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# Simulating security of supply effects of the Nabucco and South Stream projects for the European natural gas market

by
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**Abstract**

Due to the increasing European import dependency, significant additional natural gas volumes will be required. In addition to the Nord Stream pipeline, the Nabucco and South Stream pipeline are projects planned for the next decade to provide further gas supplies to the European market. As one of the European Union's energy policies' foci is security of supply, the question can be raised if and how these projects contribute to this objective not only in terms of diversification but also in case of supply disruptions such as occurred in 2009 during the Russia-Ukraine gas crisis. This paper discusses the impact of these two major gas import pipeline projects on the South-Eastern Europe gas supply and analyzes their effects on gas flows and marginal cost prices in general and in case of gas supply disruptions via Ukraine in a model-based analysis with the European natural gas infrastructure and dispatch model TIGER.

*Keywords:* Natural gas, security of supply, Nabucco, South Stream, Europe, linear-optimization, transport infrastructure

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## 1. Introduction and Background

The declining European gas production and the prevalently assumed rising European gas demand especially in Eastern Europe will lead to an increasing import dependency (EC (2008) and IEA (2008)).

There are several plans for major pipeline projects to be commissioned in the next decade. In addition to the planned investments into interconnections between countries, there are projects in focus that should not only connect the network of two European countries to improve market integration, but that should provide large-scale gas volumes from non-European gas producing to European gas consumption regions. In addition to Nord Stream, whose construction has already started, the Nabucco and South Stream pipelines are the largest projects being planned. Although both pipelines could enhance security of gas supply in the EU, they are very cost-intense projects. The ambitious objectives of the EU in terms of the percentages of renewables in the energy mix until 2050 might lead to only a moderate growth of natural gas demand in the next decade and propably a significant decrease until 2050. From this it follows that not all major pipeline projects might be essential for security of supply in Europe. This holds especially for Nabucco and South Stream both intending to supply South-Eastern Europe.

One quarter of Europe's gas demand is satisfied by imports from Russia. Eighty percent of these volumes are transported from Russia through pipelines via Ukraine (EC (2006)). The Russia-Ukraine gas dispute of January 2009 caused unprecedented disruption of gas supplies via Ukraine to the EU. This halt of gas supplies was described as the worst gas crisis in IEA history (IEA (2009)). Between these two countries disputes on the pricing of the commodity natural gas and its transit to the European Union recurred within the past decade (Stern (2009)).

Due to these threats to security of natural gas supply European policy will have to cope with the following challenges. First, gas supply from non-European countries has to be secured. Thereby, importing a high proportion of gas volumes for the European market from one or few suppliers, increases the risk of political pressure and price increases. Hence, supply sources should be diversified (Weisser (2007), Reymond (2007) and EC (2006)). However, not only the source of gas but also the transport to different European demand regions would have to be secured. Political conflicts such as the Russia-Ukraine crisis could cause supply disruptions and a halt of these transits has a significant impact on the European gas market especially during times of high demand such as winter months. Therefore transit risks need to be reduced through a diversification of gas supply routes. To secure gas supplies additional gas infrastructure, i.e. LNG import terminals, storages and major import pipelines will have to be build (Lise et al. (2008) and Cayrade (2004)). This paper investigates the effects of each of the two pipeline projects Nabucco and South Stream on

European natural gas supply security in general and with focus on a Ukraine crisis simulation. Moreover, the major security of supply risks associated with the EU's dependence on the main transit country Ukraine and the mitigating effects of Nabucco and South Stream and the European gas infrastructure system's vulnerability as well as its ability to respond and compensate are analyzed.

