METIS Studies

Study S05

Impact of PCIs on gas security of supply in Europe

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EXECUTIVE SUMMARY

ASSESSING THE IMPACT OF PCIS ON GAS SECURITY OF SUPPLY

The European Commission publishes every other year a list of key energy infrastructure projects, known as Projects of common interest (PCIs), to help create an integrated EU energy market and reach the Union's energy policy objectives of affordable, secure and sustainable energy. The main support currently used to provide information about benefits and costs of PCI candidates is the ENTSOG CBA methodology.

The objective of this study is to assess the impact of PCIs on gas security of supply in 2030. An incremental approach is used to generate METIS models and run simulations on the European gas system with different gas infrastructure:

- *FID context* with operational or already financed infrastructure in 2015;
- *PCI1 context* with infrastructure from FID context and projects from the first PCIs list (which were not removed from the second list of PCIs);
- *PCI2 context* with infrastructure from PCI1 context and additional projects from the second PCIs list.

It is to be noted that lists of PCIs are added to the model as a whole. Therefore the study does not assess the efficiency of PCIs individually, but the impact of whole lists of PCIs on gas security of supply.

These contexts are based on the ENTSOG TYNDP 2015 Grey scenario for 2030 for gas consumption and production. In this scenario, gas consumption in 2030 reaches 4940 TWh in EU28, which can be considered a high forecast for demand. It should be noted that gas demand mechanisms are not considered in this study and gas consumption is fixed, including gas demand for power generation. For each of these contexts, we analyses two indicators:

- Disrupted demand, which measures loss of load in a standard case and a cold temperature case.
- Supply source dependence, which measures the share of demand that cannot be served when a specific source of supply is unavailable. The sources considered are Ukraine transit, all Russian imports, Norwegian imports, Southern imports (from Algeria and Lybia) and Eastern imports (from Middle-East).

STATE OF SECURITY OF SUPPLY IN 2030 WITHOUT PCIS

In the FID context, no disrupted demand is observed in the European Union outside of Cyprus and Malta, where demand appears while there is currently no infrastructure to transport gas there, and 8 GWh of loss of load in Luxemburg (0.05% of national demand) in the cold case under very cold temperatures. Additionally, there is loss of load in Balkan countries (non-member states) where demand increases strongly in 2030.

Regarding supply source dependence, no import dependence is observed under the studied scenario for Norwegian imports, Southern imports and Eastern imports. Each of these sources can be substituted with an increase in LNG imports and Russian gas imports. Supply source dependence is observed for Ukraine transit and Russian imports. Southeastern countries such as Romania, Bulgaria and Hungary are strongly dependent to Ukraine transit. Russian import dependence involves more countries (Bulgaria, Estonia, Finland, Hungary, Lithuania, Latvia, Poland, Romania, Sweden, Slovenia and Slovakia) but these remain mainly limited to Eastern Europe. Overall, only 7.1% of EU28 demand is dependent on Russian imports but dependence varies from 26% to 98% of national demand for the dependent country. To achieve such low dependence, Russian imports are, for the most part, substituted with LNG imports in Western Europe.

STATE OF SECURITY OF SUPPLY IN 2030 WITH THE FIRST LIST OF PCIS

In the PCI1 context, as Cyprus and Malta are allocated sufficient infrastructure to cover their demand, no disrupted demand is observed in the European Union at the exception of low loss of load in the cold case under extreme temperatures in Luxemburg, where no import capacity is added there. Loss of load in Balkan countries decrease but remain an important share of local demand.

Dependence to Ukraine transit or Russian imports decreases sharply. Romanian dependence to Ukraine transit or Russian imports drops from over 60% to 6% of its national consumption while dependence to Russian imports in Finland decreases from 79% to 1% of national consumption. No dependence to Ukraine transit or Russian imports is observed in other member states under this scenario. Overall, EU28 dependence to Russian imports represents only 0.2% of total consumption. This drop is mainly due to new transmission capacities in Eastern Europe and new LNG terminals in dependent countries.

STATE OF SECURITY OF SUPPLY IN 2030 WITH THE SECOND LIST OF PCIS

In the PCI2 context, there is no change in disrupted demand in the European Union compared to PCI1 context. Loss of load in Balkan countries decreases thanks to new connections to Serbia and the former Yugoslav Republic of Macedonia.

Dependence in Romania is removed thanks to numerous new transmission capacities in Southeast Europe. The only remaining dependence is observed in Finland as no infrastructure is added to Finland gas system in comparison to PCI1 context.

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1 ABBREVIATIONS AND DEFINITIONS

1.1 ABBREVIATIONS

Abbreviation	Definition
BEMIP	Baltic Energy Market Interconnection Plan
CBA	Cost Benefit Analysis
ESW	Energy System Wide
FID	Final Investment Decisions means the decision taken at the level of an undertaking to definitively earmark funds for the investment phase of a project.
LNG	Liquefied Natural Gas
NSI	North-South Interconnection
OP	Operational existing infrastructure in 2015
PCI	Project of Common Interest
SGC	Southern Gas Corridor
TRA	Transmission
TYNDP	Ten Year Network Development Plan
UGS	Underground gas storage

1.2 DEFINITIONS

Concept	Definition
Context	Combination of assumptions on infrastructure and a scenario of demand. A context is a picture of the capacities and demand at a given horizon, to which can be applied various climatic variations or stress cases.
Firm technical capacity	Maximum capacity that the transmission, LNG or storage undertaking can offer to the system users, contractually and with unconditional guarantee.
Loss of load	Volume of national gas demand that cannot be met due to the inability to import or produce enough gas.
Supply source dependence	Minimum volume of loss of load that would be induced by a full year disruption of a supplier.

2 INTRODUCTION

2.1 FOREWORD

The present document has been prepared by Artelys in response to the Terms of Reference included under ENER/C2/2014-639[1]. Readers should note that the report presents the views of the Consultant, which do not necessarily coincide with those of the Commission.

2.2 INTRODUCTION

In 2013, the European Commission has published a first list of key energy infrastructure projects, known as Projects of common interest (PCIs), to help create an integrated EU energy market and reach the Union's energy policy objectives of affordable, secure and sustainable energy. This list has been updated in 2015 to constitute a second list of PCIs.

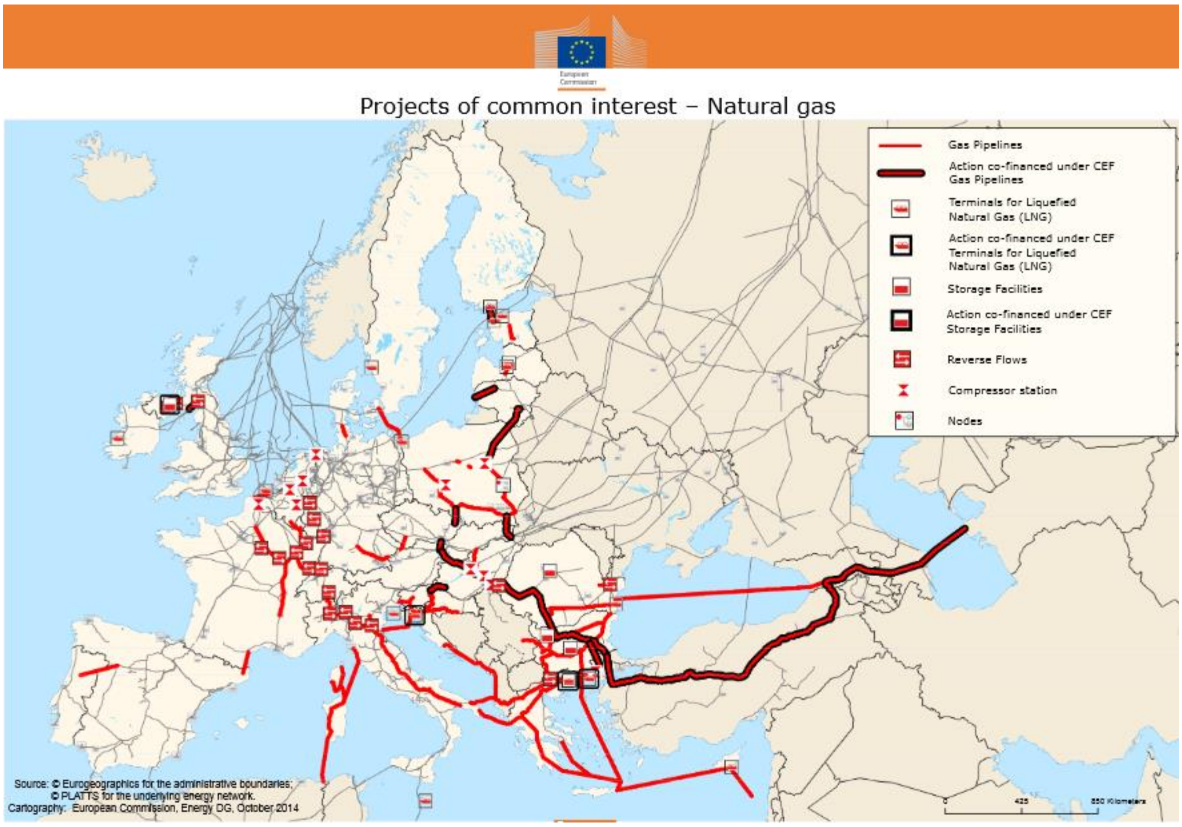

Figure 1: Map of the second list of PCIs for the gas network

Projects can be PCI candidate if they contribute to the improvement of market integration, security of supply, competition or sustainability. In this study, a particular focus will be applied to security of supply through the ability to cover gas demand in the horizon of 2030 and the dependency to certain sources of supply.

The objective of the study is to assess the impact of PCIs on gas security of supply in Europe through METIS models. These models represent the European natural gas network at its state in 2015 with additional financed projects, then include additional projects from the first list of PCIs and finally include the remaining projects from the second list of PCIs. The optimal supply and dispatch of gas throughout Europe is simulated based on these models and under different stress cases (standard and cold temperatures, source disruptions including a very strong case with no Russian import over a whole year) and results are analyzed to highlight indicators relevant to security of supply issues. The supply

[1] http://ec.europa.eu/dgs/energy/tenders/doc/2014/2014s_152_272370_specifications.pdf

and dispatch of gas throughout Europe assumes a rational utilization of all gas infrastructure – in particular interconnectors, underground gas storage, and LNG terminals – without political intervention.

This study is not a Cost-Benefit Analysis. Natural gas and LNG import prices are assumed flat and equal regardless of the source. Therefore, the benefits are only assessed with the contribution of PCIs on security of supply, which is measured with two main indicators: disrupted demand and supply source dependence. It should also be noted that lists of PCIs are added to the model as a whole. Therefore the study does not assess the efficiency of PCIs individually, but the impact of whole lists of PCIs on gas security of supply.

Section 3 provides a description of the methodology and assumptions used for the study. Section 4 assesses the current state of gas security of supply through an analysis of the results of the model before the addition of PCIs. Section 5 provides results with the addition of the first list of PCIs and assesses its impact on security of supply. Section 6 provides similar results with the addition of the second list of PCIs.

2.1 MODELLING SETUP

The study has been performed with the use of METIS software using the following configuration:

METIS CONFIGURATION	
METIS VERSION	METIS v1.1
MODULES	Gas system
SCENARIOS	ENTSOG TYNDP 2015 – GREY - Year 2030
TIME GRANULARITY	Daily
ASSET MODELLING	Fleet level at country granularity.
UNCERTAINTY MODELLING	Standard temperature with : *i. No disruption* *ii. Ukraine transit disabled (whole-year)* *iii. Russian import disabled (whole-year)* *iv. Norwegian import disabled (whole-year)* *v. Southern imports disabled (whole-year)* *vi. Eastern imports disabled (whole-year)* Very cold temperature with : *vii. No disruption*

Table 1: METIS Configuration used for study S5

3 METHODOLOGY AND ASSUMPTIONS

The objective of the study is to assess the impact of PCIs on gas security of supply in Europe. Several contexts including current infrastructure, financed projects and PCIs from the first and the second list were modeled in METIS and analyzed with indicators based on ENTSOG's cost-benefit analysis methodology.

3.1 LITERATURE REVIEW: ESW-CBA METHODOLOGY

3.1.1 OVERVIEW

The Energy System Wide Cost Benefits Analysis (ESW-CBA) Methodology has been developed by ENTSOG under Regulation (EC) 347/2013 to support the selection of PCIs, considering their compliance to general and specific criteria. The ESW-CBA methodology is composed of two steps: the TYNDP-Step which provides an overall assessment of European gas system under different level of development of infrastructure and a Project-Specific step which provide individual assessment of each project on the European gas system.

3.1.2 INPUT DATA AND SCENARIOS

Input data of the ESW-CBA methodology cover a 21-year time horizon from the year of analysis up to 20 years later, but intra-annual data do not cover every day of the year. A full year is at most represented by a yearly value, an average summer day, an average winter day, a 14-day Uniform Risk and a 1-day Design Case.

Two different scenarios have been defined: the Grey scenario, with low price of CO2 emissions and high energy prices, and the Green scenario, with high price of CO2 emissions resulting in higher gas demand to substitute for coal.

ENTSOG defined three scenarios (minimum, intermediate and maximum) for supply potential per source. These scenarios are used to define limitations on import capacities (pipelines and LNG terminals) for each period type. For a given source, the import price increases with the volume **imported**, in order to avoid excessive use of a single source. All sources have identical prices, except in price sensitivity analysis where the price of a specific source can be increased or decreased by 20%.

ENTSOG considers three infrastructure scenarios:

- *Low infrastructure* with projects for which the promoter has taken the Final Investment Decision (FID project)
- *PCI infrastructure* with FID projects and PCI projects
- *High infrastructure* with FID and Non-FID projects.

European social welfare is calculated as the sum of gas supply cost, coal supply cost and CO2 emissions cost. Social welfare is also calculated per country.

Several major supply stress have been considered, which involved disruption over the whole year of one or two of the following: Russian transit through Ukraine, Russian transit through Belarus, Langeled pipeline between Norway and UK, Franpipe pipeline between Norway and France, Transmed pipeline between Algeria and Italy, MEG pipeline between Algeria and Spain, TANAP pipeline between Azerbaijan and Greece, import route from Turkmenistan. No disruption event is considered for LNG given the global dimension of the market.

3.1.3 INDICATORS

To analyze the outputs, two types of indicators are considered: capacity-based indicators, which reflect the direct impact of infrastructures on a given country, and modeling-based indicators, which adds the indirect cross-border impact of infrastructure.

Capacity-based indicators include:

- *Import route diversification*, which measures the diversification of paths that gas can flow through to reach a zone.
- *N-1*, which measures the supply capacity of a zone deprived of its single largest gas infrastructure.
- *Bi-directional Project indicator*, which measures the balance in the firm technical capacity offered in both direction of an interconnection.

Modelling-based indicators include:

- *Disrupted demand*, which measures the volume of unserved demand in a given zone.
- *Remaining flexibility*, which measures how much demand could be added in a zone before inducing unserved demand.
- *Uncooperative and cooperative supply source dependence*, which measures the share of demand which relies fully on a specific source.
- *Supply source price diversification or dependence*, which assesses the benefits or exposure to an increase or decrease of import price from a specific source.
- *Price convergence*, which measures the difference between marginal prices of gas supply of each zone.

3.1.4 TYNDP-STEP

The TYNDP-step provides an overall assessment of the European gas system under the three Infrastructure scenarios. It is composed of the modelling of the European gas system under all cases necessary, a quantitative analysis based on indicators (described in section 3.1.3) and a monetary analysis based on the calculation of the cost of gas supply, coal consumption and CO2 emissions.

3.1.5 PROJECT SPECIFIC STEP

This step provides an assessment of specific projects under the Low and High Infrastructure Scenarios. In particular, it provides an analysis of all PCI candidates with a methodology following the same stages as the TYNDP-Step with, in addition, the calculation of the bi-directional indicator, the addition calculation of Economic and Financial Performance indicators, a sensitivity-analysis on project-specific data, a quantitative analysis commenting on the previous results to justify potential additional benefits of the projects. An incremental approach is adopted, with the assessment of Low and High Infrastructure Scenarios both with and without the specific project.

The implementation of the PS-Step is composed of 9 steps:

- Stage 1 is the description of the project with its features, background and objective.
- Stage 2 is the financial analysis to assess the financial performance of the project through indicators such as:
    - *Financial Net Present Value* which represents the discounted financial cash-flow of the project.
    - *Financial Internal Rate of Return* which represents the commercial viability of the project.
    - *Financial Benefit/Cost ratio* which is the ratio between the discounted benefits and the discounted costs.
- Stage 3 is the PS-Step modelling with the same cases as in the TYNDP-step.
- Stage 4 is the quantitative analysis based on the indicators described in section 3.1.3.

- Stage 5 is the calculation of saved-costs based on the calculation of costs than in the TYNDP-step.
- Stage 6 is the calculation of the net social welfare per country which is the subtraction of the CAPEX and OPEX of the project spent by the country from the social welfare induced by the project in the country.
- Stage 7 is the calculation of the economic performance indicators which include:
  - *Economic Net Present Value* which represents the discounted economic cash-flow of the project.
  - *Economic Internal Rate of Return* which represents the ability of the project to generate social welfare higher than its investment and operational costs.
  - *Economic Benefit/Cost ratio* which is the ratio between the discounted benefits and the discounted costs.
- Stage 8 is the sensitivity analysis which suggests variations on CAPEX, OPEX, and first full year of operation.
- Stage 9 is the qualitative analysis which includes the following steps;
  - Commenting the results of the quantitative and monetary analyses
  - Monetization of demand disruption
  - Describing uncaptured additional benefits
  - Identifying the significantly impacted country
  - Identifying the environmental impact of the project and associated mitigation measures
  - Describing the complementarity of the project with other projects.

3.2 STUDY METHODOLOGY

The study focuses on gas security of supply. The contribution of PCIs are only measured with indicators (described in subsection 3.2.1 and subsection 1) related to unserved demand and supply source dependence.

Therefore, the study is not a cost-benefit analysis. It does not assesses the economic benefits induced by PCIs on the European gas market, not does it take into account the cost of PCIs.

Three contexts including different gas infrastructure were modeled in METIS:

- *FID context*: includes all operational infrastructure in 2015 (OP[2]) and financed projects (FID[3]);
- *PCI1 context*: includes all infrastructure from FID context (OP + FID) and projects from the first list of PCIs that are still included in the second list of PCIs (PCI1[4]);
- *PCI2 context*: includes all infrastructure from PCI1 context (OP + FID + PCI1) and additional projects from the second list of PCIs (PCI2[5]).

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[2] OP infrastructure data were collected from ENTSOG, GSE and GLE 2015 map dataset.

[3] FID infrastructure data were collected from ENTSOG TYNDP-2015 Annex A.

[4] Projects from the first list of PCIs were collected from ENTSOG TYNDP-2015 Annex A and documents sent by the European Commission.

[5] Projects from the second list of PCIs were collected from ENTSOG TYNDP-2015 Annex A and documents sent by the European Commission.

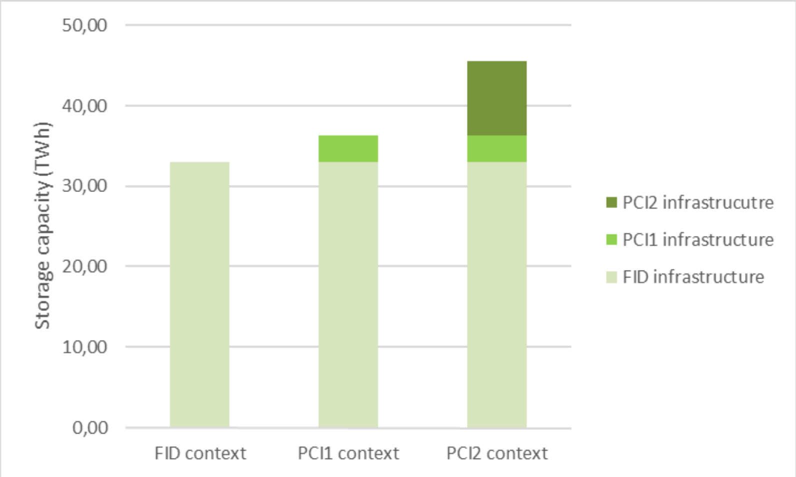

Figure 2: Storage capacity in Romania per context

Figure 2, which shows the storage capacity in Romania in each context, illustrates how the capacity of each type of infrastructure in each country can only increase from FID context to PCI2 context (which holds additional projects).

The three contexts are implemented with a daily granularity in a forecast scenario for 2030[6]. This full modeling of the year with a fine granularity represents an advantage to ENTSOG's CBA methodology as it enables a more accurate modeling of storage impact on the system.

The results on the three contexts are compared to assess the impact of PCIs on security of supply, while focusing on two indicators from ENTSOG's CBA methodology: disrupted demand and uncooperative supply source dependence.

3.2.1 DISRUPTED DEMAND

This indicator reveals the volume of demand that cannot be served under standard supply circumstances (i.e. no supply disruption). In this study, disrupted demand has been measured both in a standard temperature year case and in a cold temperature year case.

	Standard case	**Cold case**
Temperature year	2005	1985
EU28 total gas demand[7]	4937 TWh	5297 TWh (+ 7.3%)
EU28 peak demand[8]	1057 GW	1243 GW (+18%)

Table 2: Gas demand in the standard and cold case

Artelys has conducted an analysis of historical data to detect the influence of temperature and days of the week on gas consumption. This work has resulted in the generation of 50 different consumption profiles, representing each a different temperature year. In particular, 2005 has been detected as a standard temperature year while 1985 is the coldest year over the last 50 years. Figure 3 illustrates the consumption profiles for France in both cases.

