    - In particular, the model includes gas-based power generation, which makes power and gas systems interdependent.
    - This model allows to minimize operation costs of both systems over a year, at an hourly time-step, and to jointly optimize investments in gas and power infrastructure, using High Performance Computing (up to 1280 processing units).

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The model has first been used to test the resilience of the current gas system to the different scenario/stress case combinations. In these simulations, the use of gas assets (internal production, pipelines, LNG and gas imports from outside of Europe) is optimized to satisfy, as far as possible, gas demand, considering the use of gas for power as an input based on external scenarios. This allowed to highlight the key factors for European gas security of supply, and the areas most impacted by significant events, such as disruption of gas imports from a supplier or a very cold year. Corresponding results are presented in section 2.1.

In a second step, subsequent investment requirements have been assessed in a gas-only model, in which gas consumption for power is also an input of the scenario. In this case, the model optimizes jointly investments (in LNG terminals, storage and pipelines) and operation costs, in order to ensure security of supply at the minimal cost.

Finally, a coordinated gas and power approach has also been tested to deal with gas security of supply. More specifically, the potential of modulating the gas consumption for power throughout Europe to help face gas supply stress cases, was assessed in a multi-energy model. This integrated approach also included the potential for gas demand response in industry through fuel switching. This is further detailed in section 2.2.2.

These simulations allowed us to identify the trade-offs between investments in gas and power infrastructure using the simultaneous flexibilities of both gas and power systems, in particular storage and demand response. Since a wide variety of futures were considered, the simulations also bring to light the main economic drivers for each infrastructure's investments, and which investments are more robust to variations of the economic/energy context.

More information about the model and the two approaches considered can be found in the appendix online.

1.3 Key assumptions

All the main assumptions required for the model simulations are covered in the appendix, available online, but here are some of the major ones:

- The focus of the analysis is on security of supply. Elements such as the impact of investments on gas import prices are not modelled.
- Energy efficiency, deployment of variable renewable energy technologies and electrification of different sectors in the economy are key elements of the energy transition and are captured by using a wide range of scenarios for 2030. Energy end-use (by vector) is

not optimized nor affected by the model, except for fuel switching in the industry sector in the integrated approach.

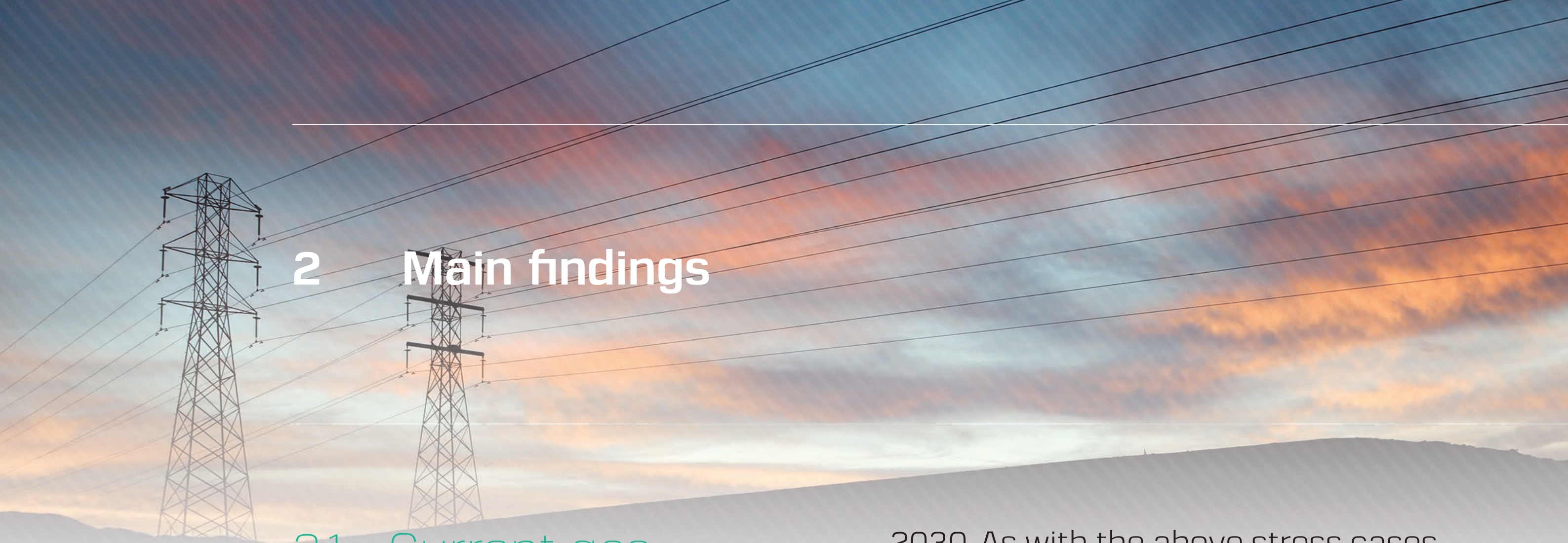
- In this work, system integration is understood as a joint optimization of gas and power systems operations and management. It does not include deeper integration options, for example, around electrification of the transport sector or demand side management across sectors beyond the assumed levels in the scenarios that were used. These are important factors with implications that require further analysis.

- Infrastructures are aggregated at country scale, with cross-border reinforcements assumed to take place from the centre of gravity of a country to another ("centre of gravity" approach). Within country reinforcements are not directly captured in this work.

- LNG imports are limited by technical capacities at the terminal. The global LNG market is not modelled.

- Simulations are performed at an hourly time granularity over a year for the different stress cases. The stress cases assume one-year disruption of a major gas source or a much colder year.

- By using 3 existing scenarios from PRIMES and ENTSO's as input for the optimization modelling, the report's findings are robust, relevant and comparable to the work from the European Commission, Member States and ENTSO-G on infrastructure adequacy. This choice, however, should not be understood as a tacit endorsement of these scenarios. The scope of this report, however, is limited to optimising infrastructure under different future scenarios, leaving aside questions around least-cost pathways.



2 Main findings

2.1 Current gas infrastructure in Europe is largely resilient to a wide range of demand levels and potential supply disruptions

The analysis shows that the current gas infrastructure is sufficient to ensure security of supply in 2030 in Europe. This is the case also under a "High demand" scenario combining high gas demand for buildings and an accelerated coal to gas switch in the power generation sector. The system is also resilient to very cold weather events, in which gas demand for heating and for power generation increase substantially. Major disruptions of gas imports from Norway or North Africa lead to important changes in the gas supply system and the gas flows, but the existing system can still serve the needs by increasing LNG imports and imports from other producing countries.

The largest impact on the system comes from a major disruption in Ukrainian gas supplies. In this case, all Russian gas transiting through Ukraine is stopped for a full year in 2030. As with the above stress cases, the European gas system can handle this massive disruption almost everywhere. The only exception is South Eastern Europe (SEE) where the interconnection to the rest of Europe is insufficient, leading to loss of load in that region.

The results are described in detail in the following sections.

2.1.1 LNG and gas imports to Europe in 2030 in normal conditions

Under standard conditions, i.e. average weather conditions and normal supply conditions, the dispatch simulations find that current infrastructure appears to be sufficient to meet consumption levels in both the On-track and Current trends scenarios. In a higher demand scenario, however, the model shows loss of load in several non-EU28 countries located in South-Eastern Europe (namely, Serbia, Bosnia and Macedonia). This is due to limited or inexistent gas production as well as pipeline congestions limiting imports from Europe, especially during winter peaks.

In any scenario, Europe's main

[5]The internal production's share of the global demand amounts to 18% in High-demand-2030 scenario, 25% in Current-trends-2030 scenario and 36% in On-track- 2030 scenario.

suppliers are Russia with 36% (On track scenario) to 55% (High demand) of global gas and LNG imports, followed by Norway with 28% (On track) to 14% (High demand), and North Africa[5].

It is worth noticing that by meeting its 2030 targets on renewable energy flows in the standard case of each scenario. Note that this picture will be used as a reference. Other figures further down this report will represent relative differences (additional or reduced flows/imports) between the given stress-cases and the standard case of each scenario.