The next section gives a literature overview on security of supply issues in the context of major European gas pipeline projects and describes the Nabucco and South Stream pipeline projects in more detail to briefly address their contribution to the first two above-mentioned objectives of European security of gas supply, i.e. security of natural gas imports and import diversification. In order to analyze the third type of security of supply effects, mitigation of supply disruptions through route diversification, the European natural gas infrastructure and dispatch model TIGER of the Institute of Energy Economics, Cologne is applied which is described in Section 3. Three different infrastructure scenarios are simulated with the model: a Baseline Scenario without any of the two pipeline projects, a scenario including the Nabucco pipeline and a scenario implementing the South Stream pipeline instead of Nabucco. In Section 4 the general effects on security of supply of the Nabucco and South Stream pipeline projects, i.e. especially effects on marginal supply costs, are analyzed for the year 2020 for a hypothetical peak winter day on which supply disruptions are most propable. Subsequently, the impact of the two pipeline projects during a hypothetical Ukraine crisis are analyzed (Section 5). The impact of a hypothetical Ukraine crisis on a peak winter day in 2020 on disruptions to consumers, changes in marginal supply costs and gas flows for the three different infrastructure scenarios in comparison to the results of the no-crisis simulation are presented. Section 6 concludes.

## 2. Security of natural gas supply and the Nabucco and the South Stream pipeline projects

### *2.1. Security of natural gas supply*

The issue of security of supply in natural gas markets has been addressed by European energy policy (EC (2000), EC (2006) and EU (2004)) and academics. Dimensions of security of supply cover a wide range of issues. Luciani (2004) provides the following definition

> Security of supply may be defined as the guarantee that all the gas volumes, demanded by non-interruptible (firms or protected) customers, will be available at a reasonable price.

(Luciani (2004) p.2)

Thus, physical availability of natural gas and the price play a significant role to guarantee security of supply. However, the precise concept defining thresholds for a threat of security of supply is a challenging task and has not reached an agreement among academics. There are many studies adressing the issue of security of energy supply but without a specific focus on natural gas (CIEP (2004) and Correlje and van der Linde (2006)). Victor (2007) discusses global geopolitical security of supply aspects for natural gas. However, there are only few studies focussing on specific pipeline projects. Holz et al. (2009) analyze European gas supplies until 2025 with the strategic model GASMOD and find that specifically pipeline availability remains a critical issue. Stern (2002) analyzes the impact of dependence on natural gas imports and the influence of liberalization on security of gas supply and recommends a policy framework to prevent disruptions to consumers. He analyzes relationships with non-European gas exporting countries and the influence of a liberalized European market on security of gas supply. He differentiates between short-term and long-term adequacy of supply and infrastructure to transport gas to the demand regions and between operational, i.e. stresses of weather and other operational influences, and strategic security, i.e. catastrophic default of infrastructure or supply sources. Further, associated with import dependence he distinguishes source dependence, transit dependence and facility dependence.

Within this paper these three latter aspects will be adressed in different ways focusing on security of supply effects of the two pipeline projects Nabucco and South Stream. The source dependence of the EU in the context of these pipelines will be discussed. The major security of supply risks associated with the EU's dependence on the main transit country Ukraine (transit dependence) are reflected in the results of the Ukraine crisis simulations for which the mitigating effects of Nabucco and South Stream and the European gas infrastructure system's ability to respond and compensate and its vulnerability (facility dependence) are analyzed.

### *2.2. The Nabucco project*

According to Nabucco Gas Pipeline International GmbH (2010) the Nabucco project describes a gas pipeline connecting the Caspian region, Middle East and Egypt via Turkey, Bulgaria, Romania, Hungary with Austria and further on with the Central and Western European gas markets. The pipeline route with a length of approximately 3,300 km should start at the Georgian/Turkish and/or Iranian/Turkish border respectively and run via Bulgaria, Romania and Hungary to lead to Baumgarten in Austria. The pipeline's transport capacity is supposed to amount 31 bcm per year. The total investment costs are approximately 7.9 billion Euro. From an EU point of view Nabucco should represent an opportunity to diversify gas supply options and to reduce the EU's dependency on Russia. As supply sources for Nabucco, the Caspian region, i.e. especially Turkmenistan and Azerbaijan, and the Middle East, i.e. Egypt Iran and Iraq are discussed. However, up to now, there are no supply contracts concluded which might affect the commissioning of the project. The problems arising in the context of suppliers for the Nabucco pipeline are often discussed. (Bilgin (2009) and Bilgin (2007))