[6] See section 3.3

[7] ENTSOG TYNDP-2015 GREY scenario for 2030

[8] Issued from Artelys work to generate 50 different consumption profiles based on historical data and temperature scenarios.

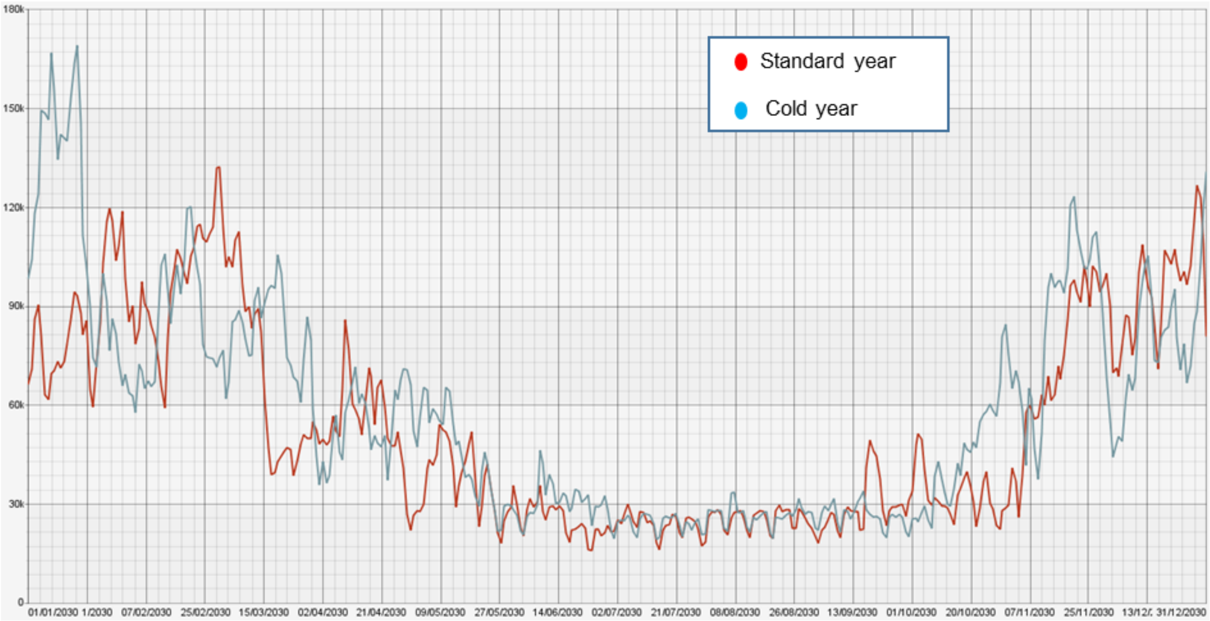

Figure 3: Demand profiles in France in 2030 in the standard case and cold case

As current infrastructure already enables gas demand coverage in 2015, the disrupted demand indicator mostly aims at revealing whether specific countries need additional infrastructure to cope with appearing or increasing demand in 2030. Measuring disrupted demand in a cold temperature year case also enables to capture the ability of the gas system to cope with very high peak demands and high demand periods.

Gas demand is a non-flexible input data. It should be noted that no demand response is considered and gas-to-power consumption is fixed, as opposed to an integrated approach with flexibility on gas demand for power generation.

3.2.2. SUPPLY SOURCE DEPENDENCE

The supply source dependence reveals the part of demand in each country that is dependent to a specific source, i.e. the proportion of demand that cannot be served without the source.

For each supply source considered, the model is run with the availability of this source set down to 0 for a whole year and the availability of the other sources unchanged. Table 3 sums up the sources considered.

ENTSOG distinguishes uncooperative and cooperative supply source dependence. In the uncooperative version, the price attached to unserved demand is set flat for all countries, independently to the volume of unserved demand. In the cooperative version, loss of load price increases with the volume of unserved demand, which induces that member states share loss of load as equally as possible. This study only focuses on uncooperative supply source dependence, as it reveals the exact share of European demand which is dependent from a source, with dependence more likely to be in countries close to the source, while a cooperative model assumes that there exists some degree of collaboration between countries to reach a more balanced distribution of disrupted demand.

Stress case	Description	Disabled cross-border transmissions
Reference	All sources available	None
Ukraine transit disabled	Russian gas delivered through Ukraine unavailable	Transmissions from Ukraine
Russian imports disabled	No imports from Russia	Transmissions from Russia, Belarus and Ukraine
Norwegian production disabled	No Norwegian production	Transmissions from Norway
Southern imports disabled	No imports from Algeria and Lybia	Transmissions from Algeria and Lybia
Eastern imports disabled	No imports from Middle-East	Transmissions from Turkey and Azerbaijan

Table 3: Sources considered for the study of uncooperative supply source dependence

3.3. SCENARIO

The selected scenario is ENTSOG TYNDP2015 GREY scenario for 2030. With a total demand of 4,937 TWh for EU28, ENTSOG GREY scenario can be considered as a high forecast for demand[9].

In addition to EU28 member states, the model includes non-member states in Europe that were also included in ENTSOG TYNDP-2015 model (Switzerland, Bosnia-Herzegovina, Serbia and the former Yugoslav Republic of Macedonia). Norway is also explicitly represented in the model and its consumption is set equal to its gas demand in 2014 (i.e. 51 TWh).

ENTSOG TYNDP2015 FID scenario was selected for production forecast to be consistent with infrastructure assumptions. EU28 production is set to 969 TWh in 2030[10], which leaves almost 4,000 TWh of demand to cover with imports.EU28 can import gas from multiple sources:

- Russia via pipelines going through Ukraine, Belarus or directly connected to member states (Germany, Finland, Latvia, Estonia). In the FID context, the maximal physical import capacity reaches 2 894 TWh/year, among which 1512 TWh/year has to transit through Ukraine.
- Norway via pipelines directly connected to member states (United Kingdom, France, Belgium, Germany). Norway is explicitly represented in the model and its production is set at the annual value of 810 TWh/year[11].
- Algeria and Lybia via pipelines directly connected to member states (Italy and Spain). In the FID context, the maximal physical import capacity reaches 769 TWh/year.
- Middle-east via pipelines connected to member states (Greece). In the FID context, the maximal physical import capacity reaches 370 TWh/year.
- LNG, via LNG terminals in 11 member states. Its maximal imports capacity reaches 2 762 TWh/year.

[9] Consumption per country can be found in appendix 8.1.

[10] Production per country can be found in appendix 8.1.

[11] Source: ENTSOG TYNDP2015 Annex C4.

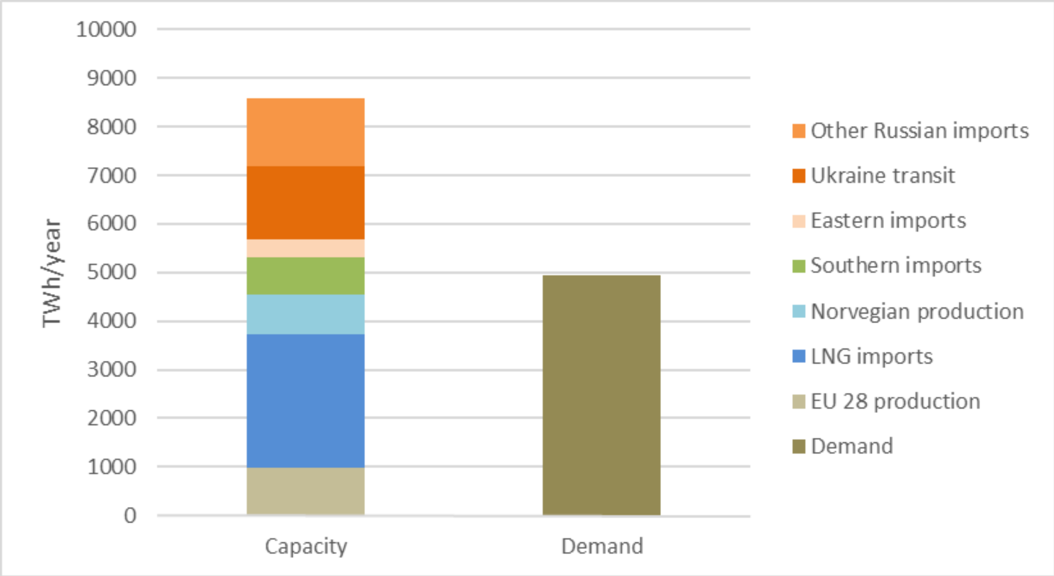

Figure 4: Yearly import capacities and demand in Europe (FID context)

We observe that on a yearly European scale, EU28 could supply enough gas to cover its demand, even without one of its suppliers. Therefore, the analysis has to be conducted on a smaller scale (country scale with daily granularity), in particular to take into account congestions and seasonality.

Import prices are set identical and flat for all countries, independently from the volume that is being imported, at 32.4 €/MWh[12]. As the study focuses on security of supply issues, there is no specific need for different prices per source, as it does not alter the volume of demand that can be covered by imports. LNG import price is set slightly higher than natural gas import (+0.001€/MWh). However, the price difference is lower than the cost of transportation through a cross-border transmission, which is calculated according to the distance between the centroids of the countries, so that LNG imports are only chosen over natural gas if it prevents transit through another European country.

At the exception of exchanges with European countries that are not in the European Union, natural gas exports are ignored in the model.

[12] Source: Current Policies Scenario from *World Energy Outlook 2011*, International Energy Agency

4 SECURITY OF SUPPLY WITH CURRENT AND FINANCED INFRASTRUCTURE

This section describes the model and results in the FID context.

4.1 GAS INFRASTRUCTURE

In FID context, the gas system includes operational infrastructure in 2015 and financed projects (labelled FID in ENTSOG TYNDP2015). As seen in section 3.3, the annual imports capacity exceeds demand on a European scale. This is partly due to high LNG import capacities, which are mainly located in Western Europe. In Eastern Europe, interconnections provide multiple entry points with high physical capacity for Russian gas and Eastern gas.

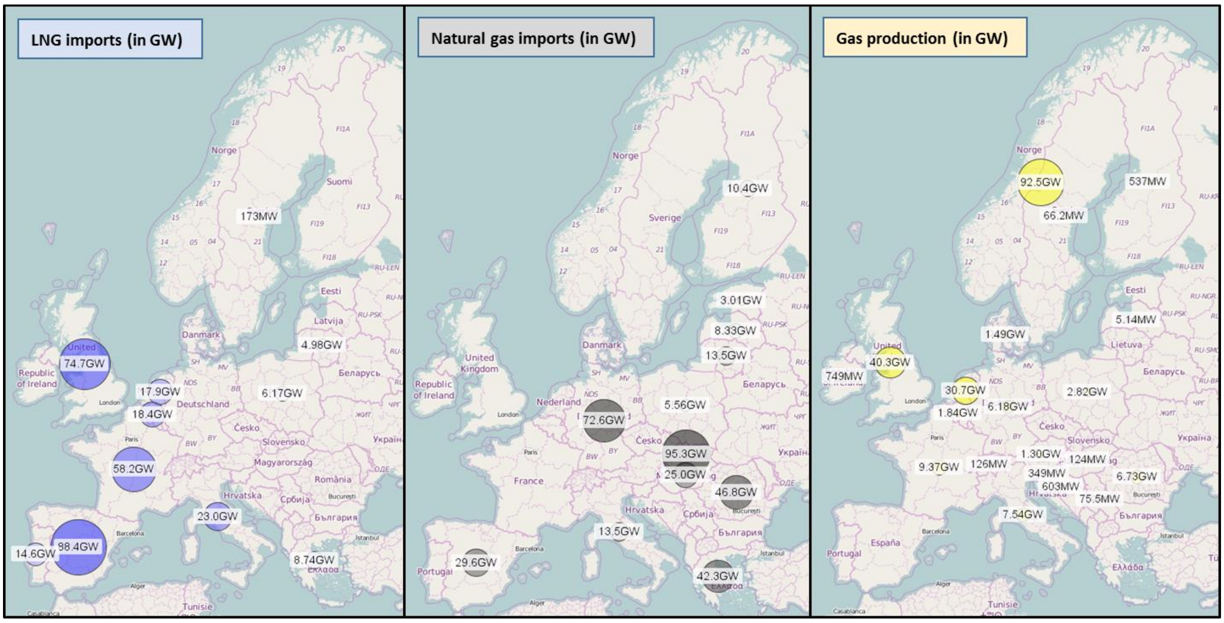

Figure 5: Maps of LNG import, natural gas import and production capacities per country in FID context

In addition, Europe produces its own gas. As Norway is explicitly implemented in the model, its gas is represented as production, in opposition with Russian gas which is represented as imports. Apart from Norway, the main sources of production in Europe are the United Kingdom and the Netherlands.

The European gas system has seasonal flexibility thanks to its storage capacities, mainly located in Western and Central Europe. The map of the gas network reveals that some countries are barely (or not at all) connected to the European gas system. For example, Cyprus and Malta have no import transmission capacities, Finland is only connected to Russia and Baltic countries are isolated from the rest of Europe. Countries like Ireland, Portugal, Sweden and Bosnia-Herzegovina also rely on the transit via a single member state (though Portugal and Sweden have LNG terminals).

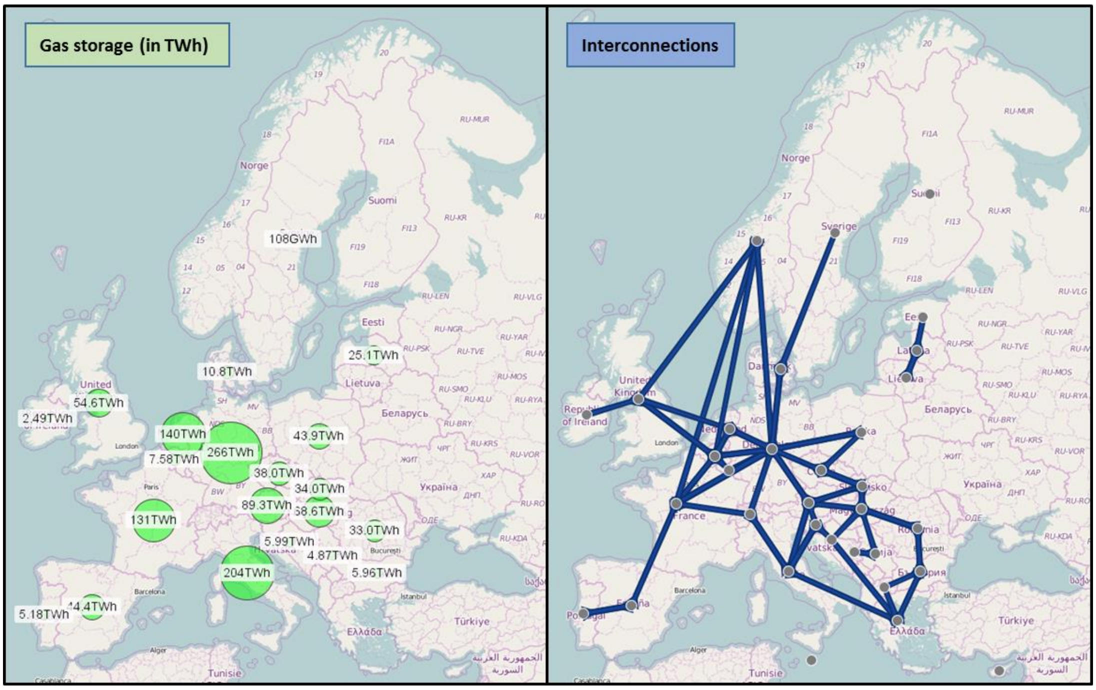

Figure 6: Maps of gas storage capacities and interconnections in FID context

4.2. DISRUPTED DEMAND

4.2.1. REFERENCE CASE

In the reference case (associated to a standard temperature year), a few member states cannot cover their demand.

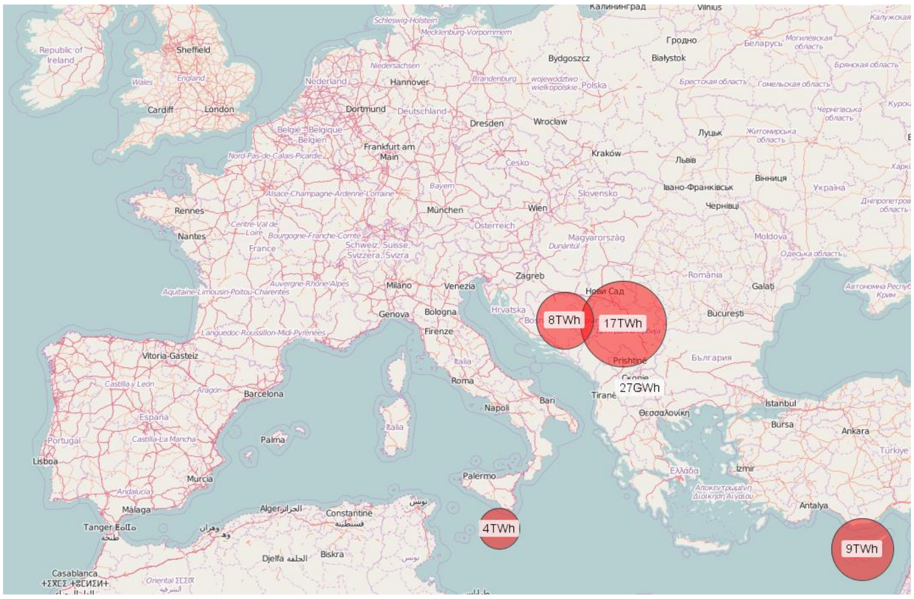

Figure 7: Unserved demand in the reference case (FID context)

In this context, Malta and Cyprus cannot cover their demand because the scenario depicts them to have certain gas demand in 2030 while no infrastructure to connect them to the European gas system is assumed to be in place.

Country	Yearly volume of unserved demand	Share of unserved demand on national demand	Number of days with unserved demand
Cyprus	8.8 TWh	100%	365
Malta	3.7 TWh	100%	365
EU28	12.5 TWh	0.24%	365
Bosnia-Herzegovina	7.5 TWh	84%	283
Former Yugoslav Republic of Macedonia	0.027 TWh	0.39%	5
Serbia	17 TWh	26%	198

Table 4: Unserved demand in the reference case (FID context)

Bosnia-Herzegovina and Serbia also have unserved demand issues as their demand increases strongly while their import capacities are very limited. In addition Bosnia-Herzegovina is only connected to Serbia, thus as Serbia already struggles to cover its demand, Bosnia-Herzegovina can only cover its demand in summer.

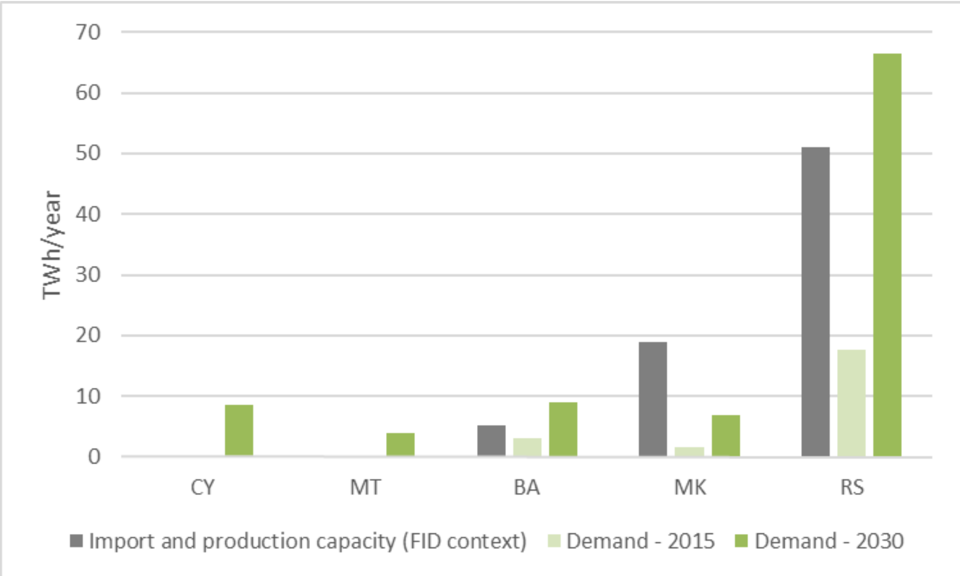

Figure 8: Import capacity and demand per country with unserved demand in the reference case (FID context)

The former Yugoslav Republic of Macedonia also faces unserved demand issues because of peak demand during 5 days of winter.