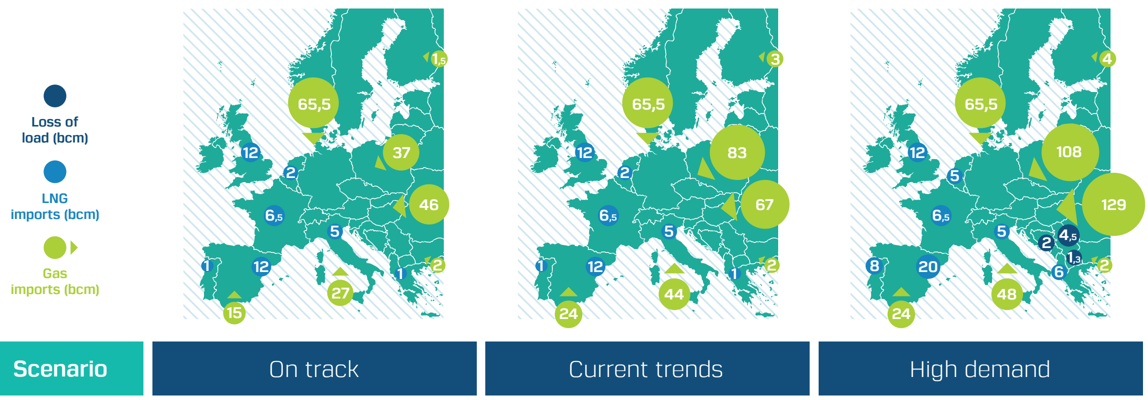


Figure 9: Gas and LNG imports to Europe in the standard case - Overview for the different scenarios

sources and energy efficiency, the EU could reduce its total imports (including LNG) by 29%, compared to the Current trends scenario (that fails to meet these targets) and by 47%, compared to a High demand scenario.

Figure 9 shows the mains import

2.1.2 Current EU gas infrastructure can supply a wide range of gas demand levels, even under a very cold year.

Figure 10 shows how the European gas network reacts to an extreme

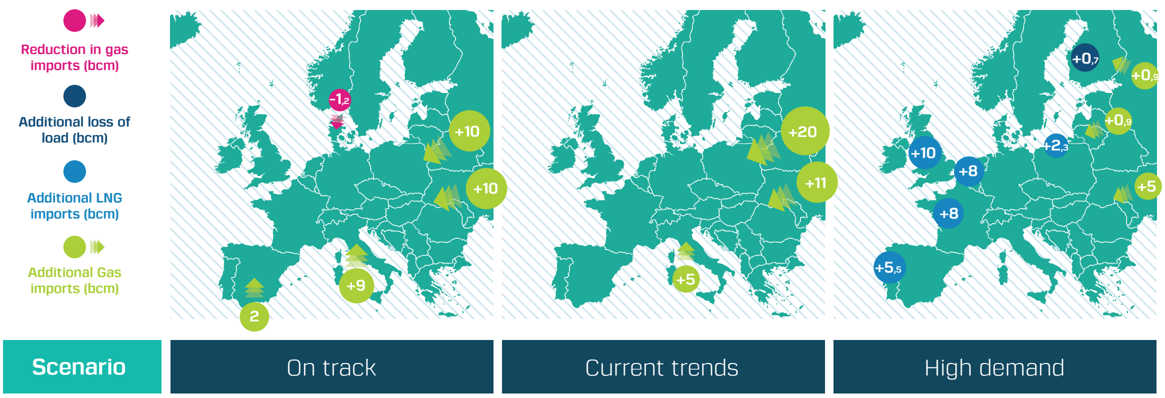


Figure 10: Additional gas imports and loss of load in the cold case, compared to the standard case

[6]This assumption is based on an analysis of the gas consumption's dependence to temperature, using ENTSO-G published consumption data and historical measures of temperature. This dependence comes mainly from the residential and commercial heating sector which impacts directly gas consumption. This also impacts greatly power consumption, and thus gas consumption for power.

cold year in 2030 (1-in-50-year) for the different demand scenarios. The cold spell corresponds to a consumption increase of around 8% in each scenario[6].

Under the Current trends scenario, current infrastructure is sufficient to meet demand even under these extreme cold weather conditions. Imports capacities are sufficient to supply all Member States, using only existing pipelines and increasing imports from Russia and North Africa.

In the High demand scenario, the system is under more stress, as demand growth is larger (+ 144 bcm across Europe). The current gas infrastructures can still cover demand in most of Europe. Finland – which is currently isolated from other European countries[7]– has some minor issues though, with loss of load of 0.7 bcm occurring during peak hours. The Finnish National Energy Security Agency (NESA) developed a specific Gas Emergency Response Plan, which includes gas demand reduction measures, control of gas deliveries, alternatives fuel stock for fuel switching and cut back of contractual supplies[8]. The situation in non-EU countries in South-Eastern Europe (Bosnia, Macedonia and Serbia) under this cold weather case is only marginally worse (0.13bcm) than under the standard case shown in figure 9 above.

Under the On track 2030 scenario, existing infrastructure is largely sufficient to cover the gas demand increase related to cold temperatures. Due to efficiency improvements in the residential and commercial sector, the sensitivity of gas consumption to temperatures is significantly lower.

2.1.3 The EU gas system is also resilient under large disruption scenarios, like the disruption of the Norwegian supply

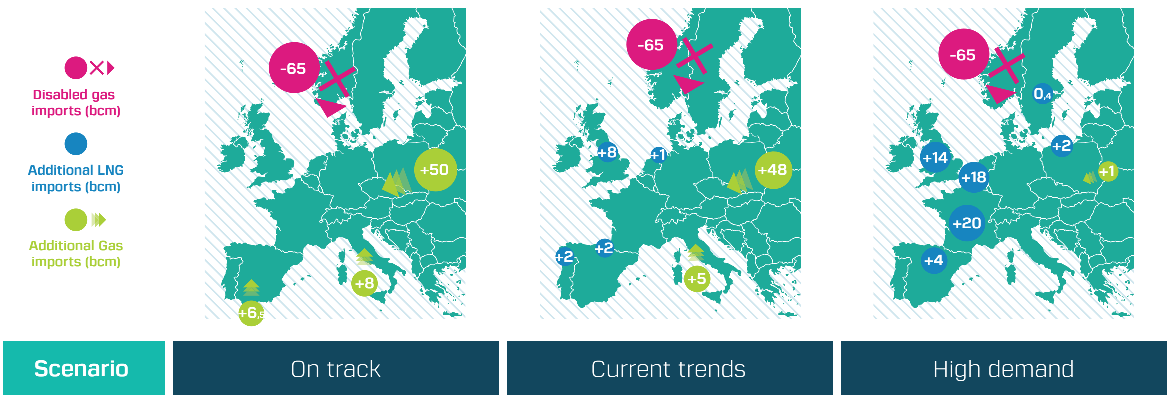


Figure 11: Additional gas and LNG imports in the Norwegian disruption case - All scenarios

[7]Finland could soon be connected to Estonia through the "Baltic connector", that would link Inkoo (FI) and Paldiski (EE) with a 7.2mcm/day capacity. More information can be found in https://ec.europa.eu/energy/sites/ener/files/documents/pci_8_1_1_en.pdf

[8]Finnish National Energy Security Agency (NESA) developed a specific Gas Emergency Response Plan, which includes gas demand reduction measures, control of gas deliveries, alternatives fuel stock for fuel switching and cut back of contractual supplies (see "Provisions for and actions in a potential disturbance in the Natural Gas supply, NESA, Oil pool committee, 2013")

Gas supply from Norway is expected to decline significantly over the next years and decades. Hence, in this study, the EU gas system was tested against a cut of imports from Norway, which is currently one of the two main gas suppliers for Europe. It assumes that Europe cannot import gas from Norway during one whole year, and has to rely on other imports, on the LNG market and from its domestic production. Simulations have shown the diversity of sources and infrastructure to be sufficient to cover the entire EU gas demand, in all three considered scenarios.

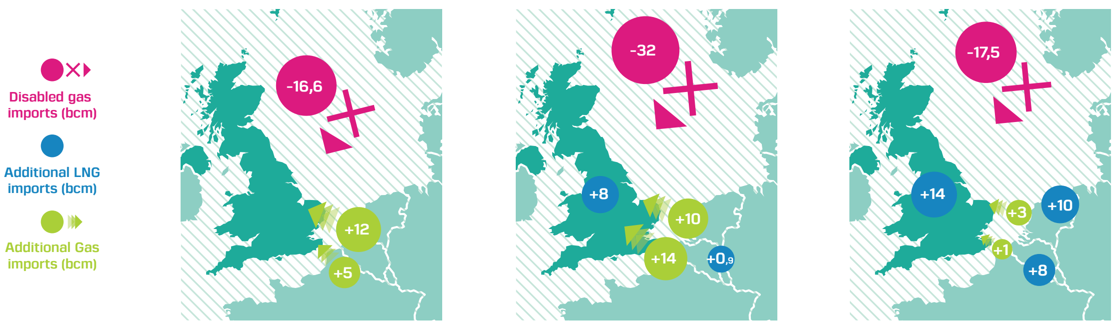
Figure 11 illustrates how the existing gas infrastructure is able to face such a Norwegian supply disruption. In the On track scenario, imports from Russia and North Africa increase to compensate the 65 bcm imports cut down from Norway.