The Nabucco pipeline will only be built if enough volumes are contracted. The political default risk of supplies however is difficult to estimate and will depend on the suppliers. In addition, Turkey plays a major political role in the negotiations on supplies. On the one hand, Turkey will need significant additional gas volumes in the future because its demand is projected to rise significantly and the country neither has an own production nor sufficient gas storages and will thus depend on large scale imports throughout the year. On the other hand, Turkey is the first transit country for the Nabucco pipeline. Turkey has already been strongly negotiating with the EU on the volumes that should be withdrawn from Nabucco to satisfy the Turkish demand. Moreover, Turkey has already signed and extended many of its gas contracts with its surrounding gas producing neighbour countries. Thus, Turkey's geopolitical position could be a chance but also a threat for the EU. One supplier could not provide enough gas volumes to fill Nabucco. Therefore, several suppliers will be contracted which increases the diversification of supply sources. Based on a geopolitical analysis, Bilgin (2009) recommends to include at least two countries from the Middle East and Caspian region as suppliers for the European gas market which could be rendered possible via Nabucco. To put in a nutshell, the Nabucco project would help to cope with the EU's security of supply challenges because: 1. it could provide significant gas volumes from non-European countries if sufficient volumes are were contracted; 2. it diversifies supply sources; and 3. it diversifies supply routes transiting mainly European Member States.

*2.3. The South Stream project*

The South Stream project[1] is a pipeline system connecting Russia and South Eastern Europe and Italy via the Black Sea. A number of optional routes are being discussed including onshore sections across the Russian Federation and several European countries, as well as offshore gas pipelines via the Black and Adriatic Seas. South Stream is supposed to provide a capacity of 63 bcm per year as of 2016. According to South Stream (2010) it has the intention to diversify the Russian natural gas supply route to Europe and thereby strengthen European Energy Security. The source of Russian gas for South Stream is as uncertain as the source for Nabucco. Natural gas production in the Volga Region is declining (Stern (2005)) and there will not be enough gas for 63 bcm to be exported per year. For the coming decades, large explored gas reserves in Russia are mainly in Western Sibiria and the Yamal Peninsula but due to the permafrost conditions and estimated high production costs in this region production is not expected to start before

[1]South Stream is a joint venture of Gazprom and Eni.

2015 (Remme et al. (2008)). Russian exports to Europe are assumed to not be much higher than 200 to 220 billion cubic meters in 2020 (Socor (2009)). In addition, this area is more than 3000 km away from the start of South Stream at Dzhubga. Russia is already importing Turkmeni gas and is also interested in purchasing gas from Shah Deniz II, an Azerbaijani gas field (Kupchinsky (2009)), which could also be used to supply South Stream. In addition, despite the long distance to avoid transit and political costs, Russia could also consider to transport its gas from the Yamal Peninsula to export it to Europe via South Stream. However, Nord Stream with 27 bcm or 54 bcm after the expansion seems to be a much cheaper option for Russia to evade the Ukraine and other transit countries and transport the gas further on within Europe and even to Southern Europe because of the higher costs of Caspian gas volumes and the long-distance of South Stream to future production regions. Considering these circumstances South Stream seems to be more a strategic than a cost-efficient option to transport Russian gas to Europe.

About 80 percent of Russian gas exports go to Europe and about 40 percent of EU imports stem from Russia (IEA (2009). Thus, a dependency exists for both parties which might lower the default risk for Europe and might be a lower risk than with contracts with Middle Eastern countries for instance. However, South Stream is definitely not supporting the intention of the EU to diversify supply sources.