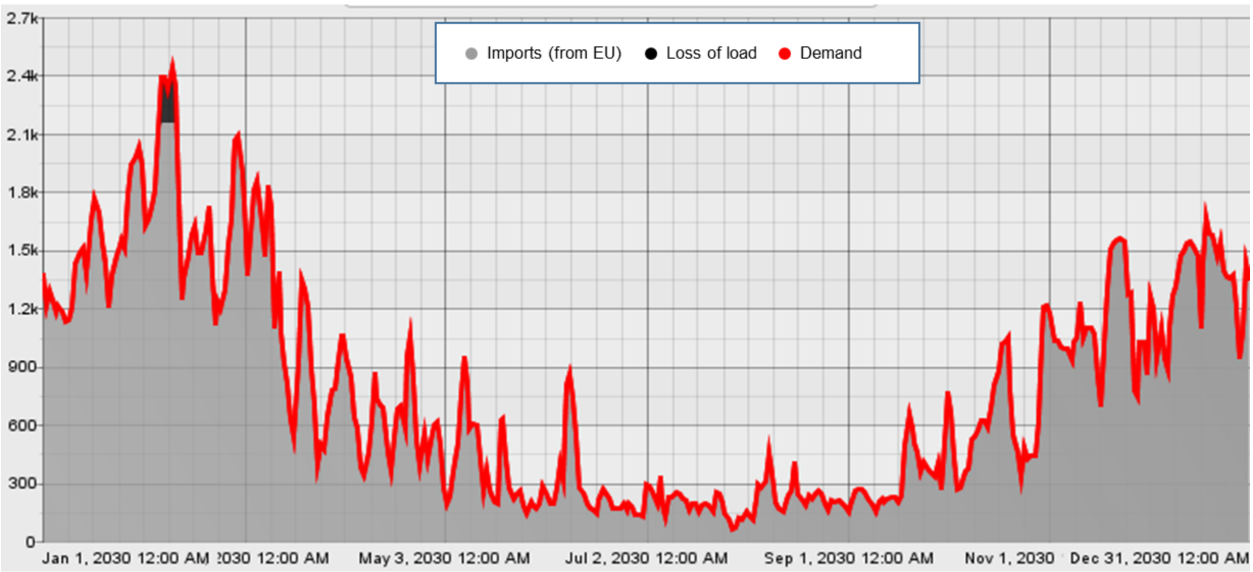

Figure 9: Imports and loss of load in MK in the reference case (FID context)

4.2.2. COLD CASE

In the cold case, in addition to states with unserved demand in the reference case, Luxemburg has some loss of load.

Country	Yearly volume of unserved demand	Share of unserved demand on national demand	Number of days with unserved demand
Cyprus	8.6 TWh	100%	365
Luxemburg	0.008 TWh	0.05%	3
Malta	4.0 TWh	100%	365
EU28	12.6 TWh	0.26%	365
Bosnia-Herzegovina	7.6 TWh	85%	280
Former Yugoslav Republic of Macedonia	0.034 TWh	0.50%	7
Serbia	18 TWh	28%	208

Table 5: Unserved demand in the cold case (FID context)

Although demand in Luxemburg increases slightly from 2015 to 2030, transmission capacities in this country are sufficient to import its annual consumption. The unserved demand is due to high peak demands in winter which exceeds import capacity, as illustrated by Figure 10.

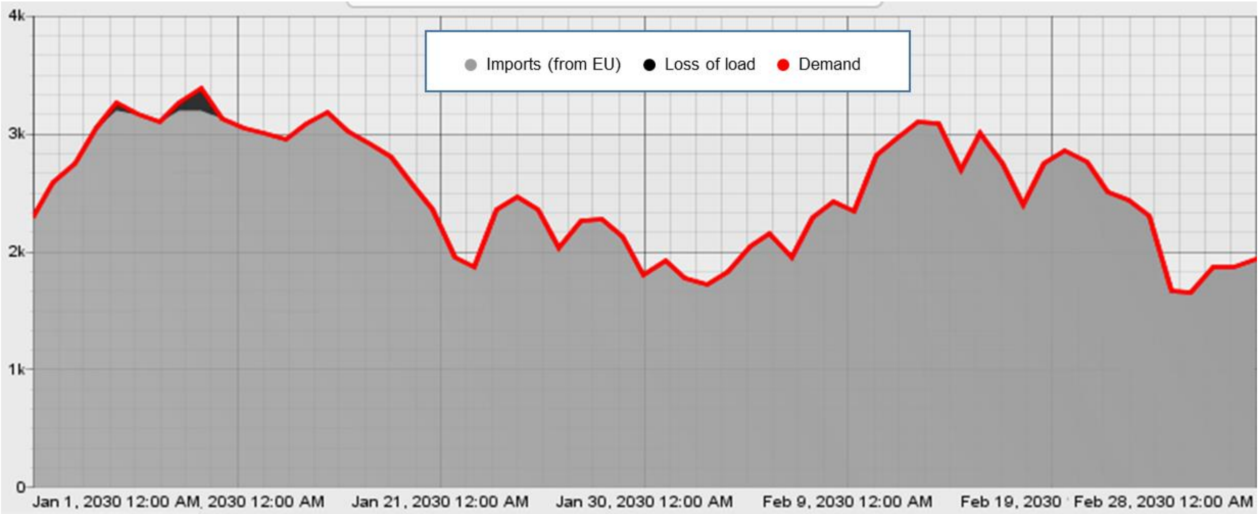

Figure 10: Imports and unserved demand in Luxemburg (January and February) in the cold case (FID context)

4.3. SOURCE DEPENDENCY

4.3.1. UKRAINE TRANSIT

In this case, the availabilities of all transmissions coming from Ukraine are set down to 0 for a whole year and we calculate dependence as the share of unserved demand due to this disruption on total demand. We observe that dependence is limited to Southeast Europe, though this zone is strongly dependent on Ukraine transit.

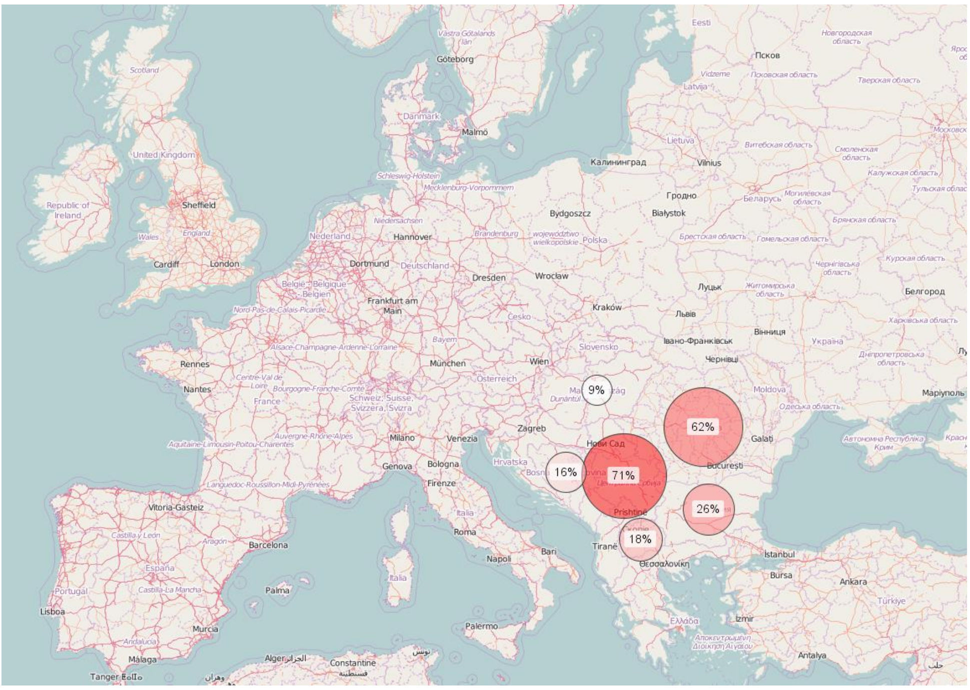

Figure 11: Map of Ukraine transit dependence (FID context)

Country	Yearly volume of dependence	Share of dependence on national demand	Number of days with dependence
Bulgaria	12 TWh	26%	221
Hungary	9.0 TWh	8.7%	66
Romania	96 TWh	62%	348
EU28	117 TWh	2.4%	365
Bosnia-Herzegovina	1.4 TWh	16%	126
Former Yugoslav Republic of Macedonia	1.3 TWh	18%	125
Serbia	46 TWh	72%	364

Table 6: Ukraine transit dependence (FID context)

On a yearly European scale, dependence is limited to 2.4% of total demand. However, dependence issues are concentrated in Southeastern countries, among which three are member states. Dependence is particularly severe in Bulgaria and Romania where it can reach 62% of local demand.

Only 18% of Russian imports that cannot be imported with Ukrainian pipelines can get around Ukraine to reach Southeast Europe. Ukraine transit gas is mainly substituted with LNG imports (around 45%), which increase strongly in Belgium and France. Around 7% of Ukraine transit gas is substituted with Eastern imports and 30% cannot be substituted with another source (see Figure 12).

As seen in section 3.3, on a yearly European scale, EU28 has enough import capacity to cover its demand without Ukraine transit gas. However, on a country scale, internal transmission capacities induce dependence. This is due to congestions in entry points to Southeast Europe (see Figure 13):

- From Central Europe to Southeast Europe, [Austria to Hungary] and [Slovakia to Hungary] are congested all year long.
- From Greece to Southeast Europe, [Greece to Bulgaria] is congested all year long and [Greece to the Former Yugoslav Republic of Macedonia] is congested 125 days in the year.

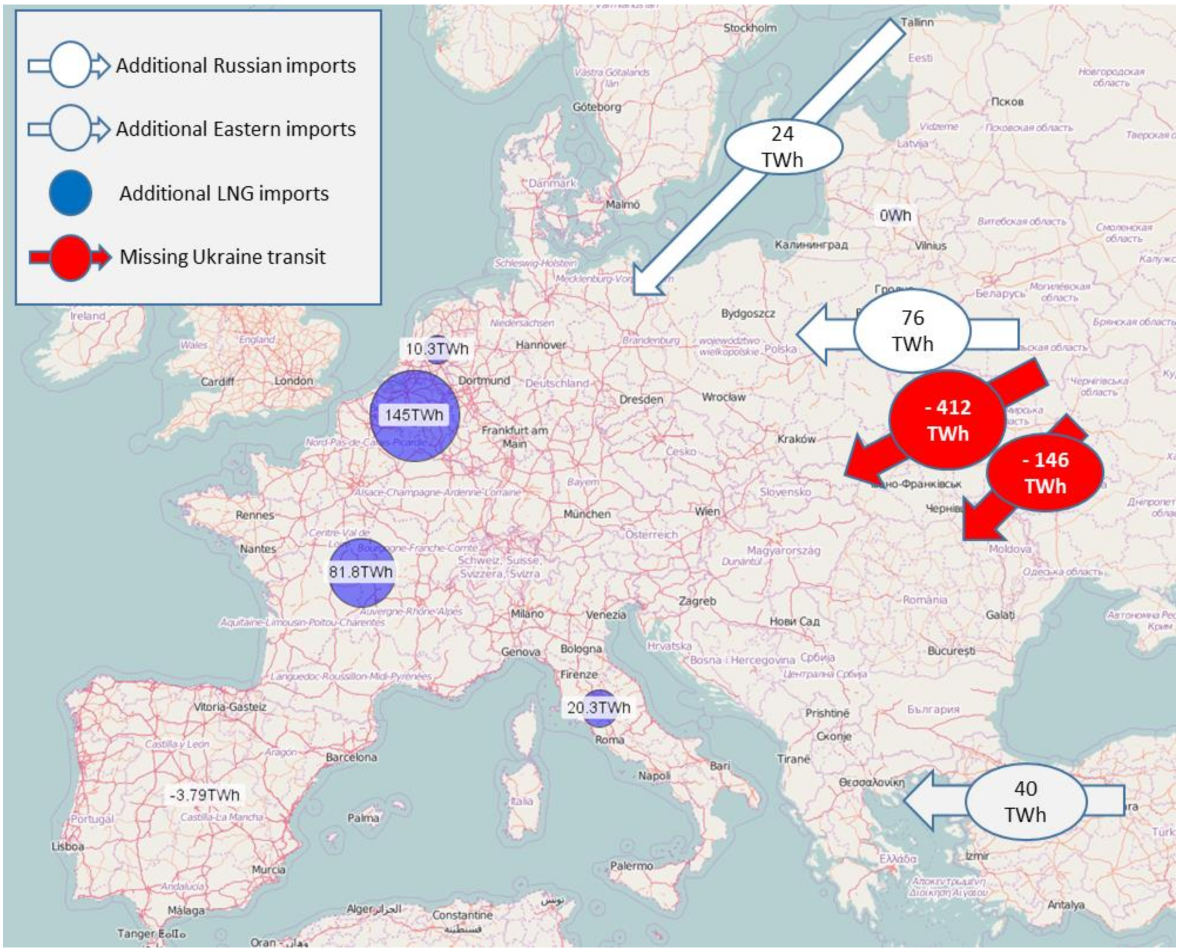

Figure 12: Map of additional imports with Ukraine transit disabled (FID context)

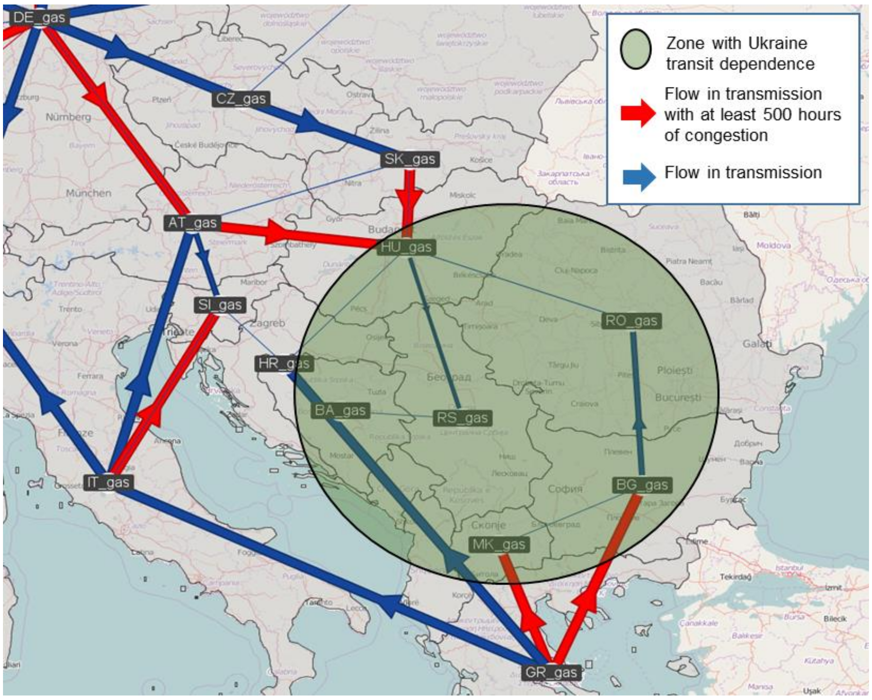

Figure 13: Map of flows and congestions with Ukraine transit disabled (FID context)

4.3.2. RUSSIAN IMPORTS

In this case, the availabilities of all transmissions from Russia, Ukraine and Belarus are set down to 0 for the whole year. We observe strong dependence in Eastern countries.

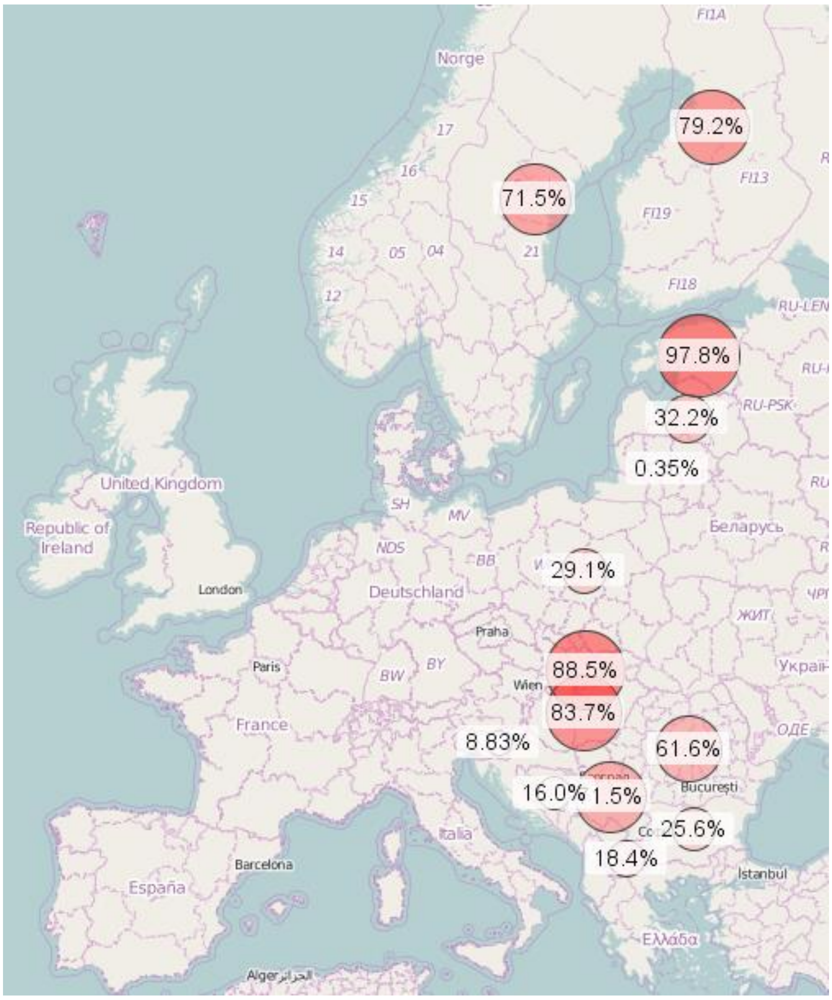

Figure 14: Map of Russian imports dependence (FID context)

Dependence issues involve 11 member states, in which the severity of dependence varies but can reach up to 98% of demand in Estonia, 89% in Slovakia and around 80% in Finland and Hungary. Overall EU28, dependence is limited to 7.1% of total demand, as Western countries manage to import gas from other sources of supply. In particular, LNG imports increase strongly to substitute for Russian imports (see Figure 15 and Figure 20).

Country	Yearly volume of dependence	Share of dependence on national demand	Number of days with dependence
Bulgaria	12 TWh	26%	231
Estonia	7.8 TWh	98%	352
Finland	18 TWh	79%	365
Hungary	86 TWh	84%	326
Lithuania	0.087 TWh	0.35%	12
Latvia	8.5 TWh	32%	131
Poland	57 TWh	29%	183
Romania	96 TWh	62%	349
Sweden	7.0 TWh	72%	323
Slovenia	0.97 TWh	8.8%	119
Slovakia	57 TWh	89%	319
EU28	350 TWh	7.1%	365
Bosnia-Herzegovina	1.4 TWh	16%	126
Former Yugoslav Republic of Macedonia	1.2 TWh	18%	125
Serbia	46 TWh	72%	364

Table 7: Russian imports dependence (FID context)

About two thirds of Russian imports are substituted with additional LNG imports. Eastern imports are also raised to cover 7% of missing Russian imports. Almost 29% of Russian imports cannot be substituted by another source.

It should be noted that these results imply that LNG terminals can be used almost at their full capacity throughout the year. In section 8.3, results show that lower availabilities of LNG terminal capacities (80%) lead to an increase of EU28's dependence up to 10.1%.

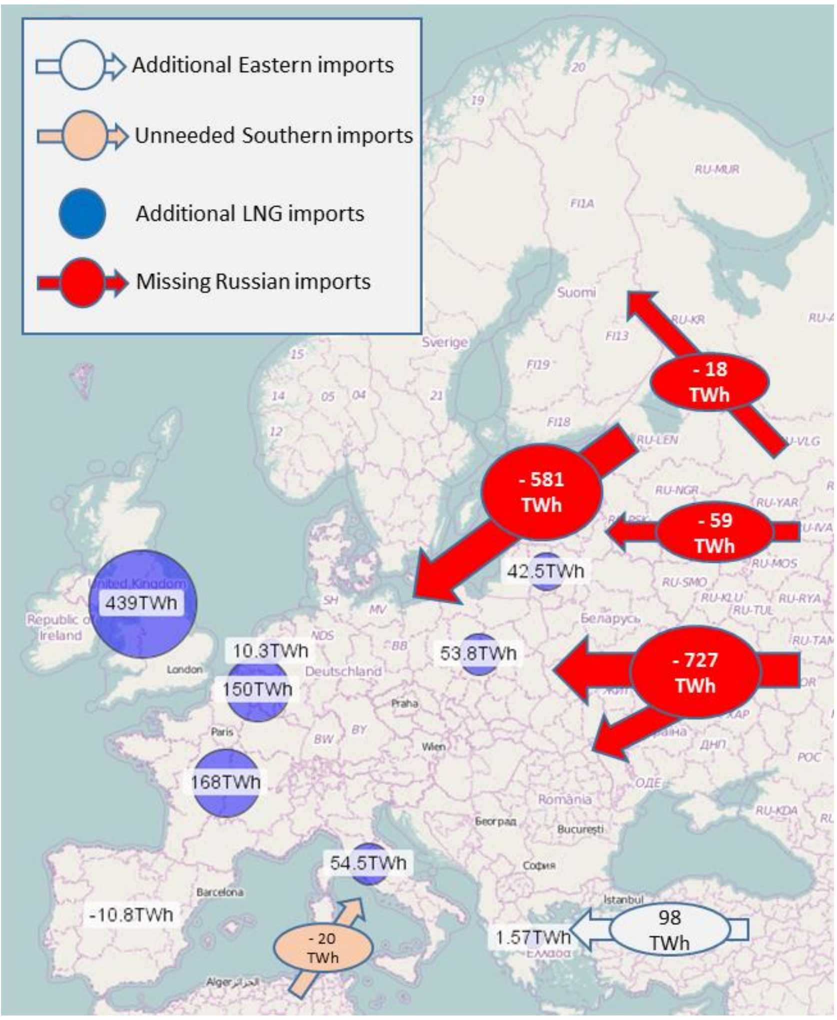

Figure 15: Map of additional imports with Russian imports disabled (FID context)

EU28 could potentially import more LNG to Western Europe, but infrastructures in the FID context do not enable the transport of so much gas from the West to the East. On Figure 16, we see that pipelines from the West to Germany are congested, so Germany cannot send enough gas to Eastern Europe. Italian exit points to Eastern Europe are also congested. In addition, the Eastern gas network lacks capacity to transport high volumes of gas (congestions from Germany and Czech Republic to Poland, from Austria and Slovakia to Hungary, no transmission to Baltic countries).