The same strategy is used in the Current trends scenario. However, less room is available for additional imports from Russia and North Africa in this scenario. Indeed, since demand is higher, flows across the system are also overall higher than in the On track scenario. Therefore, more congestions occur in pipelines linking Europe to its other suppliers, as well as in internal transmissions pipelines. Consequently, LNG imports complete the supply in Western Europe, since LNG terminals are particularly under-used in the standard case.

Under the High demand 2030 scenario, on the other hand, pipelines are already highly used in the standard case and cannot provide additional imports. However, LNG terminals capacities – which are under-utilized in the standard case – are sufficient to compensate for the entire Norwegian supply in Western and Northern Europe. Note that South-Eastern Europe faces the same gas shortage as in the standard case. Due to congestions, LNG imports in Western Europe cannot be used to supply South Eastern Europe neither in the standard case, the cold case nor this case.

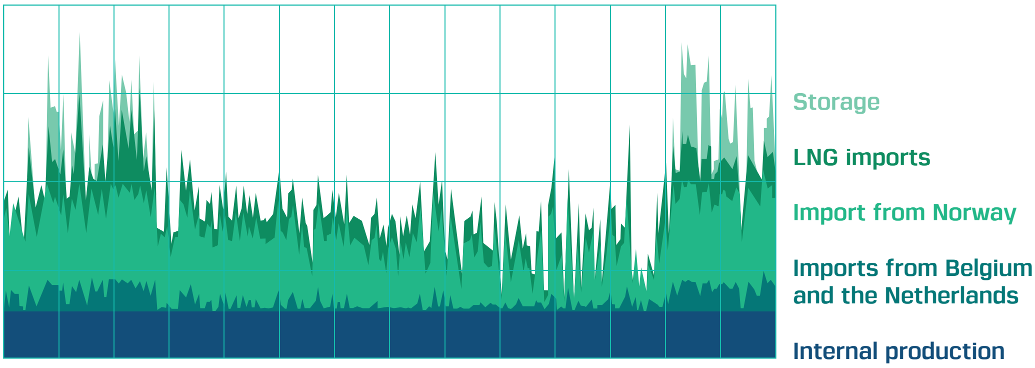
Deep dive on the UK

Figure 12 details United Kingdom's adjustment to Norwegian imports disruption. The LNG terminals in UK increase their imports, as

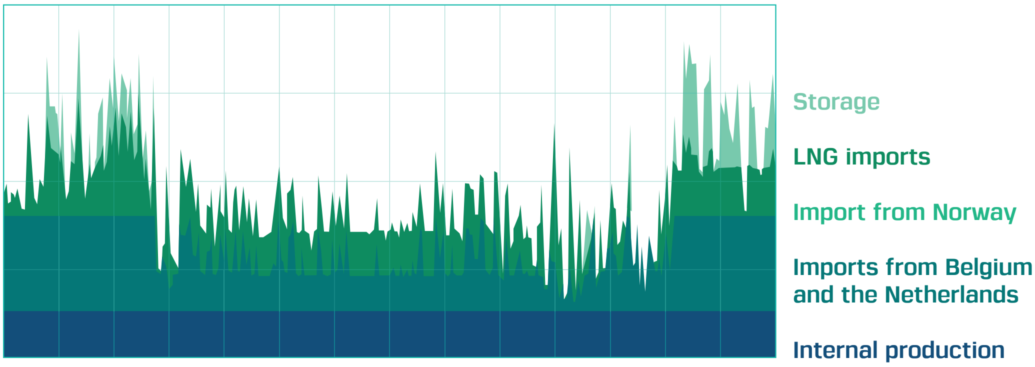


Scenario	On track	Current trends	High demand

Figure 12: Additional gas and LNG imports in the Norwegian disruption case compared to the standard case - Deep-dive on UK



Gas supply sources in UK in the standard case



Gas supply sources in UK in the Norway imports disruption case

Figure 13: Cumulative supply curves for UK in the standard case and in the Norway imports disruption case, for the Current trends scenario

well as those in Belgium and The Netherlands, which are able to send it to UK through pipelines.

Note that the values are still expressed as compared to the standard case (see Figure 9). It is also important to realize that these are the annual balances: in the High demand scenario, 2.4 bcm of gas flows from UK to Continental Europe during summer.

The High demand scenario represents an increase of overall gas usage in Europe, driven by a carbon price of 95EUR/tCO2 in 2030. In Europe, this reduces coal-fired generation to 2% in 2030 while gas-to-power increases to 25%. In the UK, however, the analysis shows that, under the same assumptions, both coal and gas-fired generation reduce in parallel (coal from 30% today to 1% in 2030 and gas from 30% today to 14%). This is due to wind and nuclear coming in first in the merit order.

The findings bring confidence that an orderly transition out of coal in the UK does not lead to gas security of supply issues or any major infrastructure investments.

Figure 13 shows the cumulative supply sources in UK during the whole year, at an hourly daily basis. The imports from Norway are replaced by imports from Belgium and the Netherlands and by increased imports into British LNG terminals. During winter, while both import capacities are used to their full capacity, existing LNG and storage capacities complete the British supply.

Deep dive on Germany

represents an accelerated switch from coal to gas in the German power sector, with coal-fired generation rapidly decreasing from 44% today to 5% in 2030 while gas shares increase

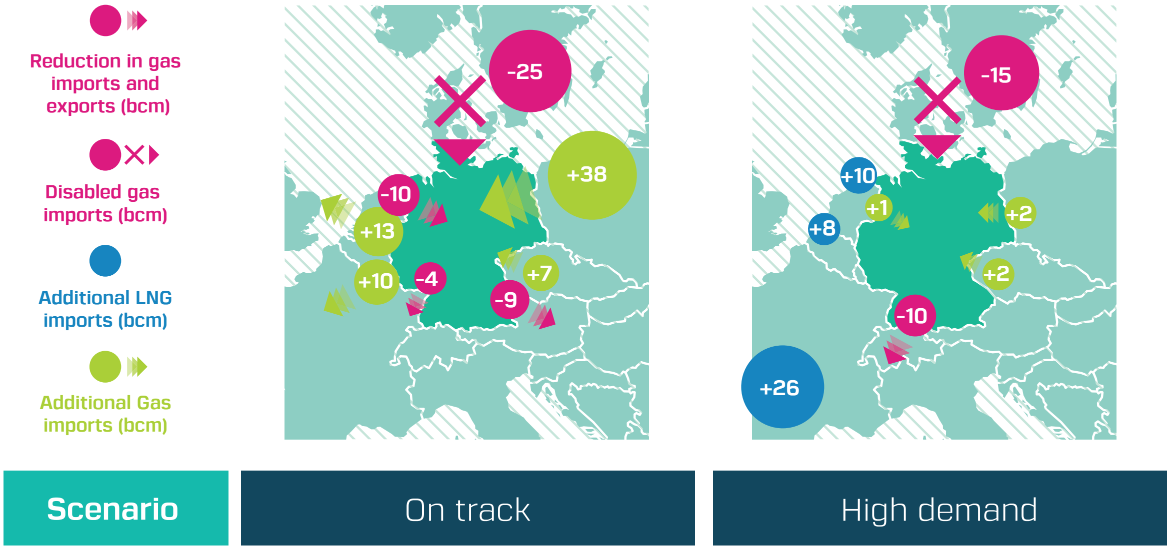


Figure 14: Additional gas and LNG imports in the Norwegian disruption case compared to the standard case - Deep-dive on Germany

Figure 14 shows how existing LNG terminals and pipelines are used to allow Germany to meet its gas demand in case of a shortage of Norwegian supply. Broadly speaking, North-to-South flows are replaced by East-to-West flows in the On track scenarios, as imports from Russia substitute imports from Norway (see Europe-wide map above).

In the High demand scenario, Germany reduces its exports to the South, which was mostly Russian gas. This, however, does not hurt Western and South-Western Europe as LNG capacities are enough to compensate the missing Norwegian gas.

Since the High demand scenario from 10% to 35%, the report finds that an orderly phase-out of coal does not lead to gas security of supply issues or any major infrastructure investments in Germany[9].

The graph also shows that, from a security of supply point of view, there is no need for new import capacity into Germany, like Nord Stream 2.