South Stream's planned extremely large capacity could also be a strategic tool and it is not clear if and how the pipeline could be completely filled.

To sum up, concerning South Stream's potential influence on the EU's security of supply: 1. it offers the option to import large-scale, i.e. twice as Nabucco, gas volumes from non-European countries; 2. gas transported via South Stream would have to be contracted with Gazprom, even if it originally stems from a Caspian country for instance; 3. it offers an alternative route to the existing routes from Russia.

## 3. Methodology

### *3.1. The TIGER-model*

The natural gas infrastructure model TIGER[2] has been developed at the Institute of Energy Economics at the University of Cologne to enable an integrated evaluation of the gas infrastructure components, i.e. pipelines, storages and terminals, and their interaction. Thus, the model can be used for a comprehensive analysis of the supply situation and gas flows within the European long distance transmission grid. TIGER optimizes the natural gas supply and dispatch of volumes for Europe, subject to the available infrastructure,

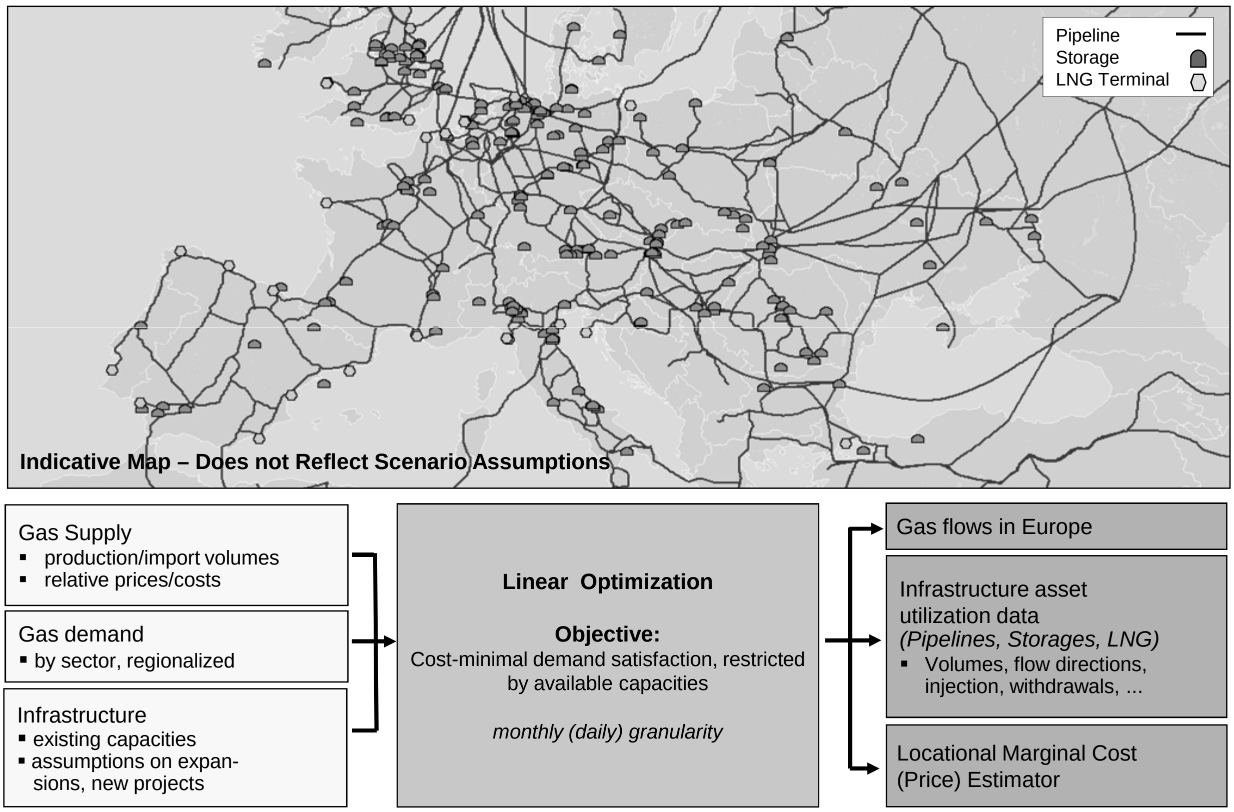
[2] TIGER stands for Transport Infrastructure for Gas with Enhanced Resolution