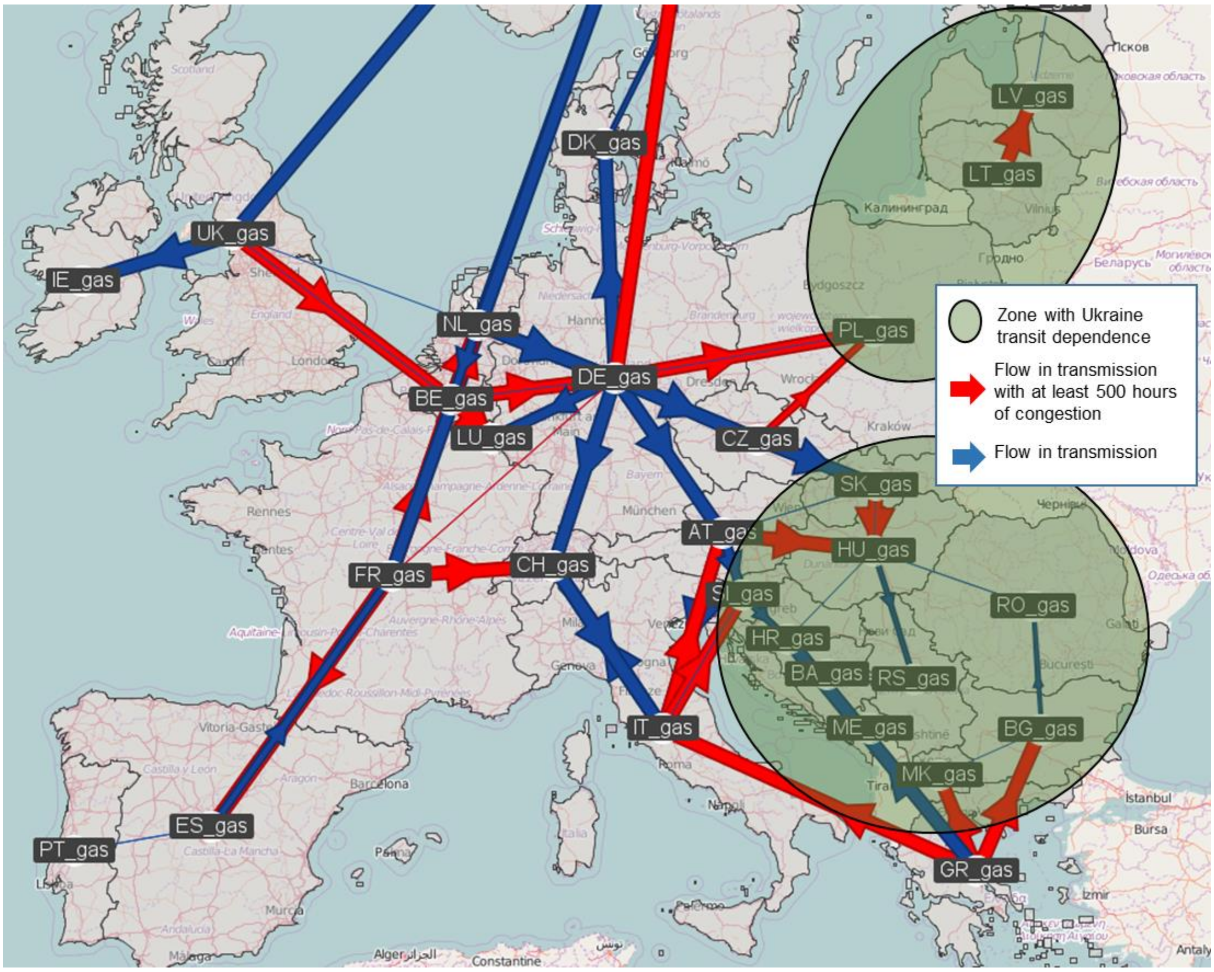

Figure 16: Map of flows and congestions with Russian imports disabled (FID context)

4.3.3. NORWEGIAN PRODUCTION

In this case, Norwegian production is unavailable for the year. Except for Norway itself, no dependence to Norwegian gas is observed under this scenario. On Figure 17, we observe that the United Kingdom, France and Belgium can substantially increase their LNG imports to substitute for Norwegian gas. Additionally, Russian imports are increased via Nordstream and Belarus transit.

These additional imports assume that capacity factors of LNG terminals, defined by the yearly send-out volume divided by the yearly send-out capacity, can be increased. However, it does not require that these infrastructure operate at their maximal regasification capacity, as we observe that capacity factors reach around 80% in the Norwegian production disabled case (see Table 8).

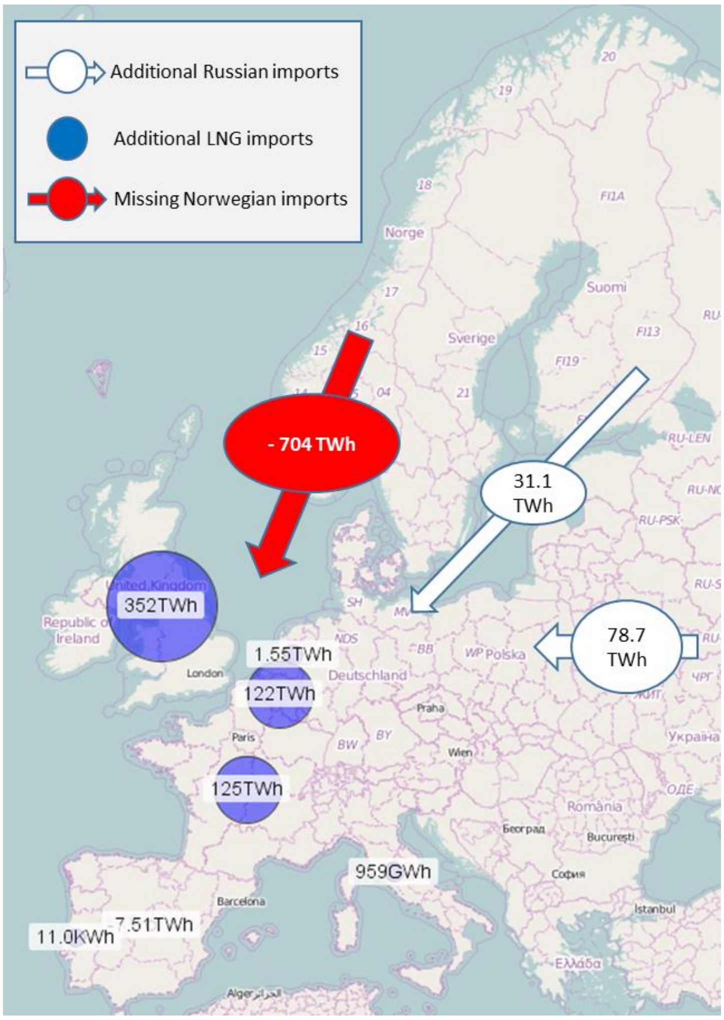

Figure 17: Map of additional imports to substitute for Norwegian gas (FID context)

Import infrastructure	Capacity factor in the reference case	Capacity factor with Norwegian production disabled
UK LNG terminals	30%	84%
FR LNG terminals	54%	79%
BE LNG terminals	4.7%	81%

Table 8: Capacity factor with Norwegian production disabled (FID context)

4.3.4. Southern imports

In this case, availabilities of transmissions from Algeria and Libya are set down to 0. No dependence to Southern imports is observed under this scenario. Spain increases its LNG imports by the same volume lost in Southern imports. Meanwhile, Italy increases its LNG imports at its maximal capacity and the rest of missing imports is substituted with imports from the East, which can be transported to Italy through a transmission from Greece to Italy, and imports from Russia through Ukraine to Slovakia and Hungary.

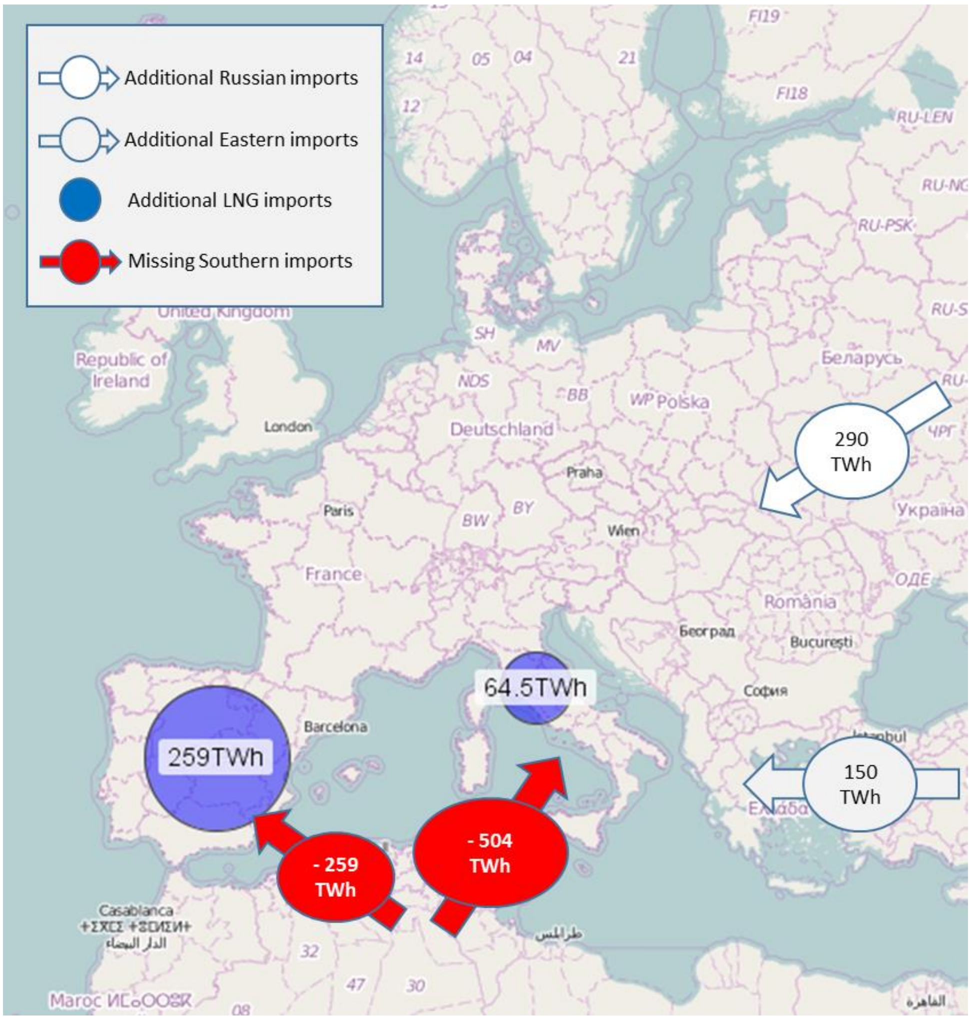

Figure 18: Map of additional imports to substitute for Southern gas (FID context)

As Spain has several LNG terminals and a very high send-out capacity, the important increase of LNG imports raises the capacity factor of Spanish LNG terminals at only 55%. In Italy, LNG terminals are used at their full capacity. However, a sensitivity analysis on LNG terminals availability reveal that the full availability of LNG terminals is not necessary to substitute with Southern imports (see section 8.3).

Import infrastructure	Capacity factor in the reference case	Capacity factor with Southern imports disabled
ES LNG terminals	21%	55%
IT LNG terminals	68%	100%

Table 9: Capacity factor with Southern imports disabled (FID context)

4.3.5. Eastern imports

In this case, availabilities of transmissions from Turkey are set down to 0. No dependence to Eastern imports is observed under this scenario. Greece increases its LNG imports and imports from Italy where LNG imports are also raised. Additionally, Russian imports through Ukraine are increase to provide Southeast Europe.

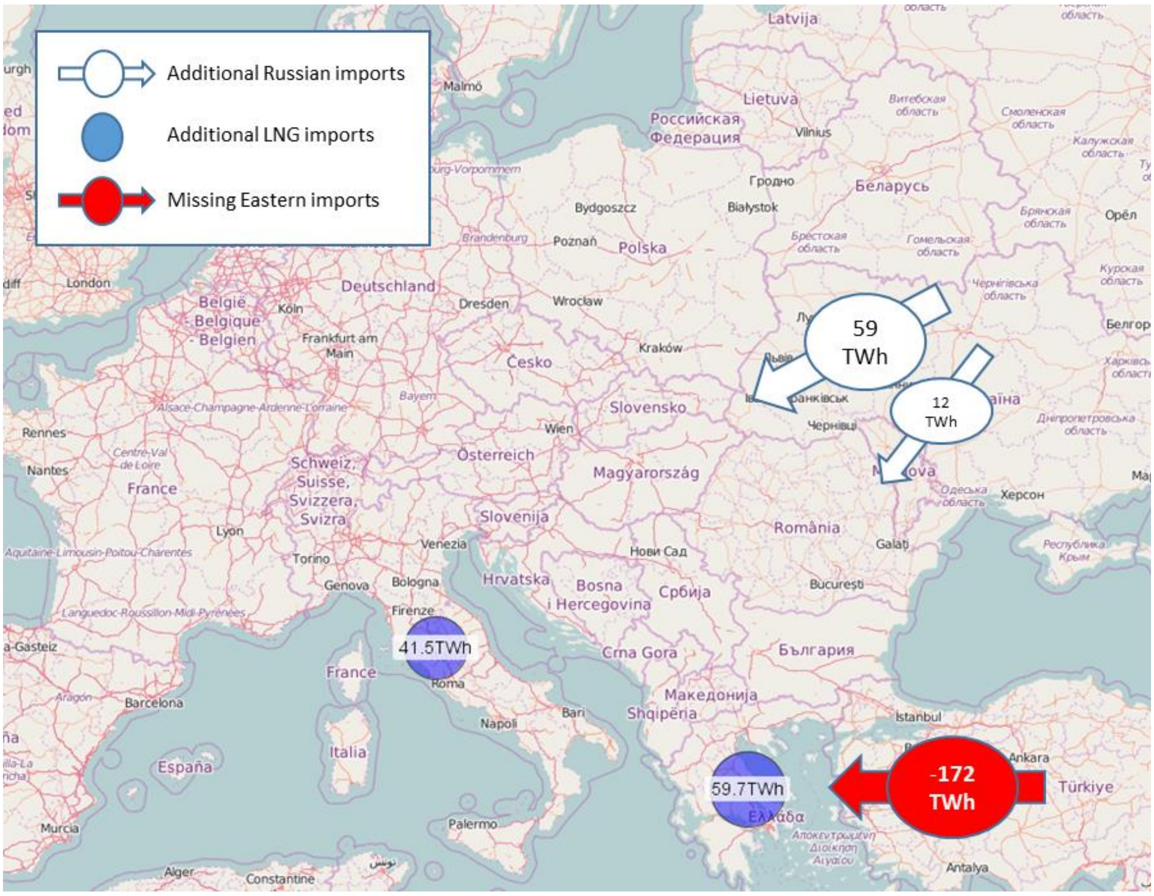

Figure 19: Map of additional imports to substitute for Eastern gas (FID context)

In Italy, LNG imports increase but do not reach their full yearly capacity. In Greece, because of high import capacities from Turkey, LNG terminals are not necessary to cover demand in a reference case. However, their capacity factors reach almost 80% in the Eastern import disabled case.

4.4. Summary

From the METIS simulation results, we conclude that:

- Unserved demand is limited to isolated countries with appearing or increasing demand and Luxemburg which lacks flexibility to pass peak demands under very cold temperatures.

Disrupted demand	**Standard year**	**Cold year**
EU28 unserved demand	12 TWh	13 TWh
EU28 unserved demand (in % of total demand)	0.25%	0.26%
Member states with unserved demand	CY,MT	CY, MT, LU
Non-member states with unserved demand	BA, MK, RS	BA, MK, RS

Table 10: Summary of disrupted demand (FID context)

- EU28 is dependent on Ukraine transit and Russian imports for the supply of gas and dependent states are located in Eastern Europe. EU28 is not dependent on other sources of supply as LNG imports and Russian gas imports can be substantially increased to compensate for the loss of other supply sources.

Source dependence	Ukraine transit	Russian imports	Norwegian imports	Southern imports	Eastern imports
EU28 dependence volume	117 TWh	350 TWh	0	0	0
EU28 dependence share (in % of total demand)	2.1%	7.1%	0%	0%	0%
Dependent member states	BG, HU, RO	BG, EE, FI, HU, LT, LV, PL RO, SE, SI, SK	-	-	-
Dependent non-member states	BA, MK, RS	BA, MK, RS	NO	-	-

Table 11: Summary of supply source dependence (FID context)

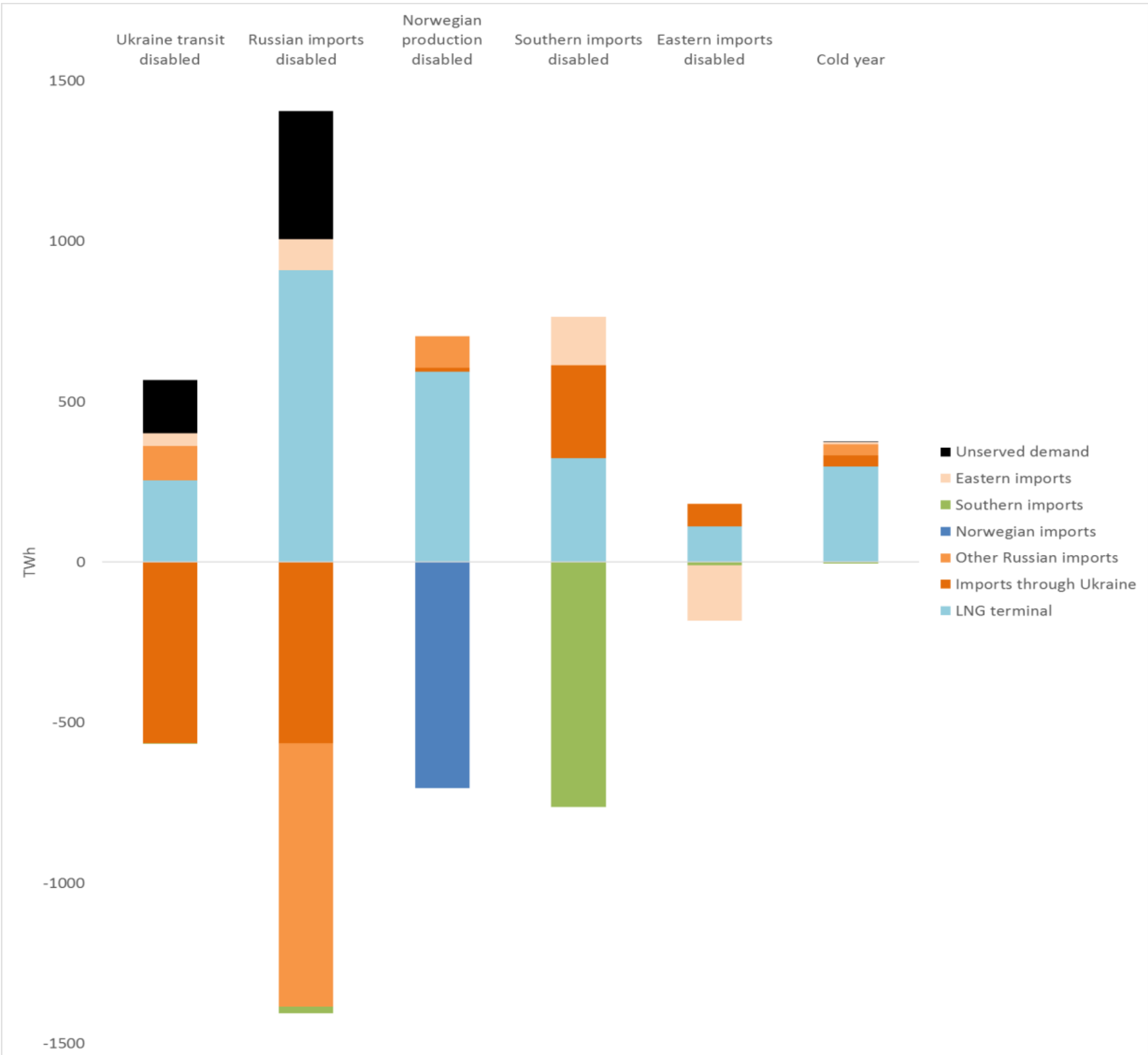

Figure 20: Additional supply per source compared to the reference case per disruption case (FID context)

5 SECURITY OF SUPPLY WITH ADDITIONAL PROJECTS FROM THE FIRST LIST OF PCIS

5.1 ADDITIONAL CAPACITY

Infrastructure in PC1 context include the same infrastructure as in FID context with additional projects enlisted in the first list of PCIs, which were not removed from the second PCI list.