2.1.4 The EU gas system is also able to cover its demand in case of a disruption of North African imports

The resilience of the EU gas system has also been tested against a disruption of imports from Libya and Algeria, which are historical gas

[9] It is worth noting that while installed capacities of most power generation fleets are inputs from the scenarios, CCGT installed capacities, OCGT installed capacities, power transmissions and electricity production of all generating assets have been optimized (cost-driven/merit order approach).

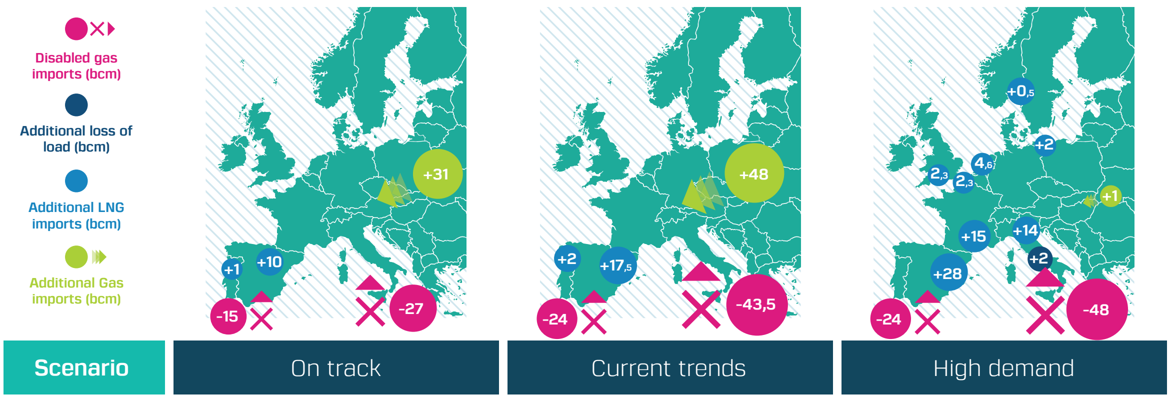


Figure 15: Additional LNG and gas imports in the North African supply disruption case (compared to the standard case) – All scenarios

providers for Europe. In 2014, gas imports from Algeria amounted to 25 bcm (11 % of total imports), while imports from Libya amounted to 7.1 bcm (3 % of total imports). In case of a shutdown of these sources, the EU system would still be able to cover most of its demand as is shown below for the three demand scenarios.

Under the On track 2030 scenario, current import capacity from Russia and the European network is sufficient to compensate the entire import shutdown from North Africa by additional imports from Russia across Europe, with the exception of Spain and Portugal. Indeed, even used at its full capacity all year, the current pipeline between France and Spain cannot supply the required volume to compensate imports from the North Africa disruption. However, LNG terminals in Spain and in Portugal can supply an additional 11 bcm to meet the demand, and still be largely under-exploited.

In the Current trends scenario, imports from Russia cannot be increased by more than 48 bcm with current infrastructures. Since it does not compensate the missing 67 bcm from North Africa imports, LNG terminals are used to complete with an additional 20 bcm.

Under the High demand 2030 scenario, LNG terminals have to be used to a large extent (close to full capacity) as pipelines are already used to a large extent for supplying

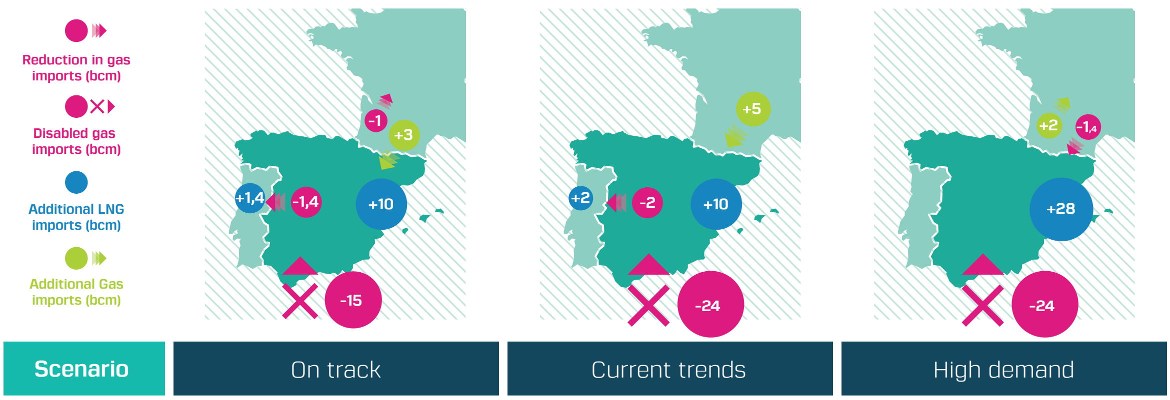
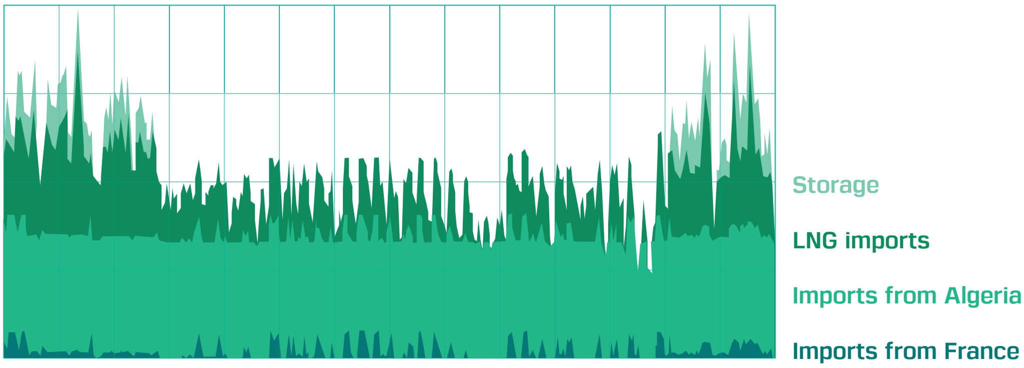


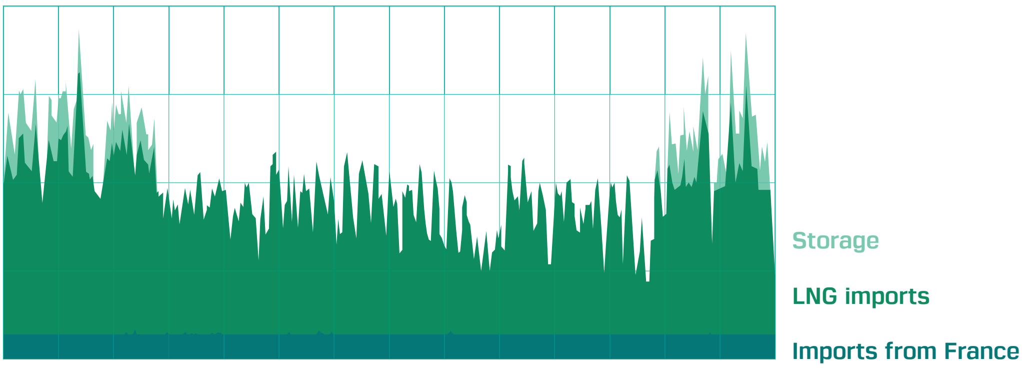
Figure 16: Additional LNG and gas imports in the North African supply disruption case – Deep-dive on Spain

the rest of Europe, which implies that imports from Russia cannot be increased unlike in the two other scenarios.

Deep dive on Spain



Gas supply sources in Spain in the standard case



Gas supply sources in Spain in the North African imports disruption case

Figure 17: Cumulative supply curves for Spain in the standard case and in the North African imports disruption case

As explained above, Spain compensates the missing imports from North Africa by importing more LNG. The following figure shows that in On track and Current trends scenarios, LNG imports are limited to Spain and Portugal uses, completed by flows from France. In the High demand scenario, however, France does not have enough inputs, due to congestions, to transmit flows into Spain. Therefore LNG terminals in Spain, which are largely under-exploited in others scenarios and stress cases, inject up to 28 bcm more in the European network, in order to meet not only Spain's demand but also France's and other countries' beyond it.