by minimizing the total cost of gas supply. Existing infrastructure and infrastructure projects can be regarded with respect to their utilization, integration into and effects on the pipeline system, the LNG terminals and the system of storages. Moreover, the model allows for the computation of locational marginal supply cost estimators. (See Figure 1 for an overview of the model.)

The model's cost-minimization approach is based on the assumptions of a perfectly competitive and effcient gas transport. This approach does not account for institutions, agents or contractual relations. A detailed description of the objective function, the main constraints and the computation of marginal supply costs is presented in the Appendix.

The results generated by the TIGER model thus reflect a first-best cost-minimal supply and transport of natural gas within Europe based on the given infrastructure and demand assumptions.

Figure 1: TIGER-Model Composition



*3.2. Applicability of the TIGER-model*

Within the linear optimization framework the marginal supply costs represent the shadow costs on each node's balance constraint for each time period. They indicate the marginal system costs for supplying one additional cubic meter of natural gas to a specific node at a certain time. In case of a supply disruption the marginal supply cost estimator rises to infinity. In terms of the simulation of gas transit disruptions, Bettzüge and Lochner (2009) and Monforti and Szikszai (2010) modelled a replication of the Ukraine transit halt of January 2009. Bettzüge and Lochner (2009) simulated the crisis with the TIGER model of EWI and could replicate many of the effects that had been observed in reality focusing on an analyis of gas flow and marginal supply cost changes. Monforti and Szikszai (2010) present a new model for providing early warnings on possible gas crisis developed in the Joint Research Center Petten for the European Commission which models the transmission system operators' gas dispatch on the basis of a propabilistic Monte Carlo approach. However, the model's resolution is on an aggregated country basis and thus much lower than the resolution of the TIGER model. In addition, the modelling of the infrastructure components such as the modelling of storages is less detailed. In contrary, the TIGER model includes more detailed data on the infrastructure especially for pipelines and storages such as storage types with detailed storage profiles and different withdrawal and injection rates. There are other natural gas transport optimization models such as presented by De Wolf and Smeers (1996), De Wolf and Smeers (2000), Ehrhardt and Steinbach (2004), Ehrhardt and Steinbach (2005) and van der Hoeven (2004) which are however more theoretical models than a reflection of the actual and potential future European gas transmission system. The same holds for Midthun et al. (2009) who present a modeling framework for analyzing natural gas markets accounting for further technological issues of gas transportation primarily the relation between flow and pressure. However, for the implementation of this relation within the TIGER model neither network data nor costs are publicly available especially not on the detail level of the model. In addition, a validation of the TIGER model for the year 2008 presented in EWI (2010) shows that the model is able to reflect the major flows within the European system. The deviation of the modelled from real flows can basically be explained by contractual flows which are not implemented in TIGER following a normative approach. The mixed-complementarity models presented by Gabriel et al. (2005), Gabriel and Smeers (2006) and Holz et al. (2009) focus mainly on different economic issues such as modelling competition and agents. Within these modelling approaches gas flows are analyzed as well but are neither in the very focus of the analysis nor do the models allow for a pipeline-specific analyis of gas transports or bottlenecks as the modelled infrastructure is aggregated. The results presented in this paper are therefore based on simulations with the TIGER model for the year 2020.