The list of additional infrastructure includes LNG terminals, gas storages and cross-border transmissions:

- Storage capacity is added in Cyprus and states with Russian imports dependence in FID context (Bulgaria, Latvia, Romania).

Country	Storage capacity in FID context	Storage capacity in PCI1 context	Variation
Bulgaria	6 TWh	11 TWh	+5 TWh (+83%)
Cyprus	-	0.3 TWh	+0.3 TWh
Latvia	25 TWh	31 TWh	+6 TWh (+24%)
Romania	33 TWh	36 TWh	+3 TWh (+9.1%)
EU28	1210 TWh	1225 TWh	+ 15 TWh (+1.2%)

Table 12: Additional storage capacity in PCI1 context

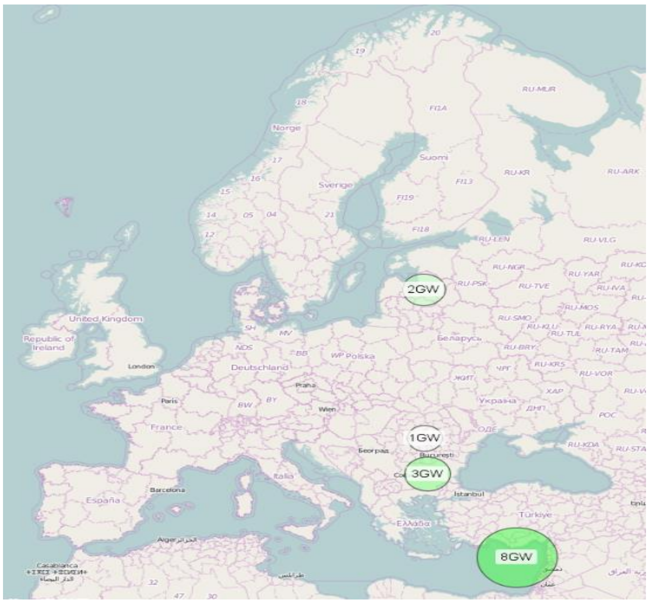

Figure 21: Map of additional storage withdrawal capacity (PCI1 context)

- LNG terminals are built in Malta (which has appearing demand in 2030), states with Russian import dependence (Poland Estonia, Sweden) and states with no particular security of supply issues observed in the section 4 (Ireland, Croatia, Greece).

Country	Send-out capacity in FID context	Send-out capacity in PCI1 context	Variation
Estonia	0 TWh/y	59 TWh/y	+59 TWh/y
Greece	77 TWh/y	143 TWh/y	+66 TWh/y
Croatia	0 TWh/y	65 TWh/y	+65 TWh/y
Ireland	0 TWh/y	64 TWh/y	+64 TWh/y
Malta	0 TWh/y	22 TWh/y	+22 TWh/y
Poland	54 TWh/y	81 TWh/y	+27 TWh/y
Sweden	1.5 TWh/y	9.5 TWh/y	+8.0 TWh/y
EU28	2760 TWh/y	3070 TWh/y	+ 310 TWh/y (+11%)

Table 13: Additional LNG terminal send-out capacity in PCI1 context

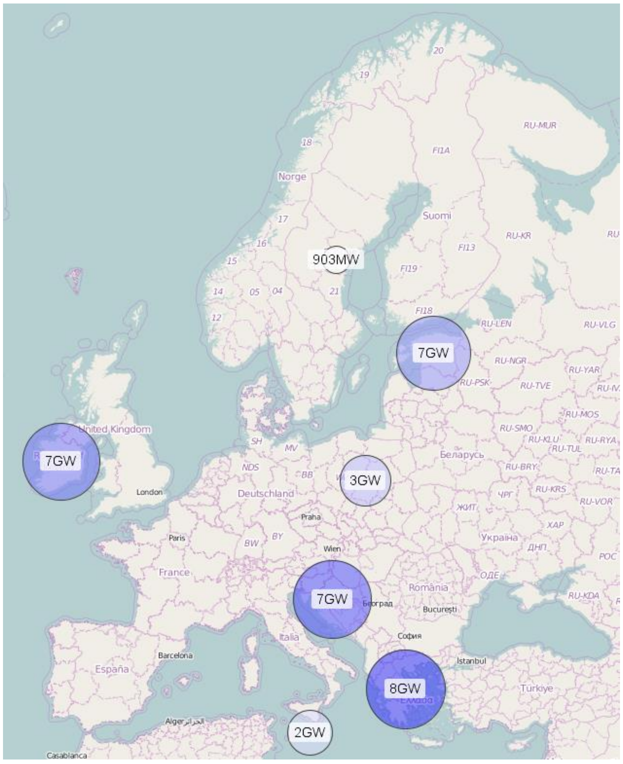

Figure 22: Map of additional LNG terminal send-out capacity (PCI1 context)

- The internal network is reinforced with additional capacities on cross-border transmissions between member states. In particular, we observe:
  - new connections to Malta and Cyprus and additional export capacity to Serbia;
  - additional entry capacity to Southeast Europe (which could decrease Ukraine transit dependence)
  - additional capacity on pipeline roads from Western to Eastern Europe and new connections to Baltic states (which could decrease Russian imports dependence)

In addition, several entry capacities to EU28 are added. Import capacity from Algeria to Italy increases by 96 TWh per year (around 9 bcm/y) and import capacity from the Middle-East Southeast Europe (via pipelines from Turkey and Azerbaijan) increases 79 TWh per year (around 7 bcm/y).

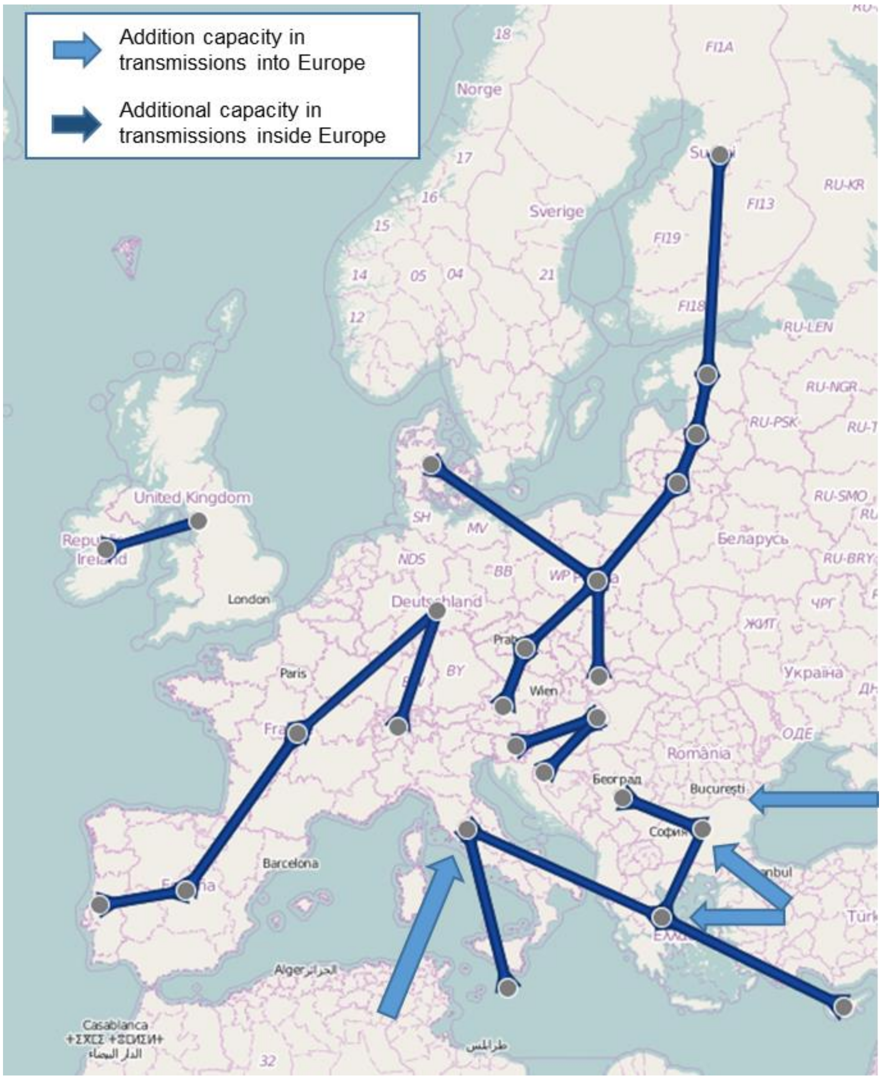

Figure 23: Map of additional transmission capacities (PCI1 context)

5.2 DISRUPTED DEMAND

5.2.1 REFERENCE CASE

In the reference case, we still observe unserved demand in Balkan countries (see Figure 24). Its volume has decreased with the addition of PCI, in particular thanks to the transmission between Bulgaria and Serbia. However, the share of unserved demand on national demand remains high in Bosnia-Herzegovina and Serbia.

Within EU28, all demand can be covered. In particular, planned capacities to cover appearing demand in Malta and Cyprus are sufficient to cover demand.

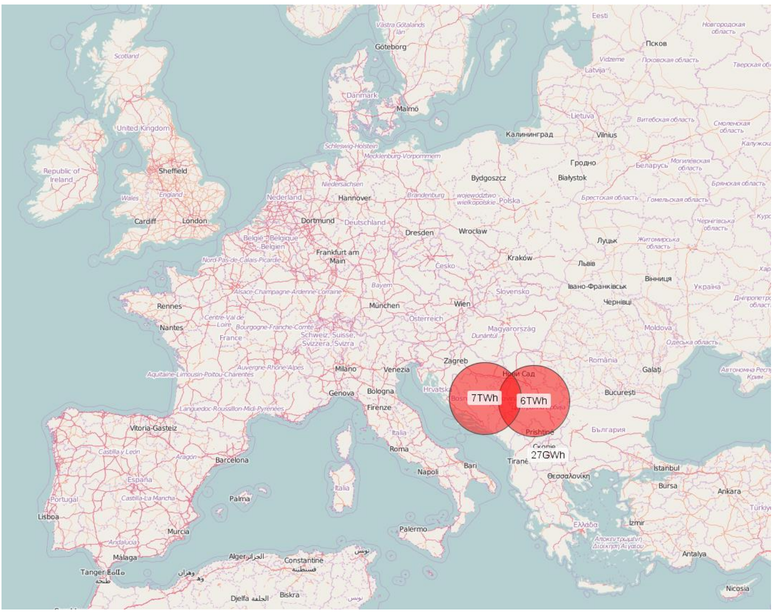

Figure 24: Map of unserved demand in the reference case (PCI1 context)

Country	Yearly volume of unserved demand (FID context)	Yearly volume of unserved demand (PCI1 context)	Share of unserved demand on national demand (PCI1 context)	Number of days with unserved demand (PCI1 context)
Cyprus	8.8 TWh	0 TWh	0%	0
Malta	3.7 TWh	0 TWh	0%	0
EU28	12.5 TWh	0 TWh	0%	0
Bosnia-Herzegovina	7.5 TWh	6.6 TWh	74%	279
Former Yugoslav Republic of Macedonia	0.027 TWh	0.027 TWh	0.39%	5
Serbia	17 TWh	6.5 TWh	10%	114

Table 14: Unserved demand in the reference case (PCI1 context)

5.2.2 Cold case

As the import capacity of Luxemburg has not changed with the addition of PCI, the same failure to cover its peak demand under very cold temperature is observed.

Country	Yearly volume of unserved demand (FID context)	Yearly volume of unserved demand (PCI1 context)	Share of unserved demand on national demand (PCI1 context)	Number of days with unserved demand (PCI1 context)
Cyprus	8.6 TWh	0 TWh	0%	0
Luxemburg	0.008 TWh	0.008 TWh	0.05%	3
Malta	4.0 TWh	0 TWh	0%	0
EU28	12.6 TWh	0.008 TWh	0.0002%	3
Bosnia-Herzegovina	7.6 TWh	6.6 TWh	74%	273
Former Yugoslav Republic of Macedonia	0.034 TWh	0.034 TWh	0.50%	7
Serbia	18 TWh	7.8 TWh	12%	107

Table 15: Unserved demand in the cold case (PCI1 context)

Except from peak demands in Luxemburg, all demand within EU28 can be covered in the cold case. As seen previously in the reference case, the transmission from Bulgaria to Serbia contributes to decreasing unserved demand in Balkan countries.

5.3 Source dependence

5.3.1 Ukraine transit dependence

With infrastructure from the first list of PCIs, Ukraine transit dependence decreases sharply and is only observed in Romania and Serbia. In particular, no dependence to Ukraine transit is observed in Hungary and Bulgaria.

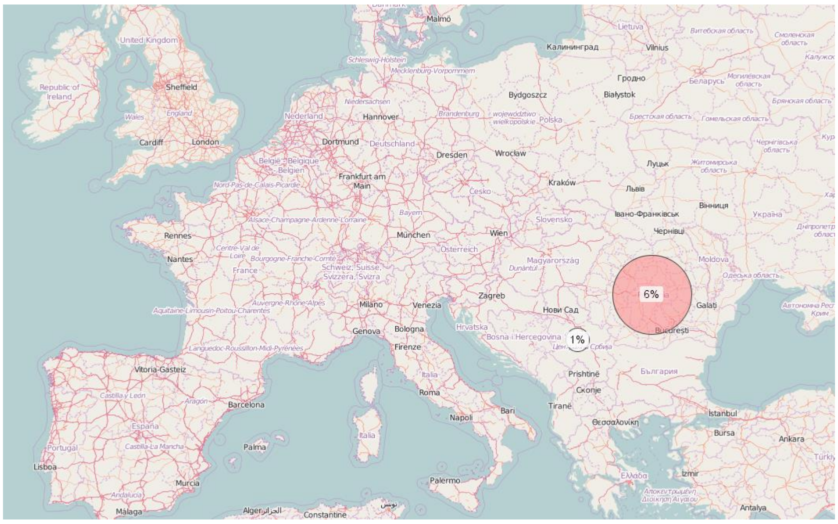

Figure 25: Map of Ukraine transit dependence (PCI1 context)

Ukraine transit dependence decreases down to 0.2% of demand in EU28. Although this is a small part of European demand, it still represents a significant part of Romanian demand.

Country	Yearly volume of dependence (FID context)	Yearly volume of dependence (PCI1 context)	Share of dependence on national demand (PCI1 context)	Number of days with dependence (PCI1 context)
Bulgaria	12 TWh	0 TWh	0%	0
Hungary	9.0 TWh	0 TWh	0%	0
Romania	96 TWh	9.9 TWh	6.4%	83
EU28	117 TWh	9.9 TWh	0.20%	83
Bosnia-Herzegovina	1.4 TWh	0 TWh	0%	0
Former Yugoslav Republic of Macedonia	1.7 TWh	0 TWh	0%	0
Serbia	46 TWh	0.35 TWh	0.54%	58

Table 16: Ukraine transit dependence (PCI1 context)

LNG imports increase to substitute for 50% of Ukraine transit gas. In particular, the additional LNG terminal in Croatia enables LNG imports very close to dependent states. Around 32% of Ukraine transit gas can be transported around Ukraine if pipelines are disabled. Additional imports from Azerbaijan and Turkey can substitute for 17% of Ukraine transit gas, which leaves 1% of Ukraine transit gas which cannot be substituted with another source.

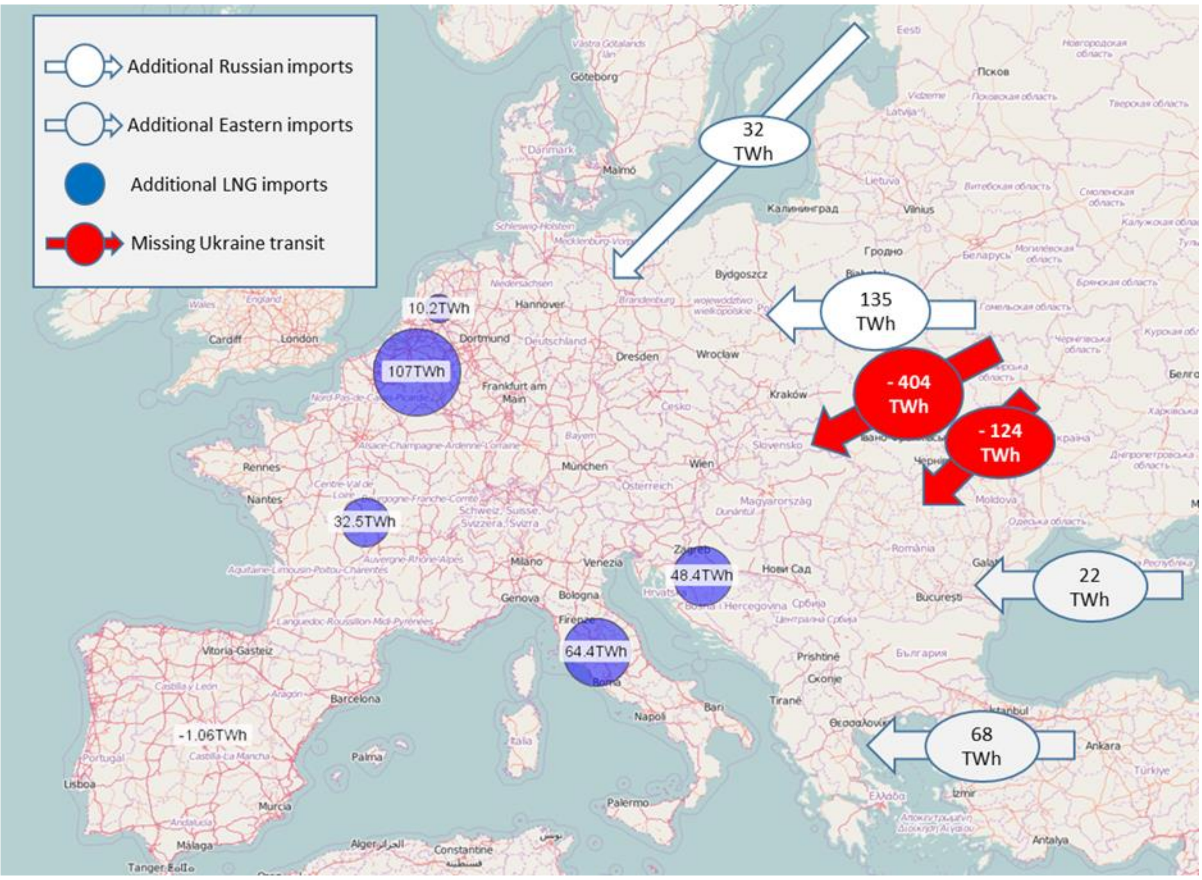

Figure 26: Map of additional imports with Ukraine transit disabled (PCI1 context)

In Figure 27, we observe that, although LNG is still the most used source to compensate the loss of Ukraine transit gas, the dependence observed in the FID context is removed mainly because Russian gas can get around Ukraine more easily to reach Southeast Europe with PCIs. Additional import capacities from the East are also used to provide Southeast Europe with gas, in particular Romania directly from Azerbaijan. Also, it is worth noting that imports through Ukraine are slightly decreased in the Reference case, which also contributes to remove the dependence to Ukraine transit.

Some dependence remains in Romania and Serbia because of congestions in transmissions in Southeast Europe. Additional transmission capacities enabled the injection of more gas in Southeast Europe (which removed dependence in Hungary and Bulgaria) but the internal network in this zone was not sufficiently developed to remove all dependence (see Figure 28).