Deep dive on France

In the High demand scenario, like in the On track scenario, congestions in the pipeline from France to Spain necessitate to have another source of supply in Spain, and therefore LNG terminals are used there. However, contrarily to the On track scenario, under High demand scenario, LNG terminals in Spain also help supply France, which cannot fully

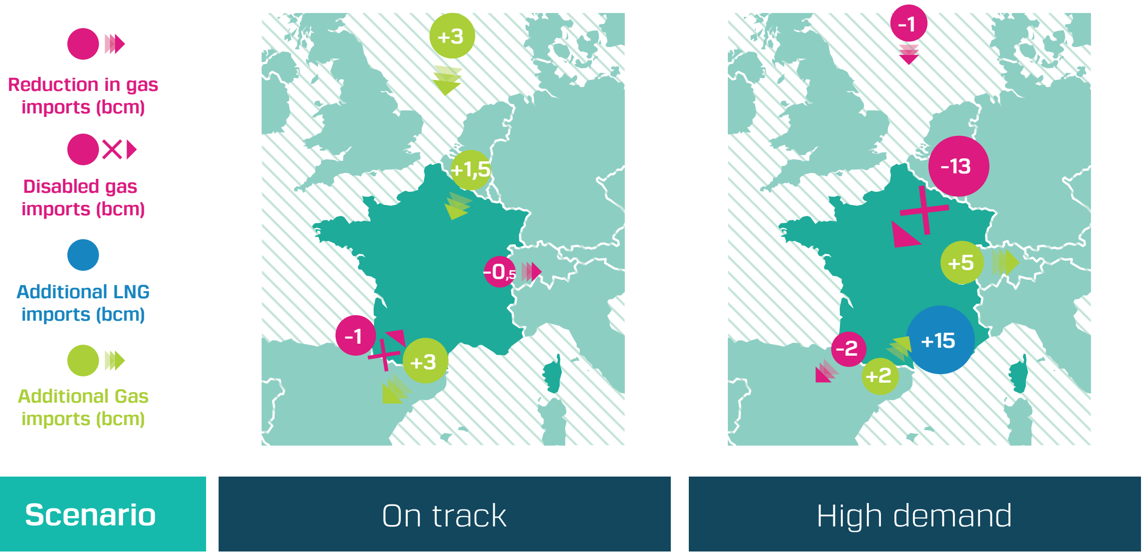


Figure 18: Additional LNG and gas imports in the North African supply disruption case - Deep-dive on France

rely on Russian and Norwegian imports. Indeed, one can notice in the following figures, representing France's particular case, that the annual balance between France and Spain is reversed in the High demand scenario, compared to the On track scenario. Finally, one may notice that, due to LNG imports in France, flows from Germany to France are reduced in the High demand scenario when shutting down imports from North Africa, which allows them to be redirected elsewhere.

Deep dive on Italy

Under the On track scenario, Italy can also cover its demand in the North African disruption case, by importing more gas from Austria and Switzerland. In the High demand case however, the existing pipeline and LNG capacities are at their limit and cannot provide all of the missing 48 bcm. A small amount of loss of load appears (2 bcm), which could be solved either by new investments in LNG for instance, by demand

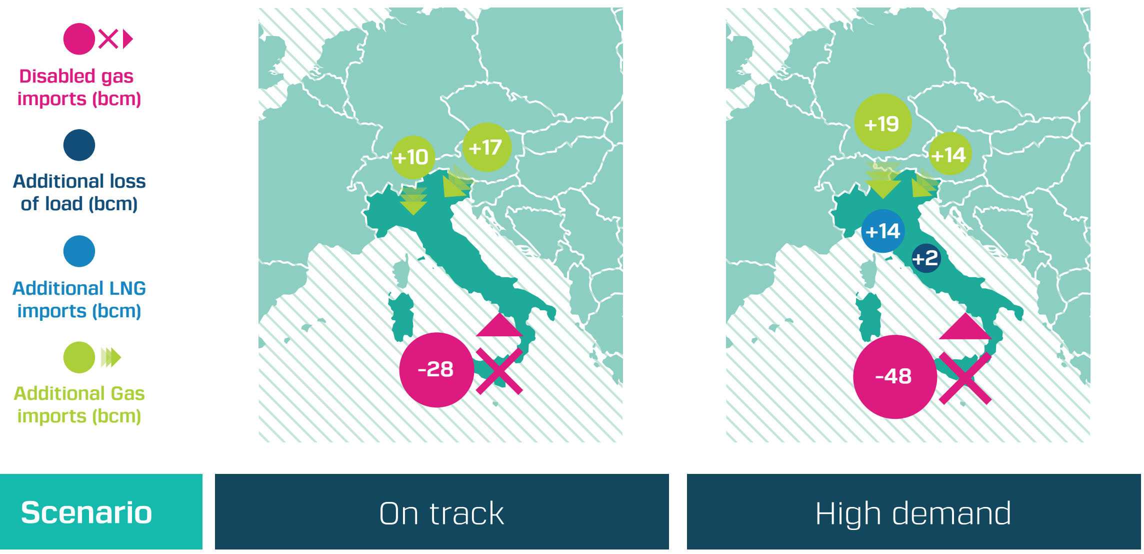


Figure 19: Additional LNG and gas imports in the North African supply disruption case - Deep-dive on Italy

response in the industry sector or even by an integrated management of gas and power systems, as Italy is a gas-heavy power system.

2.1.5 The EU gas system is also able to cover most of EU demand in the case of a Ukraine transit disruption, except in South Eastern Europe where interconnections with the rest of Europe are insufficient

In light of recent geo-political events, the resilience of the EU gas system was assessed against a disruption of imports from Russia through Ukraine. The simulations performed considered as default the part of gas imports from Russia, which transits through Ukraine. Gas transiting through Belarus or coming directly from Russia were assumed to be unaffected.

The only area suffering loss of load in this case is South Eastern Europe, where current alternatives are too limited: the pipeline connectivity capacity to central Europe is limited (1.7 bcm/yr from Slovenia, 4.3 bcm/yr from Austria, 3.9 bcm/yr from SK), and the current pipeline between Greece and Bulgaria – which could provide gas from the existing LNG plants in the region – is unidirectional[10].

The results show that in the On track scenario a disruption would lead to 21 bcm of loss of load in South-Eastern Europe (including Bosnia, Bulgaria, Croatia, Hungary, Romania, Serbia and Macedonia), which represents 57.5% of the gas consumption of the area[11]. The rest of Europe is not impacted, as import capacities from North Africa and from Russia via the Baltics are enough to cover the missing supplies.

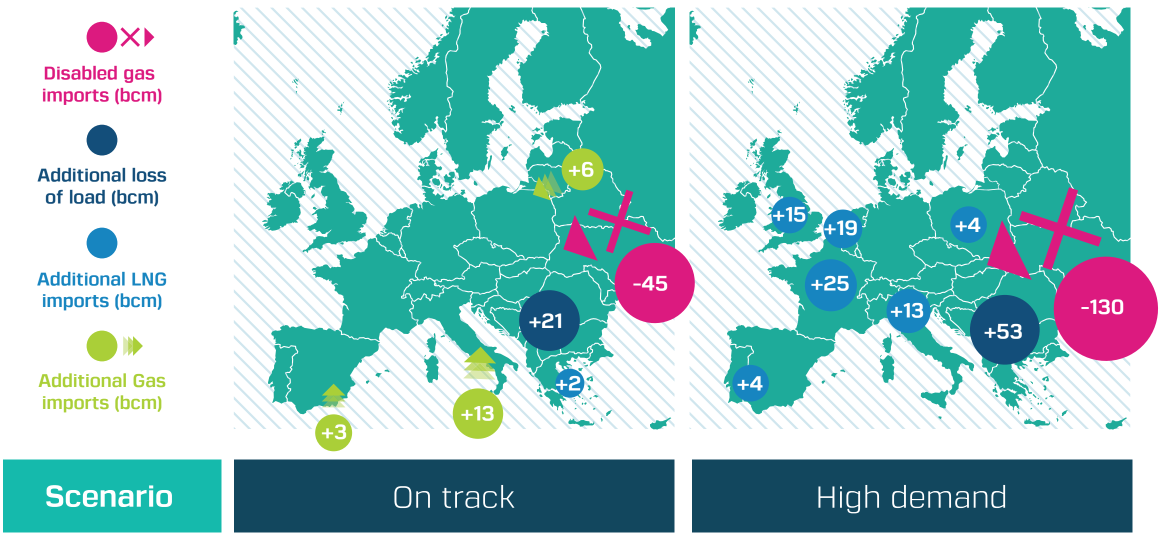


Figure 20: Additional LNG and gas imports in the Ukraine transit disruption case

[10] While the project of building reverse flows on the existing pipeline has been cancelled, another transmission of 13.7 mcm/day between Komotini (GR) and Stara Zagora (BG) is being studied. More information on https://ec.europa.eu/energy/sites/ener/files/documents/pci_6_8_1_en.pdf.