### 3.3. Assumptions

Demand, supply and infrastructure assumptions are based on EWI (2010).[3] The demand scenario taken is the EWI/ERGEG demand scenario which is a scenario based on EC (2008) but adapted to the economic crisis from 2009 on. The peak day demand assumptions applied are published in ENTSOG (2009). In terms of pipeline projects in general, i.e. new pipelines, expansions and reverse flow projects, the scheduled ones are regarded and included if they where considered to be likely by the regulators. With respect to the several intra-European pipeline projects and planned expansions of interconnector capacities between countries, those published in ENTSOG (2009) slightly adapted according to EWI (2010) are implemented in the simulations. It has to be noted that for all pipelines no contractual flows are considered and volumes are only drawn and routed in order to meet demand cost-efficiently by the model. It follows a normative approach and although it might not seem realistic that a major pipeline project will be built without contracted volumes exhibiting a low utilization, this might happen within the simulations. The results will thus be interpreted on this normative basis.

### 3.4. Scenarios

To analyse the impact of the two pipeline projects in case of supply disruptions via Ukraine, three different scenarios are simulated where the

- Baseline Scenario is based on the assumptions listed above and includes one line of Nord Stream with an annual capacity of 27.5 bcm
- Nabucco Scenario is based on the Baseline Scenario but in addition it includes the Nabucco pipeline with additional 31 bcm being online in 2020. The route of Nabucco is based on data published by Nabucco Gas Pipeline International GmbH (2010) and is running from Turkey via Bulgaria, Romania and Hungary to Baumgarten, Austria with several connections to the national grids which allow for a withdrawal and consumption of Nabucco gas on the way.
- South Stream Scenario comprises the South Stream instead of the Nabucco pipeline and is otherwise also based on the same assumptions as the Baseline Scenario. The pipeline's route is implemented as published by South Stream (2010) from Russia via the Black Sea to Bulgaria and from there on with two different onshore connections: one via Serbia, Hungary and Slovenia to Arnoldstein in Southern

[3]The model's database has just been updated in the context of the EWI's study conducted for the European Regulator's Group for Electricity and Gas (ERGEG) (EWI (2010)).

Austria and the other route via Serbia and Hungary to Baumgarten, Austria. The third route via Greece to Brindisi, Italy is not implemented in the simulations as a pipeline connecting Greece and Italy is included and this third route is assumed to be unlikely if, such an interconnector is commissioned.

The three infrastructure scenarios have been simulated first allowing for supplies via Ukraine to generate some general results and to establish a basis for comparison for the simulation of a hypothetical Ukraine crisis. These evaluations presented in the following section are based on simulated daily gas flows.

## 4. Results: General effects on European supply security

This section presents results of a no-crisis simulation comparing the Nabucco and South Stream Scenario with the Baseline Scenario in which neither of these two projects is implemented. The results of the three infrastructure variations focus on a peak winter day in 2020 which is the day during this year with the highest demand and thus the strongest impact on security of supply. However, focusing on the changes between the scenarios, the consideration of an average winter day would lead to the same results qualitatively.

### *4.1. Change of marginal supply costs including Nabucco or South Stream*

In a perfectly competitive and efficiently organized gas transport market, the marginal supply costs at each node in the system should be equal to theoretical wholesale prices at that node. Thus, to analyze marginal supply cost changes gives an indication of the effects the simulated scenarios could have on market prices in a perfectly competitive market.

Figure 2: Marginal Supply Cost Changes - Nabucco in Comparison to Baseline Scenario Without a Crisis