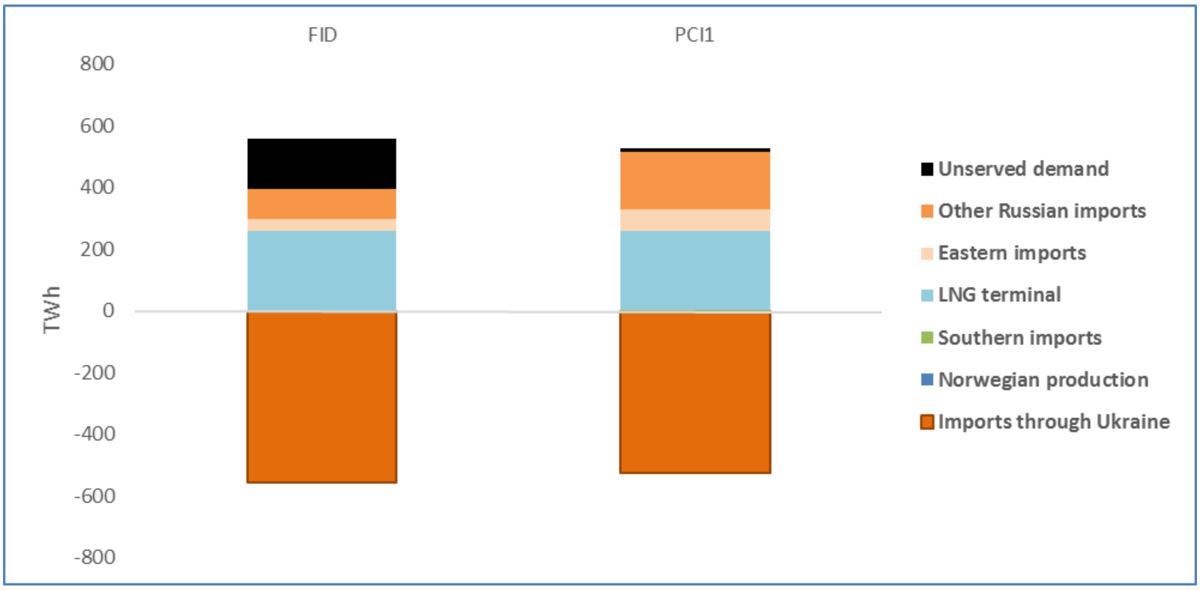

Figure 27: Supply per source compared to the reference context with Ukraine transit disabled

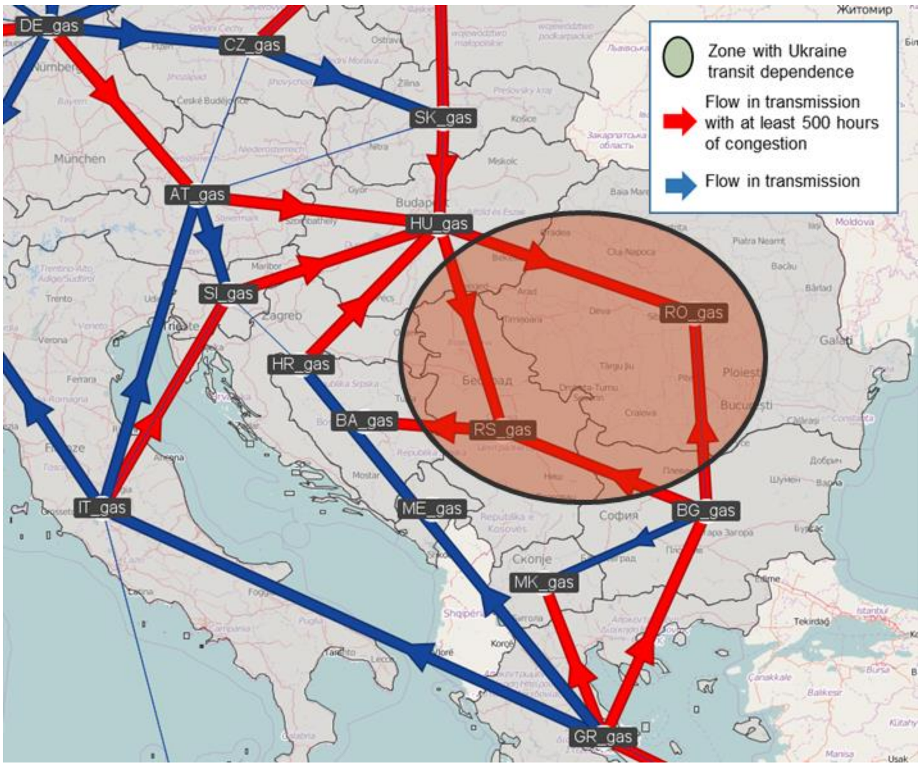

Figure 28: Map of flows and congestions with Ukraine imports disabled (PCI1 context)

5.3.2 RUSSIAN IMPORTS DEPENDENCE

As in the previous case, we observe that PCIs have a great impact on Russian imports dependence as it is almost completely removed, at the exception of Finland, Romania and Serbia.

Figure 29: Map of Russian import dependence (PCI1 context)

The dependence Romania and Serbia remains unchanged, highlighting their strong dependence on Ukraine transit to supply Russian gas.

Country	Yearly volume of dependence (FID context)	Yearly volume of dependence (PCI1 context)	Share of dependence on national demand (PCI1 context)	Number of days with dependence (PCI1 context)
Finland	18 TWh	0.28 TWh	1.22%	32
Romania	96 TWh	9.9 TWh	6.4%	83
EU28	117 TWh	10 TWh	0.21%	101
Serbia	46 TWh	0.35 TWh	0.54%	58

Table 17: Russian import dependence (PCI1 context)

Finland is almost autonomous from Russian imports as it is connected to the rest of Europe thanks to additional transmissions between Finland and Estonia and between Poland and Lithuania (which, with existing transmissions between Lithuania, Latvia and Estonia, create a gas route from Poland to Finland). However, it is still slightly dependent on Russian gas as its import capacity from Estonia is not high enough to cover peak demand under cold temperatures, as illustrated in Figure 30.

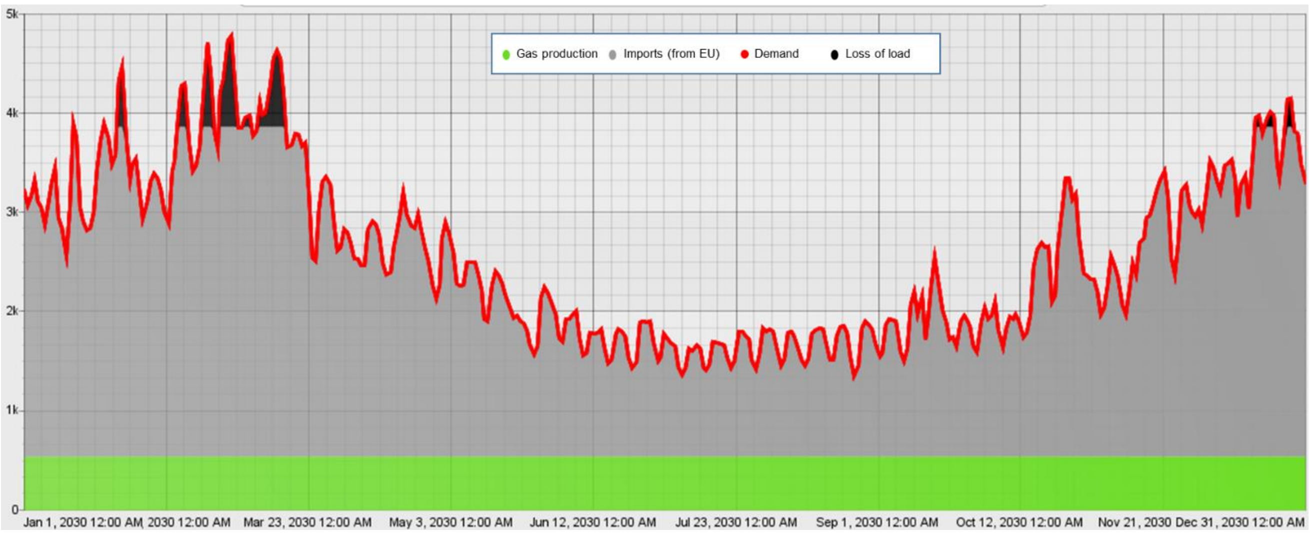

Figure 30: Supply and loss of load in Finland with Russian import disabled (PCI1 context)

On Figure 31 and Figure 32, we see that Russian gas is mainly substituted with LNG imports. In particular, we note the use of new LNG terminals close to countries with dependence issues in FID context (Croatia, Poland, Estonia), which mainly explains the decrease in dependence between FID context and PCI1 context. In addition, Eastern imports increase with new import transmission to Southeast Europe.

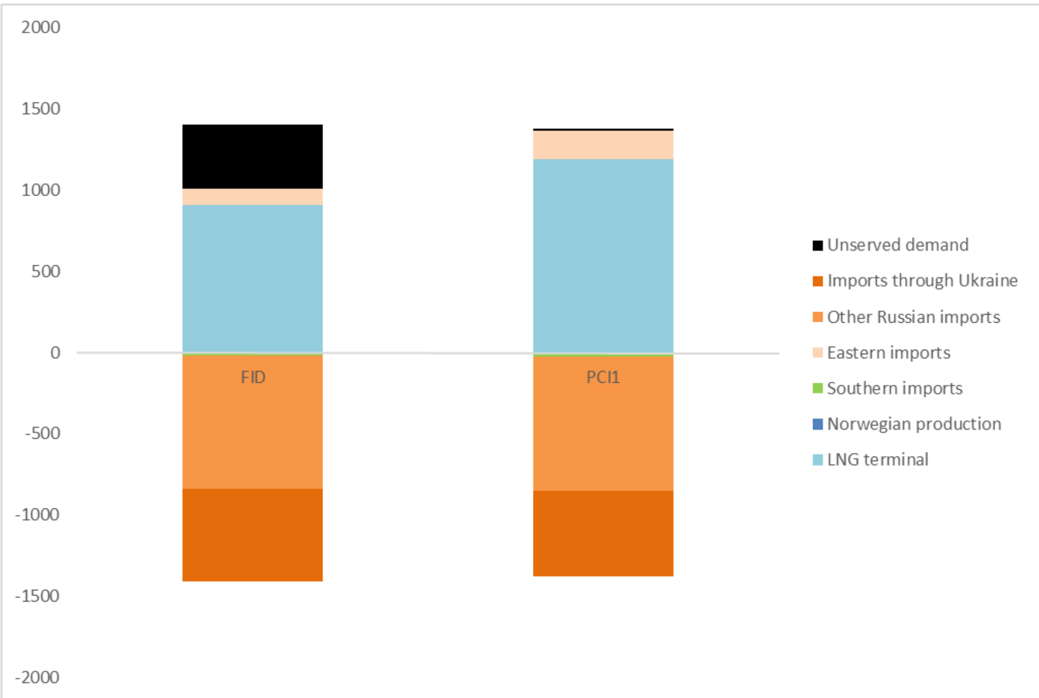

Figure 31: Supply per source compared to the reference context with Russian import disabled

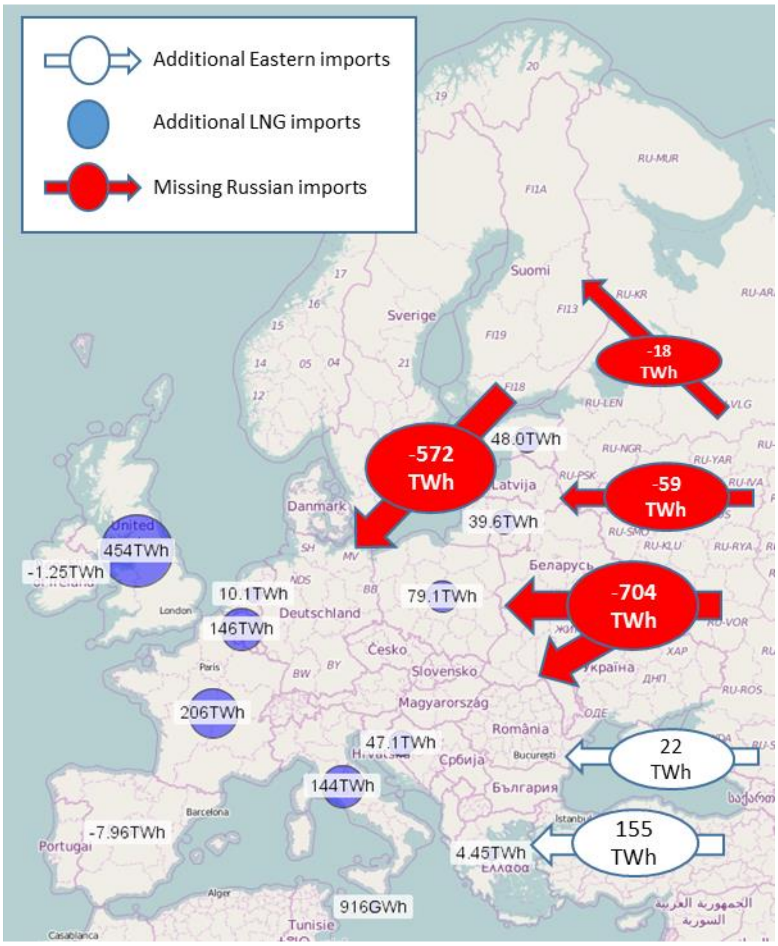

Figure 32: Map of additional imports with Russian import disabled (PCI1 context)

5.4 SUMMARY

From the METIS simulation results, we conclude that:

- Malta and Cyprus are no longer concerned by unserved demand issues, which are limited to Balkan countries in the reference case. Luxemburg still lacks import capacity to manage peak demands under very cold temperatures.

Disrupted demand	Standard year	Cold year
EU28 unserved demand	0 TWh	0.008 TWh
EU28 unserved demand (in % of total demand)	0%	0.0001%
Member states with unserved demand	-	LU
Non-member states with unserved demand	BA, MK, RS	BA, MK, RS

Table 18: Summary of disrupted demand (PCI1 context)

- Dependence on Ukraine transit and Russian imports has sharply decreased and is limited to Finland, Romania and Serbia.

Source dependence	Ukraine transit	Russian imports
EU28 dependence volume	9.9 TWh	10 TWh
EU28 dependence share (in % of total demand)	0.20%	0.21%
Dependent member states	RO	FI, RO
Dependent non-member states	RS	RS

Table 19: Summary of supply source dependence (PCI1 context)

If Ukraine transit is disabled, the addition of PCIs bring new transmissions which enable the transport of Russian gas around Ukraine. When all Russian imports are unavailable, new LNG terminals are used to import more LNG and import it directly in the countries where it is needed.

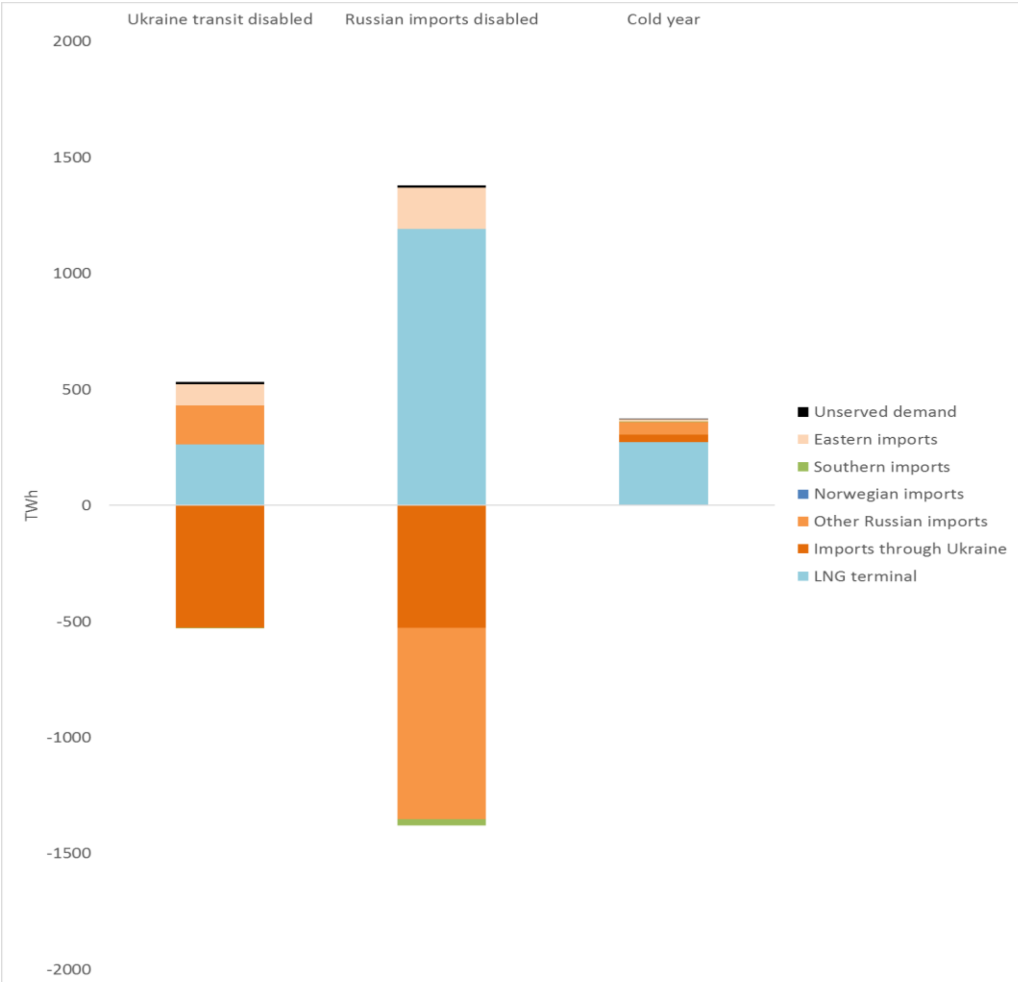

Figure 33: Additional supply per source compared to the reference case per disruption case (PCI1 context)

6 SECURITY OF SUPPLY WITH ADDITIONAL PROJECTS FROM THE SECOND LIST OF PCIS

6.1 ADDITIONAL CAPACITY

Infrastructure in the PCI2 context include the same infrastructure as in PCI1 context with additional projects enlisted in the second PCI list, which were not in the first PCI list.
The list of additional infrastructure includes gas storages and cross-border transmissions:

- Storage capacity is added in Romania, which has dependence issues in PCI1 context.

Country	Storage capacity in PCI1 context	Storage capacity in PCI2 context	Evolution
Romania	36 TWh	45 TWh	+9 TWh (+25%)
EU28	1225 TWh	1234 TWh	+ 9 TWh (+0.73%)

Table 20: Additional storage capacity in PCI2 context

- The internal gas network is developed with additional capacity on cross-border transmissions between member states. In particular, we observe a strong reinforcement of the network in Southeast Europe. In addition, several entry points to EU28, mostly from the Ukraine and the Middle-East to Southeast Europe.

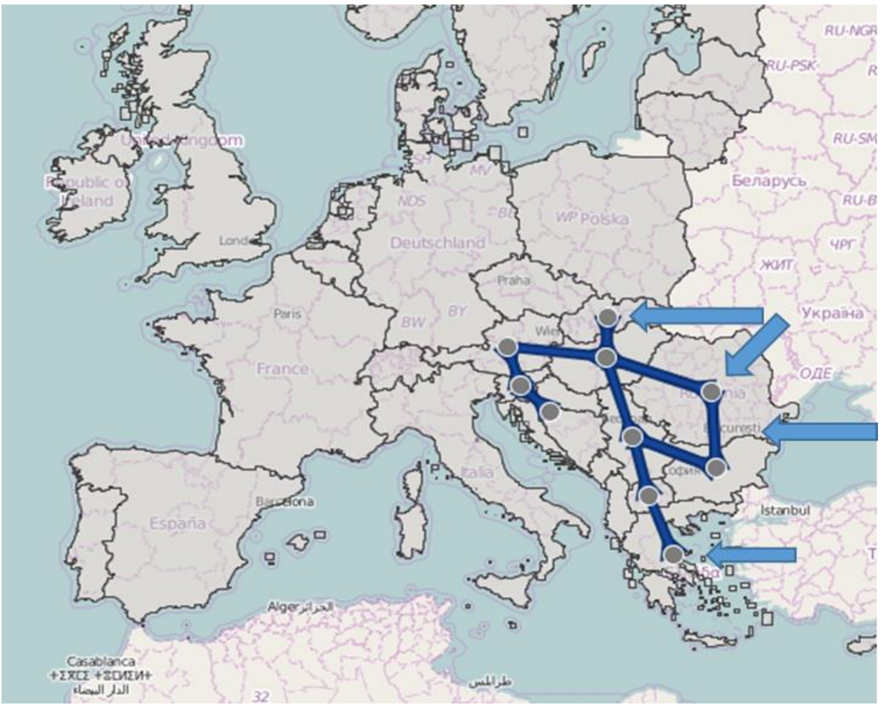

Figure 34: Map of additional transmission capacities in PCI2 context

6.2 DISRUPTED DEMAND

6.2.1 REFERENCE CASE

In the reference case, unserved demand remains only in Bosnia, as no additional transmission to this country is added while connections with Serbia and the Former Yugoslav Republic of Macedonia are reinforced.

Country	Yearly volume of unserved demand (PCI1 context)	Yearly volume of unserved demand (PCI2 context)	Share of unserved demand on national demand (PCI2 context)	Number of days with unserved demand (PCI2 context)
Bosnia-Herzegovina	6.6 TWh	4.0 TWh	45%	279
Former Yugoslav Republic of Macedonia	0.027 TWh	0 TWh	0%	0
Serbia	6.5 TWh	0 TWh	0%	0

Table 21: Unserved demand in the reference case (PCI2 context)

6.2.2 COLD CASE

As the import capacity of Luxemburg has not changed with the addition of PCIs, there are still issues to cover peak demands under very cold temperatures.

Country	Yearly volume of unserved demand (PCI1 context)	Yearly volume of unserved demand (PCI2 context)	Share of unserved demand on national demand (PCI2 context)	Number of days with unserved demand (PCI2 context)
Luxemburg	0.008 TWh	0.008 TWh	0.05%	3
EU28	12.6 TWh	0.008 TWh	0.0002%	3
Bosnia-Herzegovina	7.6 TWh	4.0 TWh	45%	272

Table 22: Unserved demand in the cold case (PCI2 context)

6.3 SOURCE DEPENDENCE

6.3.1 UKRAINE TRANSIT DEPENDENCE

With the addition of multiple connections towards Romania and Serbia, no Ukraine transit dependence is observed anymore.