[11] Gas consumption reaches 36.5 bcm in SEE in the On track 2030 scenario. This includes exports to Turkey, which were supposed at the same level than today (12.5 bcm) in all simulations.

The dependence on Russian imports through Ukraine is even more visible in the High demand, where the loss of load in SEE reaches 53 bcm of gas which represents 83% of the consumption of the area in this scenario. The rest of Europe is still able to meet its demand due to the high LNG capacities in Western Europe.

In the next section (2.2), different investment strategies to provide optionality to Russian imports via Ukraine are analysed.

2.2 Better integration of energy systems significantly reduces energy security costs.

The previous section shows that the EU gas system is largely resilient to several extreme disruption cases, with the exception of South-Eastern Europe where some investments or reinforcements to the systems are needed to provide alternatives to Russian imports through Ukraine or to cover for a very cold year. The question is to what extent that means new investments in gas infrastructure assets – gas solution to gas problems –, or whether an integrated perspective on gas, electricity and building infrastructure together can help meet supply security standards at lower costs.

The analysis shows that investments remain limited to 3.7€ billion in the "On-track 2030" scenario. This amount can be reduced by 25% with more integration of gas and power systems. Failing to attain the 2030 energy efficiency targets would increase the investment needs by 80%, highlighting again the wide-reaching impact of energy efficiency measures.

In a "High gas demand" scenario, the investment needs increase to €14.1 billion. Here, an integrated energy systems approach shows even stronger potential in this case, with potential savings of €6.4 billion.

2.2.1 Looking only at gas infrastructure options, investments between 3.7 and 14.1 Bn€ are needed to secure supplies

All the simulations show that large disruptions in supply would significantly affect only one region, South Eastern Europe (that is to say Bosnia, Bulgaria, Croatia, Hungary, Macedonia, Romania and Serbia). However, the investments required in the region to solve this supply risk are relatively limited: for the "On track" scenario they amount to €3.7 billion over the next 15 years. For comparison, all major investments (LNG terminals, cross border pipelines) supported through the list of Projects of Common Interest represent around €40 to 50 billion of investments, of which more than €10 billion are dedicated to the Southern Gas corridor, connecting the EU directly to the Caspian region. This includes making the pipelines

[12] Countries in circles are for South-Eastern Europe: BA, BG, HR, HU, MK, RO, RS; and for Central Europe: AT, CZ, DE, DK, PL, SK, SI. For central Europe, most investments are made on SK-HU and SI-HR.

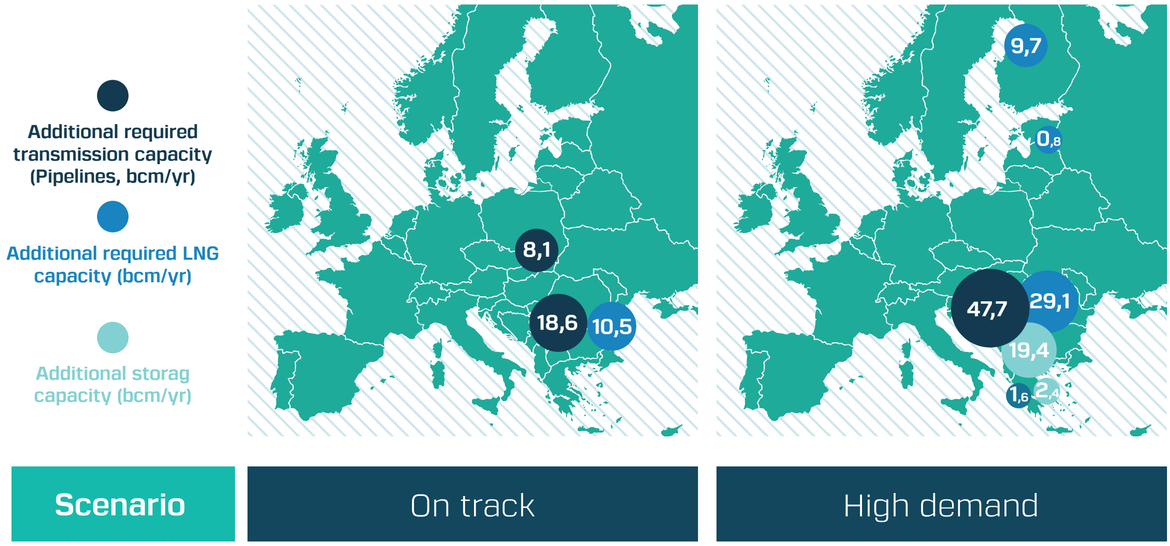


Figure 21: Investments to ensure security of supply in Europe – GAS ONLY approach[12]

to Greece bidirectional, increasing connectivity to the rest of Europe and adding new LNG capacity in the region.

In the On track scenario, the security of supply issues identified in South-Eastern Europe in the case of a year-long Ukraine transit disruption could be solved by some limited investments in the region. These include a mix of 10.5 bcm/yr of LNG, 26.7 bcm/yr of pipelines, and no additional storage capacities. The analysis builds a new interconnector of 7.1 bcm/yr between Slovakia and Hungary to reinforce connections between South-Eastern Europe and the rest of Europe, and a smaller one (1 bcm/yr) between Slovenia and Croatia. Investments in these new capacities amount to around 3.7€ billion, as shown in Figure 21 and Figure 22.

The High demand scenario, where EU energy efficiency targets are

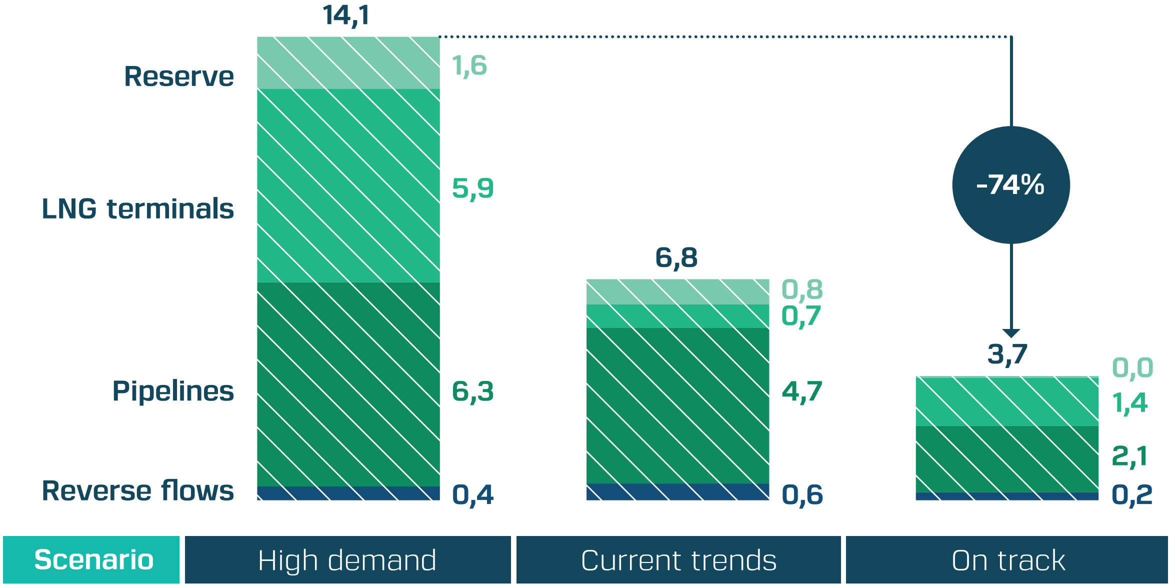


Figure 22: Investment and fixed operation costs to ensure security of supply in Europe (in bn EUR)– GAS ONLY approach

not met and where there is a larger coal to gas shift, is also illustrated in Figure 21 and Figure 22. It shows 14.1€ billion in investment needs. This includes mostly new LNG and storage capacities in South-Eastern Europe and reinforcements of pipelines in the area. The connection between Slovakia and Hungary is also reinforced by 21.8 bcm/yr.

This figure can be reduced through smarter joint planning and modelling of the gas and electricity systems as described in the following section.

2.2.2 An integrated perspective can optimize power and gas systems jointly, reducing the gas infrastructure requirements

When both the gas and electricity systems are looked at together, some new and cost-effective solutions arise to solve the issues identified in South-Eastern Europe. The investments costs in the region (see Figure 24) could be reduced by 25% to 45% if investments for security of supply were decided using an integrated gas/power approach.

This integrated approach allows for fuel switching in the industry sector, in case of periods of lack of gas supply. Indeed, a relatively high share of industries[13] are already equipped with oil back-up capacities and could switch during crisis situations to oil consumption – instead of stopping completely their production – which would reduce the stress on the gas system and thus reduce the investment needs.