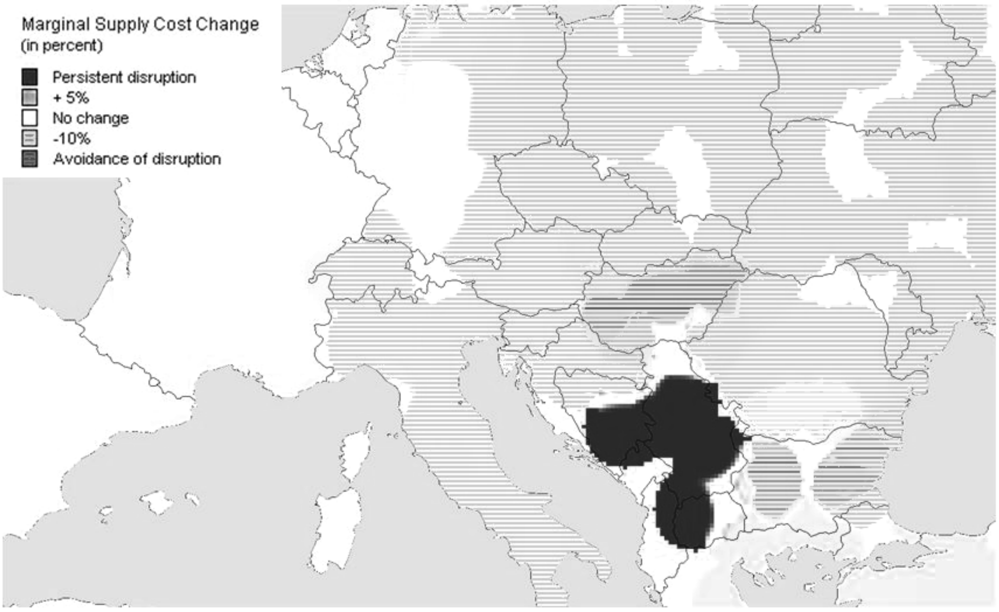
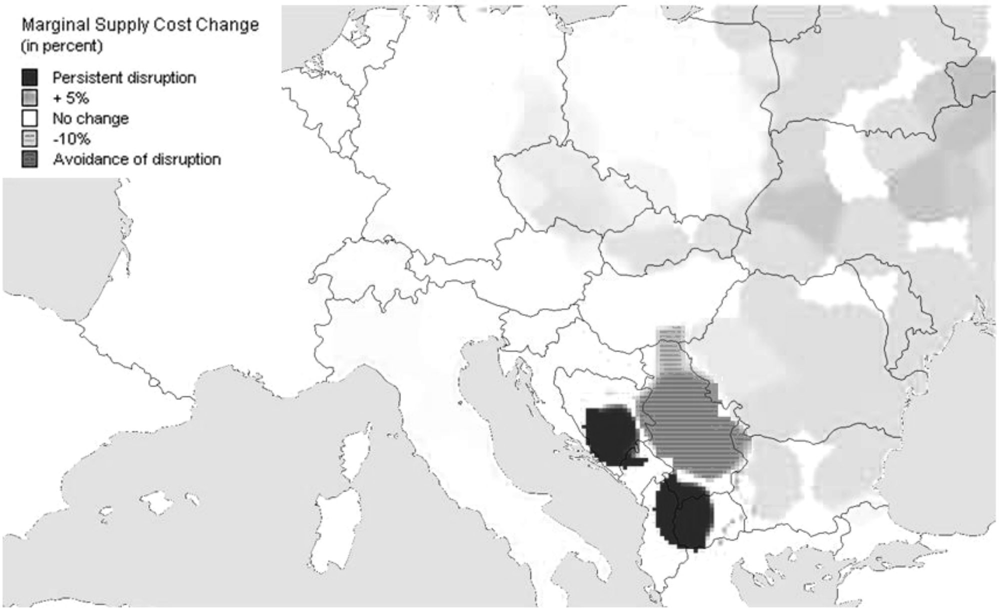



Figure 2 and 3 show the marginal supply cost changes of this comparison. The dark plus the dark striped area indicate the regions where supply disruptions occur in the Baseline Scenario on a peak winter day in 2020 despite the prospectively planned infrastructure projects being implemented. The plain dark marking displays persistant disruptions in Serbia (in Figure 2), Bosnia and Herzegovina and the Former Yugoslavian Republic of Macedonia (FYROM) whereas the dark striped marking indicates where disruptions are avoided (in Serbia in Figure 3). The inclusion of Nabucco reduces marginal supply costs significantly within Eastern Europe (see striped grey area in Figure 2) especially in Hungary and Bulgaria. However, the disruptions in the three Balkan countries cannot be prevented.