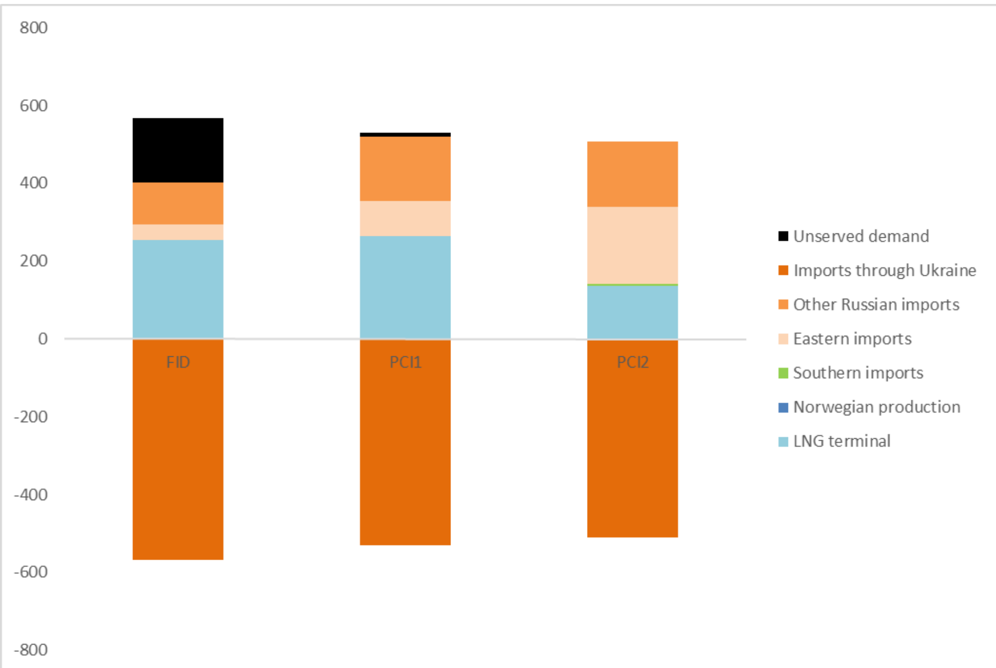

Figure 35: Supply per source compared to the reference case with Ukraine transit disabled

About 39% of Ukraine transit is substituted with gas from Middle-East, which takes advantage of stronger connections with Greece and Romania to reach Southeast Europe. Therefore, although additional LNG imports still substitute for 27% of Ukraine transit gas, the increase of LNG imports is less important than in PCI1 context, in particular in Benelux and Italy.

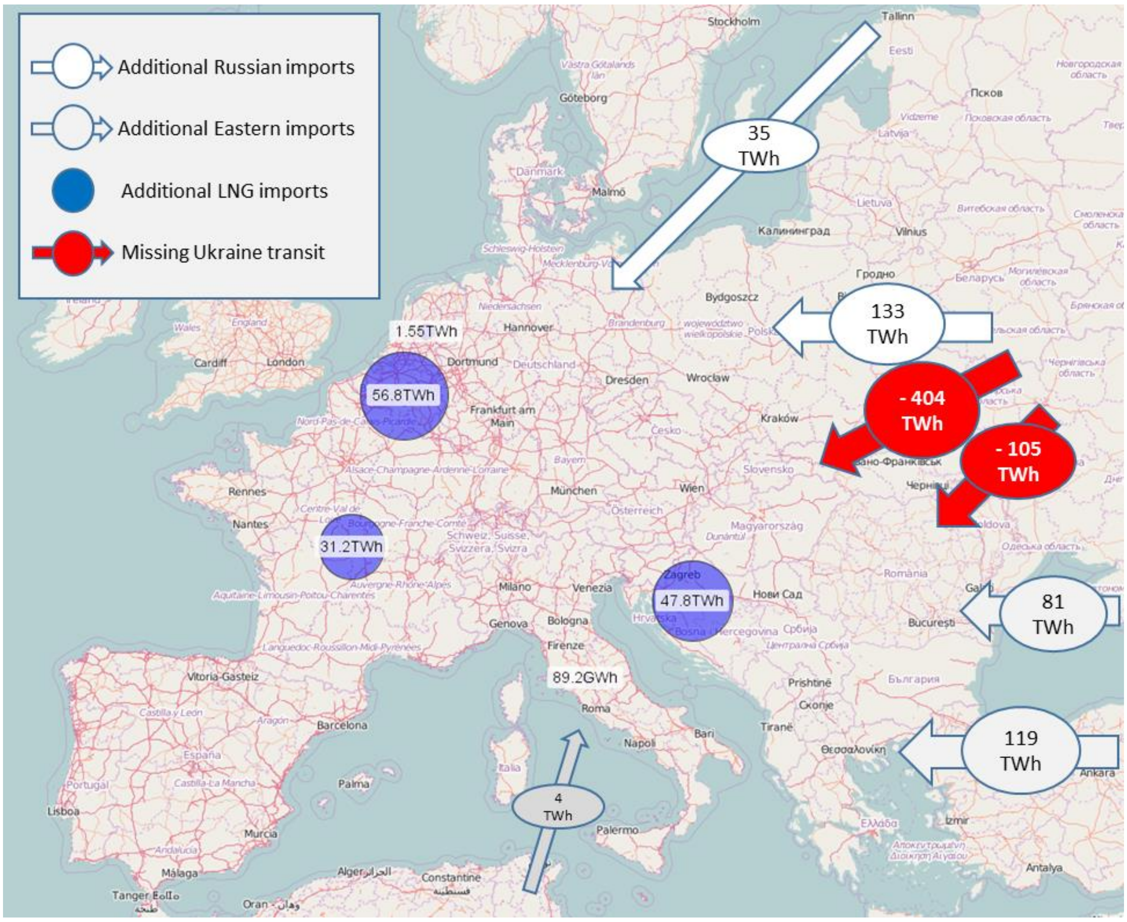

Figure 36: Map of additional imports with Ukraine transit disabled (PCI2 context)

6.3.2 RUSSIAN IMPORTS DEPENDENCE

As in the previous case, source dependence has been removed in Southeast Europe. Some dependence remains in Finland, as no additional import capacity has been added in the second list of PCI.

Country	Yearly volume of dependence (PCI1 context)	Yearly volume of dependence (PCI2 context)	Share of dependence on national demand (PCI2 context)	Number of days with dependence (PCI2 context)
Finland	0.28 TWh	0.28 TWh	1.22%	32
EU28	10 TWh	0.28 TWh	0.006%	32

Table 23: Russian import dependence (PCI2 context)

The sources used to compensate for the loss of Russian gas are close to the ones used in the PCI1 context. Additional LNG imports still substitute for over 85% of Russian gas. Remaining dependence in Southeast Europe is removed with slightly more imports from the Middle-East than in PCI1 context.

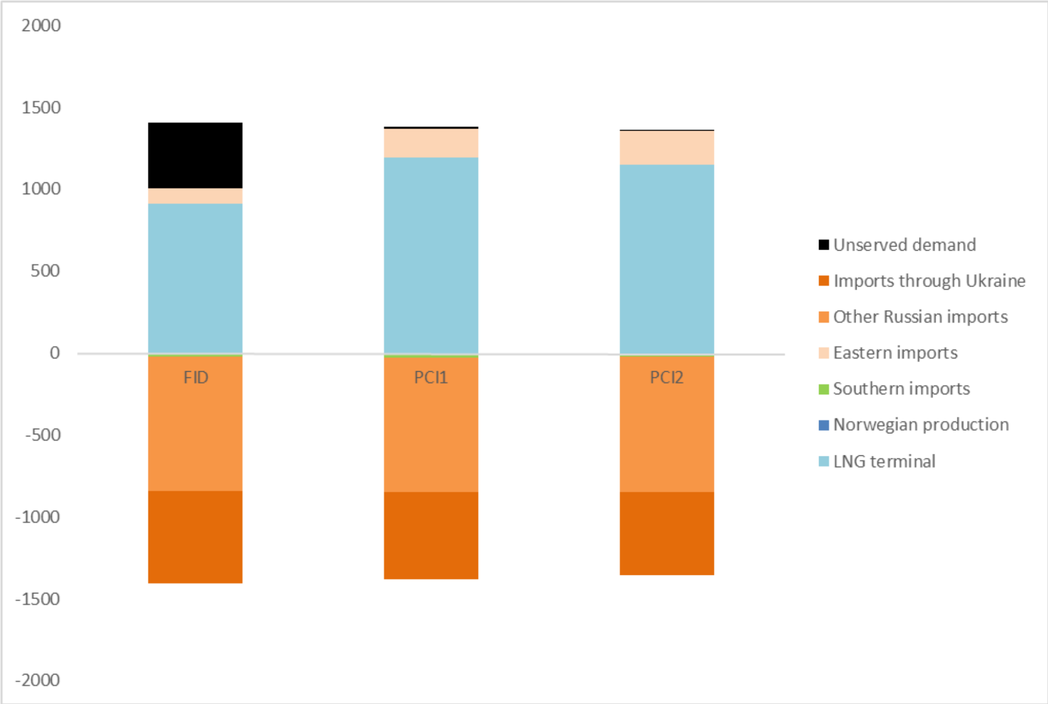

Figure 37: Supply per source compared to the reference case with Russian import disabled

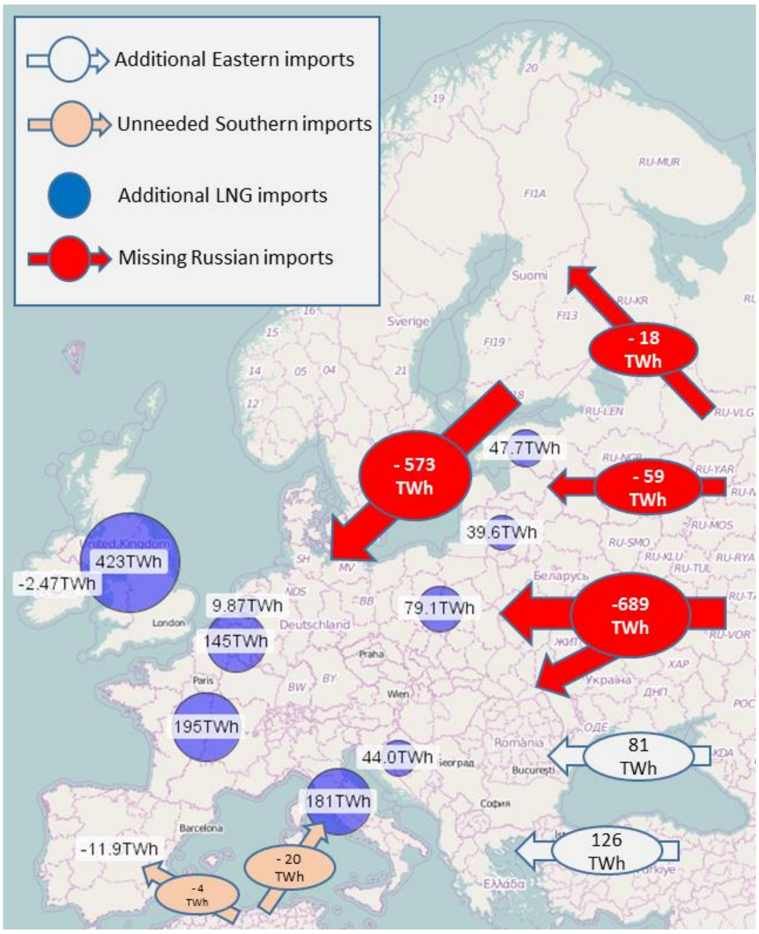

Figure 38: Map of additional import with Russian import disabled (PCI2 context)

6.4 SUMMARY

From the METIS simulation results, we conclude that:

- Unserved demand issues are almost completely removed and only remain in Bosnia-Herzegovina and Luxemburg in very cold temperatures.

Disrupted demand	Standard year	Cold year
EU28 unserved demand	0 TWh	0.008 TWh
EU28 unserved demand (in % of total demand)	0%	0,0001%
Member states with unserved demand	-	LU
Non-member states with unserved demand	BA	BA

Table 24: Summary of disrupted demand (PCI2 context)

- Dependence on Ukraine transit and Russian imports has been almost completely removed, at the exception of little Russian imports dependence in Finland to cover very cold days.

Source dependence	Ukraine transit	Russian imports
EU28 dependence volume	0 TWh	0.27 TWh
EU28 dependence share (in % of total demand)	0%	0.006%
Dependent member states	-	FI
Dependent non-member states	-	-

Table 25: Summary of supply source dependence (PCI2 context)

The addition of projects from the second list of PCIs brings a stronger network to Southeast Europe additional import capacity to remove remaining dependence. LNG imports remain the most important source of supply to compensate for a loss of Russian imports.

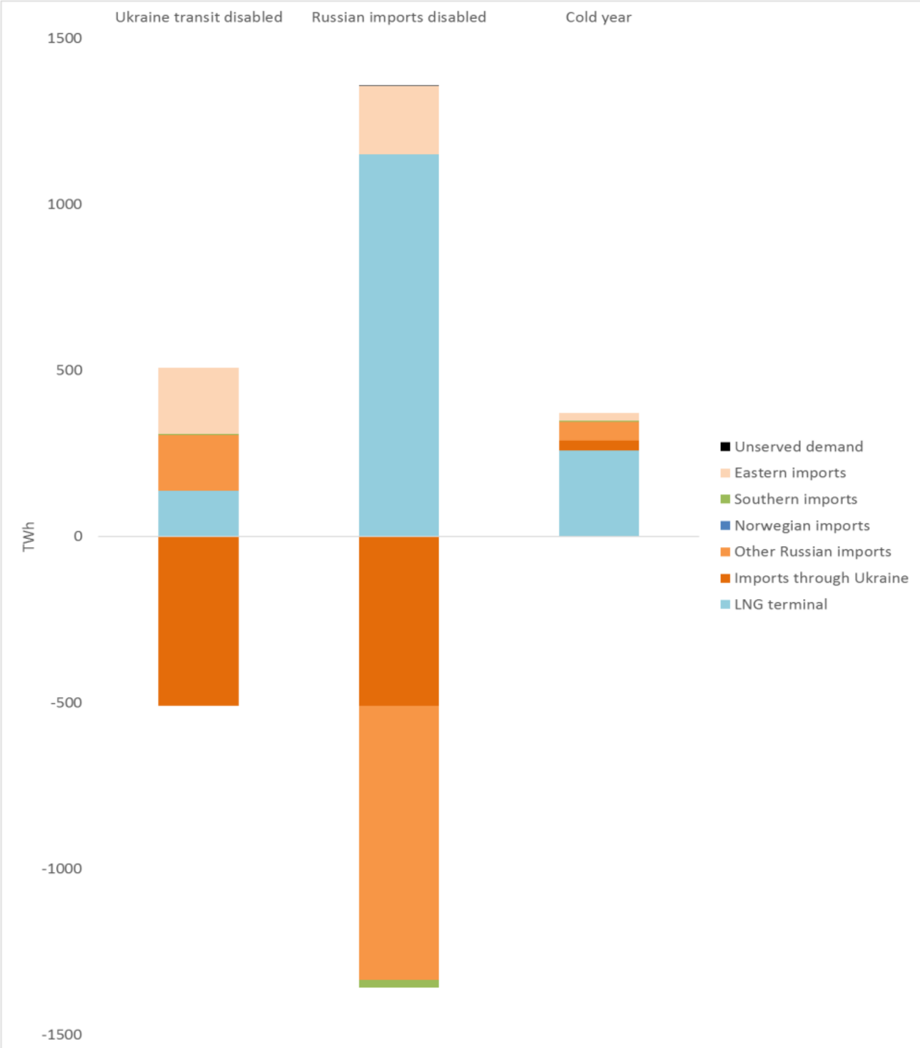

Figure 39: Additional supply per source compared to the reference case per disruption case (PCI2 context)

7 CONCLUSION

Under ENTSOG TYNDP2015 consumption scenario, PCIs have a strong impact on gas security of supply, which was measured through two indicators: disrupted demand and supply source dependence.

In the METIS model with current and already financed infrastructure (FID context), we observe that disrupted demand was already limited to countries with little import capacity. Among PCIs, new infrastructure bring connections to isolated systems such as Malta and Cyprus, and reinforce transmissions between EU28 member states and Balkan countries. After the addition of all PCIs, disrupted demand issues are limited to low loss of load in a very cold year in Luxemburg (0.05% of national demand) under extreme temperatures and Bosnia.

In the FID context, supply source dependence is observed for Russian imports and Ukraine transit, while Norwegian production or other sources of imports can be substituted with LNG and additional Russian imports. Russian gas dependency is mostly found in Eastern countries, in particular Southeastern countries which are highly dependent on Ukraine transit. In the METIS models with PCIs, dependence on Ukraine transit is removed as new gas routes to reach Southeast Europe are created or reinforced, which makes it easier for Russian gas to get around Ukraine. New LNG terminals and transmissions from Western Europe to Eastern Europe also contribute in decreasing strongly dependence on Russian imports. In PCI2 context, Russian import dependence is only observed in Finland which lacks import capacity from other sources.

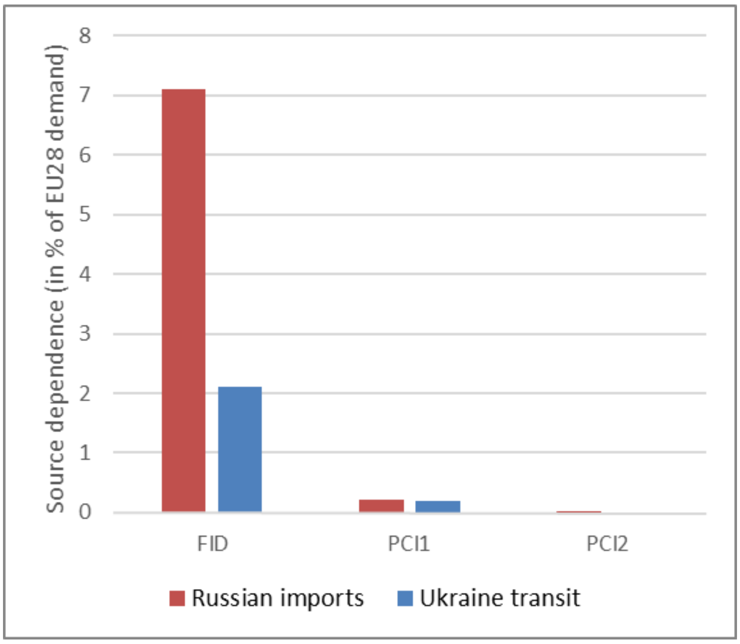

Figure 40: Source dependence in EU28 (in % of demand) without and with PCIs

The study was focused on security of supply issues, leaving aside costs and benefits aside from the saved volume of loss of load. By 2017, functionalities will be developed in METIS to model gas markets in Europe, thus enabling studies that could complete these analyses, in particular by providing a more accurate modeling of import prices.

8 APPENDIX

8.1 GAS CONSUMPTION AND PRODUCTION PER COUNTRY

Yearly consumption volumes were collected from ENTSOG TYNDP 2015 GREY scenario. Yearly production volumes were collected from ENTSOG TYNDP 2015 FID scenario.

Country	Consumption in 2030 (in TWh/y)	Production in 2030 (in TWh/y)	Country	Consumption in 2030 (in TWh/y)	Production in 2030 (in TWh/y)
AT	73.75	11.35	**IT**	796.07	66.09
BA	8.92	-	**LT**	24.72	-
BE	211.55	16.15	**LU**	13.65	-
BG	48.45	-	**LV**	26.24	0.04
CH	37.01	1.10	**ME**	0.00	-
CY	8.75	-	**MK**	6.88	-
CZ	117.03	-	**MT**	3.74	-
DE	536.89	54.13	**NL**	464.42	268.54
DK	19.15	13.01	**NO**	51.31	810.07
EE	8.00	-	**PL**	193.96	27.72
ES	422.23	-	**PT**	97.06	-
FI	22.60	4.70	**RO**	155.06	58.94
FR	468.92	82.09	**RS**	64.87	0.66
GR	65.88	-	**SE**	9.80	0.58
HR	26.32	5.28	**SI**	11.02	3.06
HU	102.72	1.09	**SK**	64.59	-
IE	45.74	6.56	**UK**	898.64	352.84

Table 26: Consumption and production per country in 2030

8.2 DETAILED CAPACITIES OF PCIS

The following tables enlist the PCIs considered for the study. PCIs were collected from ENTSOG TYNDP 2015. They include projects for transmission capacities, storages and LNG terminals.

Displayed capacities in the following tables are <u>additional</u> capacities and should be added to existing and FID infrastructure to obtain the total capacities used in the models (available in sections 5.1 and 6.1).