The integrated approach also optimises the gas consumption for power generation while taking into account constraints on the gas system. In this case, the use of gas power plants (CCGTs) would be displaced from a region with high gas congestion issues to another region, using existing interconnections to import power in South Eastern Europe.

In standard conditions (Figure 23 - left side), South-Eastern European CCGT fleets are used as mid-merit generation, i.e. during a relatively high number of hours (2000-3000 hours usually), leading to high local gas consumption for power, while power interconnections are used mainly

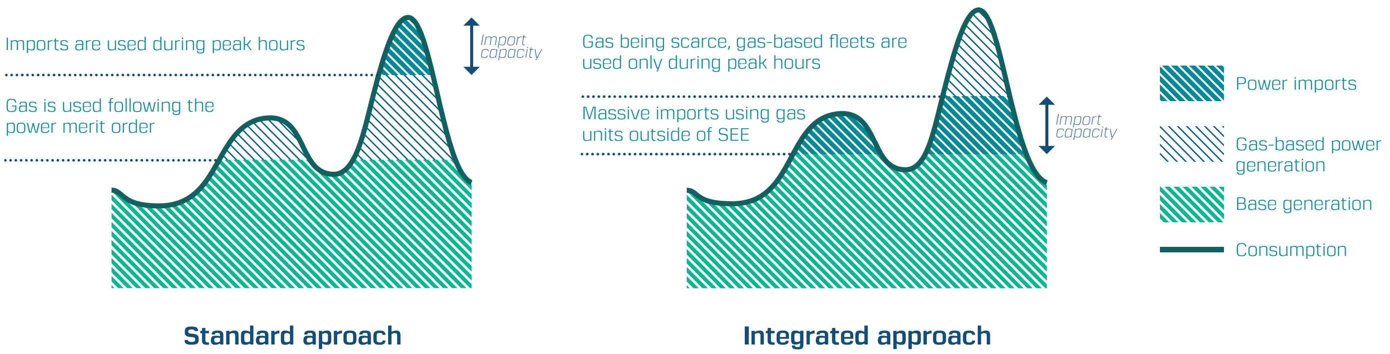


Figure 23. Illustrating the shift in power generation in SEE in case of gas supply disruption, as seen by the standard and integrated approaches

[13]It was assumed in the simulations performed that 30% of industries were equipped of oil back-up capacities, figure driven by studies on current industry mix.

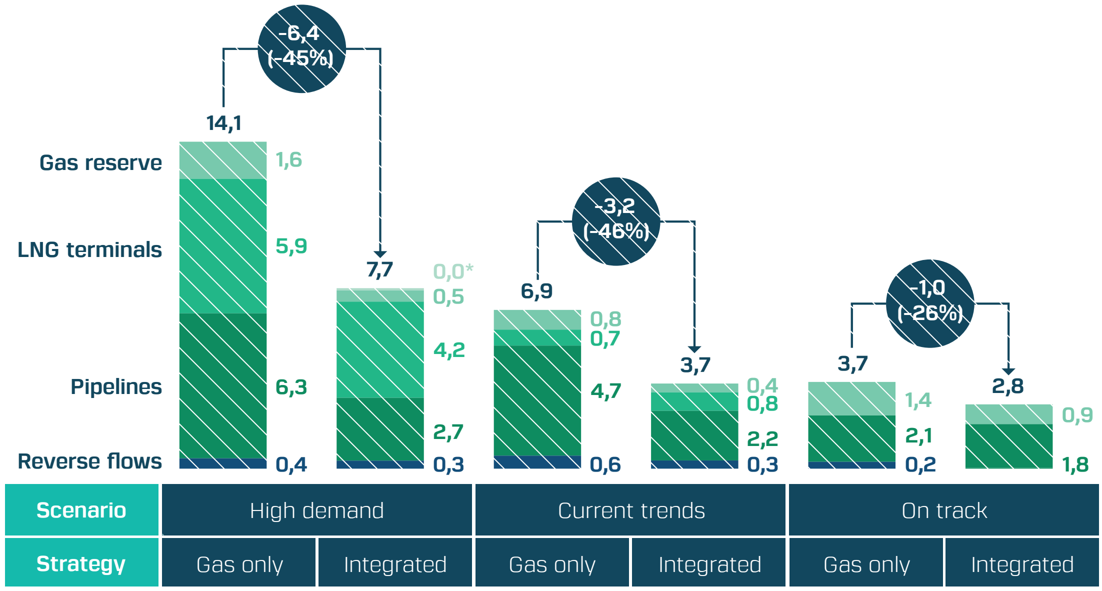


Figure 24: Investment and fixed operation costs (bn€) - Costs reduction through integrated strategy

for peak hours and for trade-offs between variable generation costs.

Under crisis situations (Figure 23 - right side), existing power import capacities are used more frequently, with the South-Eastern European gas-based generation running only during peak hours for the power system. In this case, the yearly gas demand for power in South-Eastern Europe diminishes substantially, leading to lower investment needs in the region. In that aspect, the integrated approach assumes that the system will react in a coordinated way, to minimize costs for security of supply in every country for both gas and power systems. This could be achieved for example through adequate price signals during scarcity on both gas markets and power markets, although outside the scope of this report.

For the power system, the report

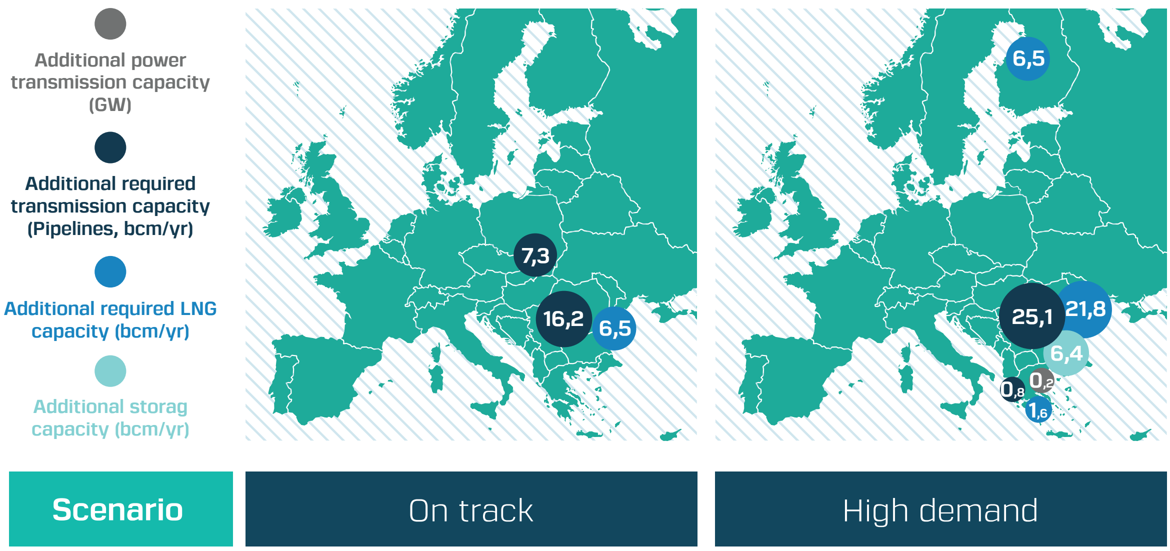


Figure 25: Investments to provide alternatives to Russian imports through Ukraine – Integrated approach

assumes 2030 consumption and generation capacities as defined in each scenario, and power interconnections are optimized beforehand in a power-only model. Hence, the build-out of electricity wires is assumed to follow the needs of the power system, regardless of what happens in the gas system. This ensures that the integrated approach does not profit of over-capacities in power interconnections and only gets its value from a better management of power generation and exchanges. Indeed, in this case 2030 power interconnections are built for power-only purposes, regardless of what happens in the gas system.

Under the On track scenario, the integrated approach allows to displace 1.5 bcm of gas used for power generation outside of South-Eastern Europe, corresponding to roughly 9.5 TWh of electricity, which are instead imported for the rest of Europe. Under the High demand scenario, in which gas-based units become base generation due to a switch in the merit order of coal and gas fleets, 14.6 bcm are removed from the South-Eastern Europe consumption, corresponding to 93 TWh of electricity.

As illustrated below, and depending on the demand scenario, an integrated approach on gas and electricity systems can save up to 46% of gas-related investment costs.

This approach is robust by and in itself. The results are not dependent on the ability to carry on energy efficiency measures. Indeed, even under the High demand scenario, the integrated strategy reduces necessary investments by about 45% (-6.4 billions). In this case, the results also show a small additional investment in power capacity between Greece and Bulgaria, to displace more gas consumption for power outside SEE.