PCI list	Corridor	No.	TYNDP Ref	From	To	Capacity (GWh/d)
1	NSI West	5.1.1	TRA-N-059	IE	GB	38.5
1	NSI West	5.10	TRA-N-208	CH	DE	357.6
1	NSI West	5.19	TRA-N-031	IT	MT	48.2
1	NSI West	5.19	TRA-N-031	MT	IT	48.2
1	NSI West	5.20	TRA-N-012	DZ	IT	258
1	NSI West	5.4	TRA-N-168	PT	ES	50
1	NSI West	5.4	TRA-N-168	PT	ES	47
1	NSI West	5.4	TRA-N-168	PT	ES	45
1	NSI West	5.4	TRA-N-168	ES	PT	75
1	NSI West	5.4	TRA-N-168	ES	PT	32
1	NSI West	5.4	TRA-N-168	ES	PT	35
1	NSI West	5.5	TRA-N-161	FR	ES	80
1	NSI West	5.5	TRA-N-161	ES	FR	230
1	NSI West	5.5	TRA-N-252	FR	ES	80
1	NSI West	5.6	TRA-N-047	FR	DE	100
1	NSI East	6.1.1	TRA-N-136	PL	CZ	153.2
1	NSI East	6.1.1	TRA-N-136	CZ	PL	219.1
1	NSI East	6.10	TRA-N-137	RS	BG	51
1	NSI East	6.10	TRA-N-137	BG	RS	51
1	NSI East	6.15	TRA-N-139	AZ	RO	65.3
1	NSI East	6.2.1	TRA-N-275	SK	PL	174.5
1	NSI East	6.2.1	TRA-N-275	PL	SK	143.9
1	NSI East	6.23	TRA-N-112	HU	SI	38
1	NSI East	6.23	TRA-N-112	SI	HU	38
1	NSI East	6.4	TRA-N-021	CZ	AT	201.42
1	NSI East	6.4	TRA-N-021	AT	CZ	201.42
1	NSI East	6.5	TRA-N-075	HU	HR	129
1	NSI East	6.5	TRA-N-075	HR	HU	205
1	NSI East	6.8.1	TRA-N-378	GR	BG	90
1	NSI East	6.8.1	TRA-N-378	GR	BG	60.5
1	SGC	7.1.2	TRA-N-128	TR	GR	54.4
1	SGC	7.1.4	TRA-N-010	IT	GR	252.5
1	SGC	7.1.4	TRA-N-010	GR	IT	329.4
1	SGC	7.3.1	TRA-N-330	GR	CY	30
1	SGC	7.3.1	TRA-N-330	CY	GR	329.4
1	SGC	7.4.2	TRA-N-140	BG	TR	86
1	SGC	7.4.2	TRA-N-140	TR	BG	86
1	BEMIP	8.1.1	TRA-N-023	EE	FI	79.8
1	BEMIP	8.1.1	TRA-N-023	FI	EE	79.8
1	BEMIP	8.2.1	TRA-N-342	LV	LT	59.8
1	BEMIP	8.2.1	TRA-N-342	LT	LV	57.4
1	BEMIP	8.2.2	TRA-N-084	LV	EE	23
1	BEMIP	8.2.2	TRA-N-084	EE	LV	94
1	BEMIP	8.3	TRA-N-271	DK	PL	91.1
1	BEMIP	8.3	TRA-N-271	PL	DK	91.1
1	BEMIP	8.5	TRA-N-212	LT	PL	30.6
1	BEMIP	8.5	TRA-N-212	PL	LT	73.4

Table 27: Transmission capacities from the first list of PCIs

PCI list	Corridor	No.	TYNDP Ref	From	To	Capacity (GWh/d)
2	2-NSI East	6.24.1	TRA-N-126	HU	RO	76.9
2	2-NSI East	6.24.1	TRA-N-126	RO	HU	128
2	2-NSI East	6.24.2	TRA-N-358	RO	BG	28.8
2	2-NSI East	6.24.6	TRA-N-123	AT	HU	25
2	2-NSI East	6.24.6	TRA-N-123	HU	AT	153
2	2-NSI East	6.24.8	TRA-N-362	AZ	RO	178
2	2-NSI East	6.25.1	TRA-N-654	BG	TR	570
2	2-NSI East	6.25.1	TRA-N-654	BG	TR	570
2	2-NSI East	6.25.1	TRA-N-654	BG	TR	712
2	2-NSI East	6.25.1	TRA-N-654	RO	BG	570
2	2-NSI East	6.25.1	TRA-N-654	RO	BG	570
2	2-NSI East	6.25.1	TRA-N-654	BG	RO	570
2	2-NSI East	6.25.1	TRA-N-654	BG	RO	570
2	2-NSI East	6.25.1	TRA-N-654	BG	RO	712
2	2-NSI East	6.25.1	TRA-N-655	RO	BG	342
2	2-NSI East	6.25.1	TRA-N-655	RO	BG	370
2	2-NSI East	6.25.1	TRA-N-655	HU	RO	570
2	2-NSI East	6.25.1	TRA-N-655	HU	RO	570
2	2-NSI East	6.25.1	TRA-N-655	RO	HU	570
2	2-NSI East	6.25.1	TRA-N-655	RO	HU	570
2	2-NSI East	6.25.1	TRA-N-655	UA	RO	570
2	2-NSI East	6.25.1	TRA-N-655	UA	RO	570
2	2-NSI East	6.25.1	TRA-N-655	RO	UA	342
2	2-NSI East	6.25.1	TRA-N-655	RO	UA	370
2	2-NSI East	6.25.1	TRA-N-656	SK	HU	570
2	2-NSI East	6.25.1	TRA-N-656	SK	HU	570
2	2-NSI East	6.25.1	TRA-N-656	HU	SK	570
2	2-NSI East	6.25.1	TRA-N-656	HU	SK	570
2	2-NSI East	6.25.1	TRA-N-628	UA	SK	570
2	2-NSI East	6.25.1	TRA-N-628	UA	SK	570
2	2-NSI East	6.25.1	TRA-N-628	SK	UA	342
2	2-NSI East	6.25.1	TRA-N-628	SK	UA	370
2	2-NSI East	6.25.1	TRA-N-628	RO	UA	570
2	2-NSI East	6.25.1	TRA-N-628	RO	UA	570
2	2-NSI East	6.25.1	TRA-N-628	UA	RO	342
2	2-NSI East	6.25.1	TRA-N-628	UA	RO	370
2	2-NSI East	6.25.2	TRA-N-631	GR	MK	675
2	2-NSI East	6.25.2	TRA-N-631	TR	GR	792
2	2-NSI East	6.25.2	TRA-N-582	MK	RS	640
2	2-NSI East	6.25.2	TRA-N-582	GR	MK	675
2	2-NSI East	6.25.2	TRA-N-630	MK	RS	783
2	2-NSI East	6.25.2	TRA-N-630	RS	HU	582
2	2-NSI East	6.25.2	TRA-N-585	HU	AT	524
2	2-NSI East	6.25.4	TRA-N-592	RS	BG	59.4
2	2-NSI East	6.25.4	TRA-N-592	BG	RS	59.4
2	2-NSI East	6.25.4	TRA-N-592	RO	BG	30.8
2	2-NSI East	6.25.4	TRA-N-592	BG	RO	30.8
2	2-NSI East	6.25.4	TRA-N-593	BG	RO	1366
2	2-NSI East	6.25.4	TRA-N-594	BG	TR	192.5
2	2-NSI East	6.26.5	TRA-N-389	AT	SI	181
2	2-NSI East	6.26.5	TRA-N-389	SI	AT	165
2	2-NSI East	6.26.6	TRA-N-390	HR	SI	165
2	2-NSI East	6.26.6	TRA-N-390	SI	HR	165
2	2-NSI East	6.8.3	TRA-N-431	RO	HU	85.5
2	2-NSI East	6.8.3	TRA-N-431	BG	RO	85.5
2	2-NSI East	6.8.3	TRA-N-431	RO	BG	85.5

Table 28: Transmission capacities from the second list of PCIs

PCI list	Corridor	No.	TYNDP Ref	Zone	Withdrawal capacity (mcm/d)	Injection capacity (mcm/d)	Storage capacity (mcm)
1	NSI West	5.1.3	UGS-N-294	UK	22	12	500
1	BEMIP	8.2.4	UGS-N-374	LV	5	0	500
1	SGC	7.3.2	UGS-N-067	CY	18,1	18,1	109.62
1	NSI East	6.20.4	UGS-N-233	RO	3,3	3,3	300
1	NSI East	6.20.2	UGS-N-138	BG	5,8	5,8	450
2	2-NSI East	6.20.6	UGS-N-371	RO	4	4	650
2	2-NSI East	6.20.5	UGS-N-366	RO	2	2	200

Table 29: Gas storages from both list of PCIs

PCI list	Corridor	No.	TYNDP Ref	Zone	Send-out capacity (mcm/d)	Storage capacity (m3 LNG)
1	NSI West	5.19	LNG-N-211	MT	5,5	180,000
1	NSI West	5.3	LNG-N-030	IE	16,1	200,000
1	BEMIP	8.1.2.2	LNG-N-079	EE	3,84[13]	160,000
1	BEMIP	8.1.2.3	LNG-N-146	EE	11[14]	90,000
1	BEMIP	8.7	LNG-N-272	PL	6,84	160,000
1	BEMIP	8.6	LNG-N-032	SE	2	33,000
1	NSI East	6.5	LNG-N-082	HR	16,5	360,000
1	NSI East	6.9.1	LNG-N-062	GR	16,8	170,000

Table 30: LNG terminals from both list of PCIs

N.B.: There was no additional LNG terminal in the second list of PCIs.

[13] This value was collected from the ENTSOG TYNDP 2015 and GLE. However it can be noted that, in addition to an hourly capacity equivalent to 3.84 mcm/d, GLE provides an annual capacity equivalent to 6.84 mcm/d.

[14] This value was collected from the ENTSOG TYNDP 2015 and GLE. It corresponds to the highest capacity foreseen by the promoter.

8.3 SENSITIVITY ANALYSIS: REDUCTION OF LNG TERMINAL SEND-OUT CAPACITY

Results reveal that dependence on different source, in particular Russian imports, is limited in Europe thanks to very important LNG import capacities. In some disruption cases, certain LNG terminals were used at their full capacity throughout the year. In this section, we present some results for supply source dependence with the availability of LNG terminals set to 80% of its maximal send-out capacity.

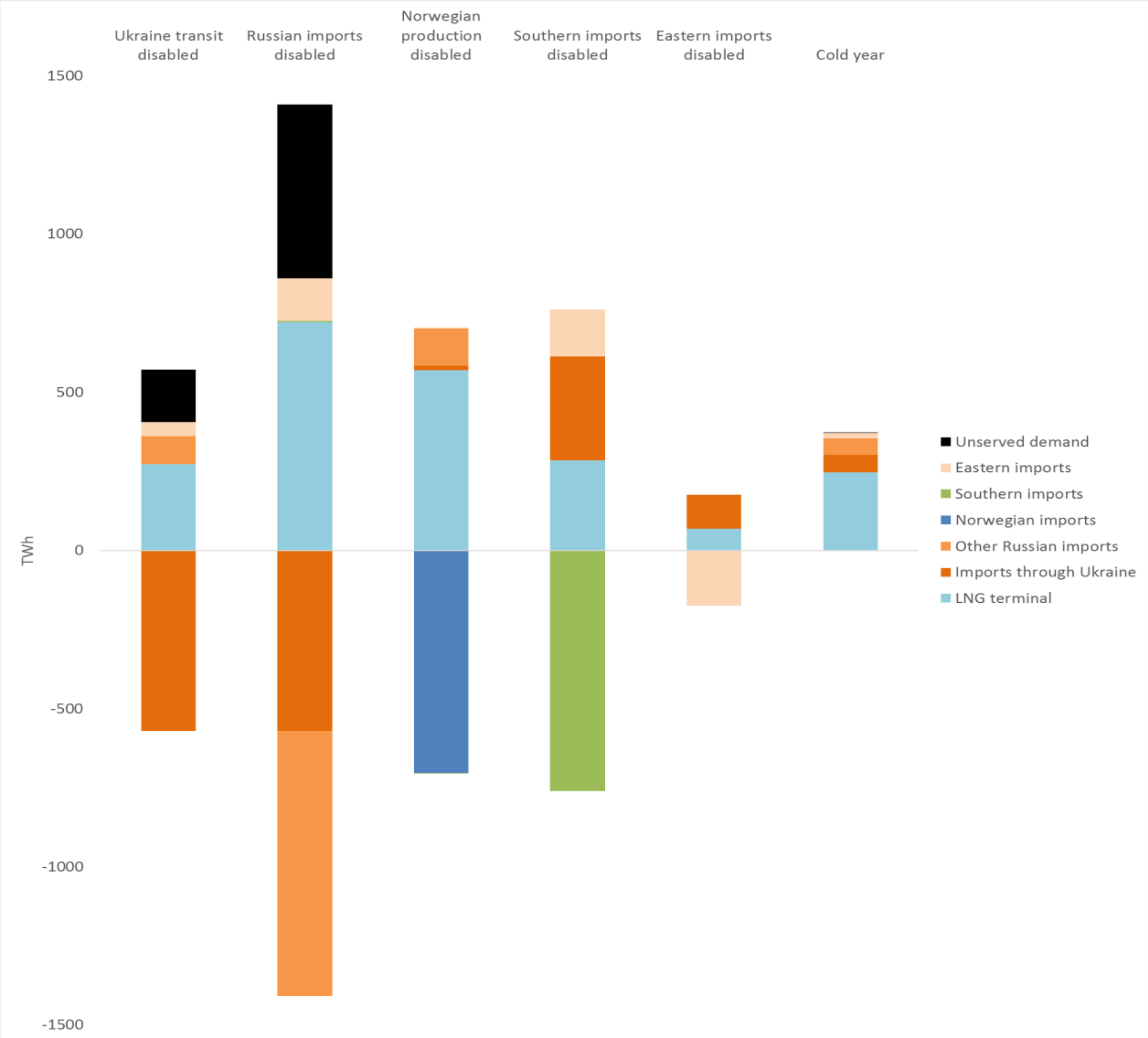

Figure 41: Additional imports per source according to the disruption case (FID context and LNG at 80%)

We still only observe dependence on Ukraine transit and Russian imports. Other supply source can still be substituted with LNG imports from terminals (at 80% maximal send-out capacity) or with additional Russian gas instead of additional LNG imports.

In the Ukraine transit stress case, the volume of LNG imports remains the same as LNG imports can increase in the United Kingdom to compensate for lower LNG imports in Benelux.

Import infrastructure	Capacity factor in the FID context (Ukraine transit disabled)	Capacity factor with 80% maximal availability on LNG imports (Ukraine transit disabled)
UK LNG terminals	30%	41% (+71 TWh)
FR LNG terminals	70%	69% (-8 TWh)
BE LNG terminals	95%	74% (- 33 TWh)
NL LNG terminals	99%	79% (-31 TWh)

Table 31: Capacity factor of LNG terminals with Ukraine transit disabled

In the FID context, limitations on LNG terminals send-out capacity induce a 38% raise on Russian import dependence, which reaches 10.1% of total EU28 demand and involves several more countries, in particular countries which rely on transit through other member states. However, we observe that western countries with important gas consumption (Belgium, France, Germany, Italy, Spain and United Kingdom) are still able to substitute their Russian imports with other supply sources.

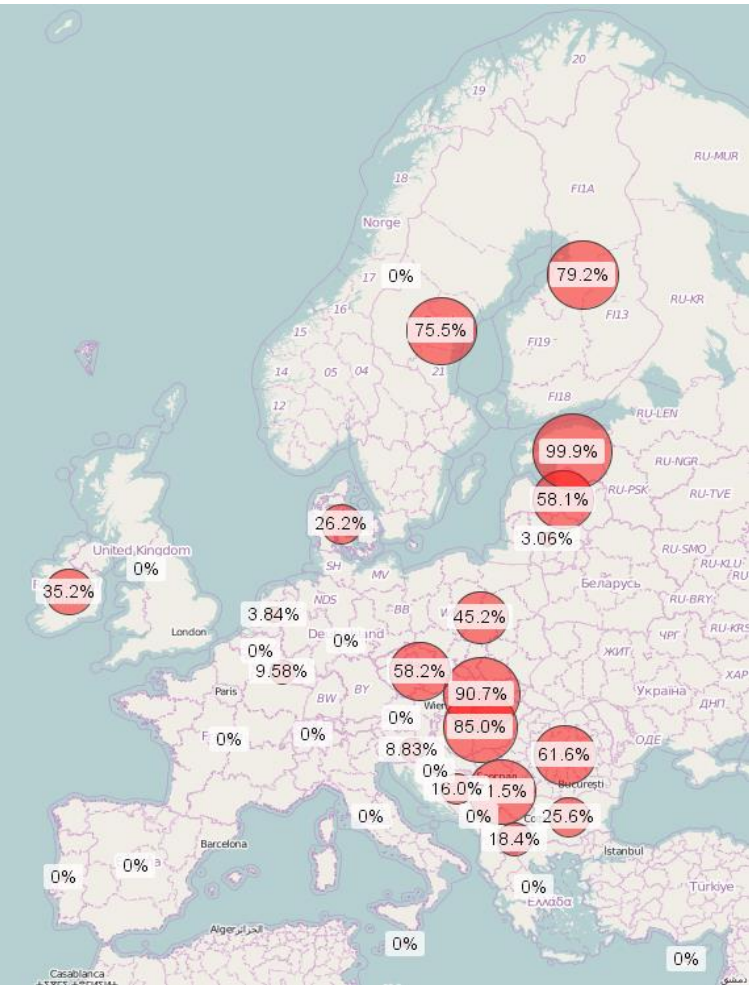

Figure 42: Map of Russian import dependence (FID context with 80% availability on LNG imports)

With the addition of PCIs, we observe that dependence is removed (at the exception of Finland), despite the limitations on LNG terminals. We can notice that without PCI2, dependence remains high in Eastern Europe even with the additional projets from the first list of PCIs.

Russian import dependence	FID context without limitations	FID context with limitations	PCI1 context without limitations	PCI1 context with limitations	PCI2 context without limitations	PCI2 context with limitations
EU28 dependence share (in % of total demand)	7.1%	10%	0.20%	1.5%	0.006%	0.006%
Dependent member states	BG, EE, FI, HU, LT, LV, PL RO, SE, SI, SK	BG, CZ, DK, EE, FI, HU, IE, LT, LU, LV, NL, PL RO, SE, SI, SK	FI,RO	CZ, DK, FI, HU, LT, NL, PL RO, SE, SI, SK	FI	FI

Table 32: Russian import dependence with and without limitations on LNG terminals

In conclusion, the results presented in this report do not fully rely on a full availability of LNG terminals. Even with limited availability of LNG terminal send-out capacities, supply source dependence results only increase in regards of Russian imports, and the addition of all PCIs remain sufficient to remove almost all dependence in this case.

8.4 METHODOLOGY

This section aims at giving a description of the tools and analysis process used for the study.

8.4.1 CREATION OF CONTEXTS

Data were collected from sources such as ENTSOG, GLE, GSE to model the European gas system through national capacities per technology. In addition, Artelys used gas consumption historical data to generate 50 scenarios of consumption based on historical year of temperatures.

These data were integrated into the METIS database and combined with PCI data collected from DG ENER and ENTSOG to constitute three sets of data, each of them representing one of the studied context.

With import scripts, contexts were created in METIS based on the data. For each of the three contexts (FID, PCI1 and PCI2), seven different cases were generated (reference, cold, Ukraine transit disabled, Russian import disabled, Norwegian production disabled, Southern import disabled, Eastern import disabled). Then simulations were run for each of these contexts under the different stress cases.

8.4.2 ANALYSIS OF INPUT DATA

METIS provides multiple tools to analyze input data. In particular, the following indicators were used for this study:

- *Demand*, to display yearly demand per country;
- *Installed capacities*, to display the send-out capacities of LNG terminals, the withdrawal capacities of storages and the entry capacities of transmissions with outer Europe;
- *Storage capacity*, to display storage capacities;
- *Transmission capacities*, to display the gas network.

Although this does not display new information (as these are input data), METIS provides a geographical view of these data that is essential to understand the European gas system. In particular, the use of the comparator view between contexts can be used to display additional projects from PCI lists.

8.4.3 ANALYSIS OF OUTPUT DATA

METIS provides multiple tools to analyze output data. In particular, the following indicators were used for this study:

- *Loss of load*, to display the energetic volume of unserved demand;
- *Loss of load Expectation*, to display the number of hours with unserved demand;
- *Expected Energy not served*, to display the share of unserved demand on national demand;

N.B.: These three indicators were used both to calculate the indicator Disrupted demand (which is the *Loss of load* in the reference and cold case) and the indicator Supply Source Dependence (which is the *Expected Energy not served* in a source disabled case minus the *Expected Energy not served* in the reference case).

- *Capacity factor*, to display the utilization rate of gas infrastructure;
- *Supply (detailed)*, to display the volume of gas produced or imported via each infrastructure type per country;
- *Transmission flows (gas),* to display gas flows and congestions in transmission pipelines.

There indicators helped explaining loss of load when it was observed. For example, in the Ukraine disabled case of the FID context, we observed dependence in Southeast Europe via the indicator *Expected Energy not served*. However, the indicator *Capacity factor* revealed that LNG terminals in Italy and Greece were not used at their maximal level though they were the closest infrastructures to Southeastern countries. The view *Transmission flows (gas)* then revealed the congestions that prevented gas to be transported from Italy and Greece to Southeast Europe.

In addition to these indicators, METIS provides tools to analyze detailed results at the country and daily granularity.

8.5 COMPARISON OF LNG IMPORTS WITH ENTSOG TYNDP SUPPLY SCENARIOS

In ENTSOG TYNDP 2015, different scenarios are described for supply. For each source of supply, minimum, intermediate and maximum scenarios were elaborated. In the hereby study, LNG imports were subjected to wide variations, according to the considered disruption case.

Figure 43: LNG imports per case and TYNDP2015 LNG import scenarios

In Figure 43, we display LNG imports for each stress case. In most cases, LNG imports are below the TYNDP2015 intermediate scenario level of 1500 TWh. In the Norwegian production disabled case, LNG imports exceed but remain close to this level. In the Russian import disabled case, LNG imports increase sharply to exceed 2000 TWh in PCI1 and PCI2 contexts. However, they always remain below the maximum scenario level of 2350 TWh.

Although LNG imports rise sharply in a case without Russian gas, they remain within the range defined by the TYNDP2015 supply scenarios in all of the studied cases and contexts.

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