While gas infrastructure risks to become stranded in 2050 (see section 5.3), the risks for power interconnections are much lower. Their value to the power system is more secured in the longer term, given that power demand and the share of variable renewable energy is expected to increase.

Figure 24 also highlights how the need for new gas infrastructure decreases if the 2030 energy efficiency targets are met. In the integrated approach, investment requirements in South Eastern Europe increase by €1 billion in the Current trends scenario (€3.7 billions) compared to the On track scenario (€2.8 billions), meaning that for each 1% of energy efficiency[14], gas infrastructure investment requirements in SEE are reduced 0.1 bn€. Going to even lower energy efficiency like in the High demand scenario leads to an even larger increase, with investment costs rocketing up to 7.7 bn€ when efficiency measures are not enforced.

2.3 New gas infrastructure assets will be superfluous by 2050

In a 2050 perspective, considering a scenario aligned with the long-term

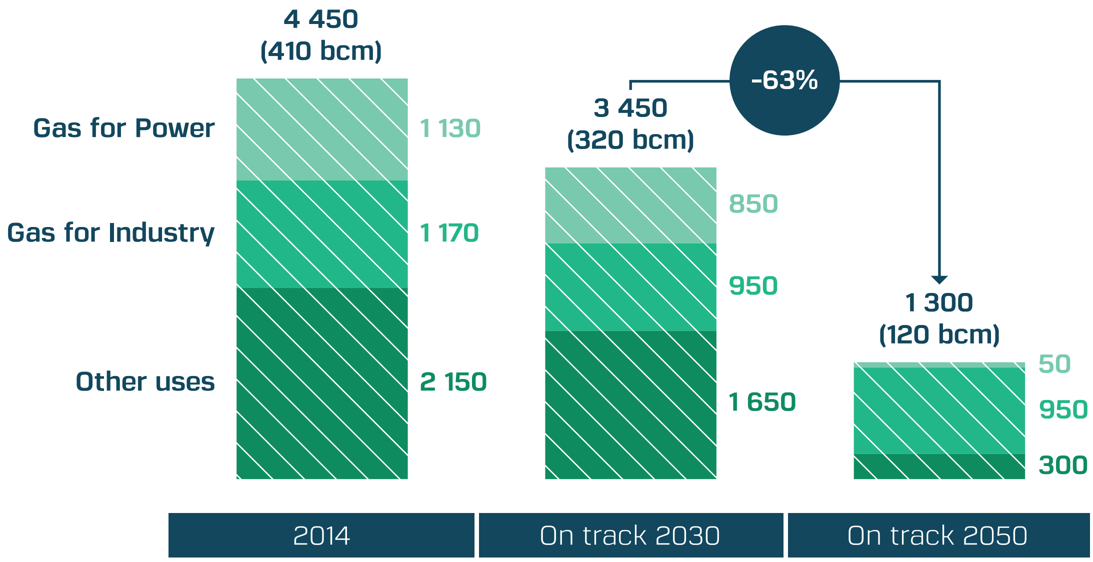


Figure 26: Gas consumption per sector in Europe (TWh and bcm)

climate goals, gas demand in the economy decreases to an extent that Europe requires much fewer imports, reducing the risk of gas loss of load to practically zero.

The On track 2050 scenario assumes a decrease of EU final gas demand by 63% compared to the On track 2030 one, due in particular to a high electrification of the residential and commercial heating sector and a low gas share in the power system as shown in Figure 26.

In these conditions, the current EU infrastructure would be more than sufficient to cover its demand as shown in Figure 27.

Since imports are very low, this system is also fully resilient to

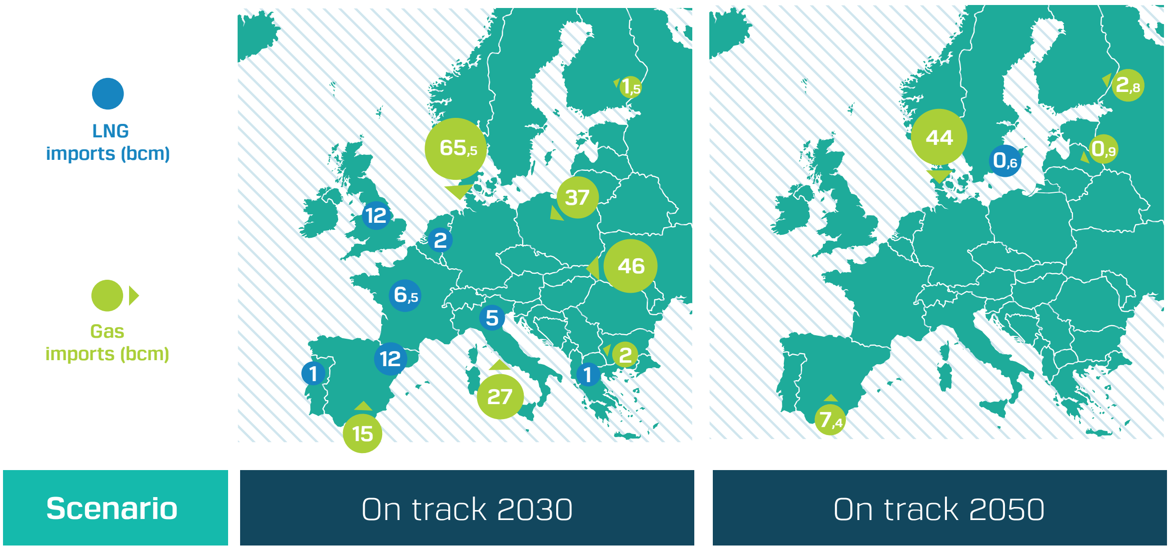


Figure 27. Gas imports in 2030 and 2050 On track scenarios, under standard conditions (normal year – no disruption)

[14]Current trends scenario assumes 21% of energy savings, while the On track one assumes 30% (source: Trends to 2050, European Commission, 2013, and Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy)

imports disruptions or to poor weather conditions. That is to say that any investment in additional long living cross-border gas infrastructure will lead to a stranded asset by 2050. In comparison, for power interconnections, the risk of stranded investment is much lower. The value of the electricity wires in the EU energy system is more secure in the longer term, given that power demand and the share of variable renewable energy is expected to increase.

3 Concluding remarks

In 2015, the European Commission set out a vision for the Energy Union with a Forward-Looking Climate Policy to gradually move away from an economy driven by fossil fuels.

The *Energy Union Choices* consortium aims to support that debate with new, cutting-edge analysis on what it means in terms of the decisions necessary to remain on a pathway to an orderly transition towards that ultimate goal.

The report's findings present a fresh and challenging hypothesis on infrastructure and energy security and in particular gas security of supply. On a technical level, the report's findings bring a compelling perspective on the importance of integrated and regional risk assessment methodologies and their role in the process of defining infrastructure priorities. On a higher political level, the report's findings add to the debate around the risk of asset stranding and lock-in of fossil infrastructure.

In a post-Paris world, how should decision makers think about fossil fuel infrastructure? What is the public value and justification for the use of public funds? Is there a role for public institutions to monitor and approve private investments and contracts? How can an orderly and effective transition to a low carbon energy system be ensured?

These are primarily questions of governance. They are for decision makers to consider as they prepare for the post-2020 climate and energy framework aligned with the UNFCCC Paris Agreement.

Acknowledgments

Energy Union Choices: A Perspective on Infrastructure and Energy Security in the Transition breaks new ground by describing the resilience of the European energy infrastructure today and throughout the energy transition in the next decades. The report is based on extensive analysis conducted by Artelys, Element Energy and Climact and commissioned by the *Energy Union Choices* consortium**.**

Recognised as a world-class company in energy system modelling and decision support, **Artelys** has been in charge of the technical coordination of the study and lead all quantitative analysis.

The interactions with the consortium and external energy experts were conducted by **Climact**, who also helped build the narrative behind the results, using their great knowledge on long term energy and climate strategies.

The demand-side modelling has been done by **Element Energy**, benefitting from their extensive experience studying energy demand in the buildings and industry sectors.

Throughout the project, which started in October 2015, a wide range of experts from different economic sectors and geographies has been consulted. We wish to thank representatives from the Buildings Performance Institute Europe (BPIE), Transport & Environment (T&E), Gas Infrastructure Europe (GIE), The European Commission (DG ENER) and the International Energy Agency (IEA) for the valuable feedback. The willingness of the *Energy Union Choices* consortium and the experts to be consulted in the course of this work should not be understood as an endorsement of all its assumptions or conclusions.

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