The simulation results show that South Stream is in general poorly utilized as long as the Ukraine route is available which is the more cost-efficient route to supply the European market within the modelling framework. However, three million cubic metre per day (mcm/d) are sent via South Stream to mitigate disruptions that occur in the Baseline Scenario in the Balkan region, i.e. especially in Serbia. These disruptions are thus avoided in the South Stream scenario (see the dark striped area in Figure 3). But, disruptions in Macedonia and Bosnia and Herzegowina remain persistent. Moreover, the rerouting of Russian gas compared to the Baseline Scenario results in a decrease of marginal supply costs in Hungary but also in an increase of marginal supply costs in Ukraine, Belarus, Romania, Bulgaria, Slovakia and the Czech Republic.

The Russian volumes that are sent via South Stream to Serbia are transported via Belarus and Poland and via Ukraine in the Baseline Scenario. Due to the minimization of total system costs it is efficient to meet Serbian demand in the South Stream Scenario to prevent disruption there and to accept these slight marginal supply cost increases northwards.

Figure 3: Marginal Supply Cost Changes - South Stream in Comparison to Baseline Scenario Without a Crisis

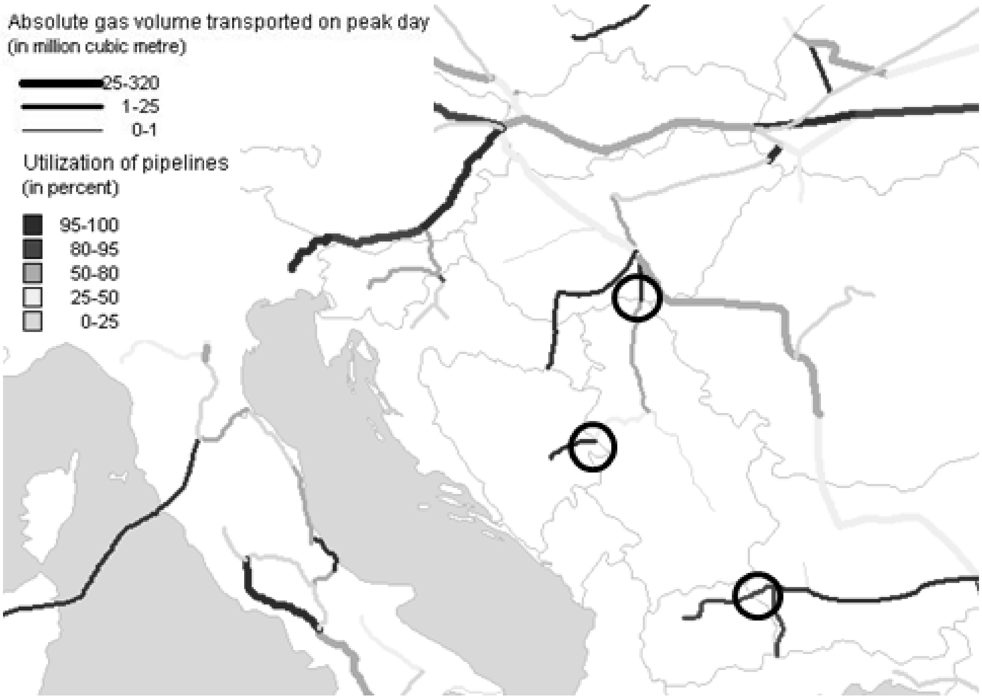



Both pipelines provide additional capacity and another option to transport gas volumes to the European market and therefore improve the supply situation measured here in terms of changes in marginal supply costs which are only observed in Eastern and Central Europe. For neither the inclusion of South Stream nor of Nabucco significant effects can be detected for Western Europe.

*4.2. Pipeline project specific bottlenecks in South-Eastern Europe*

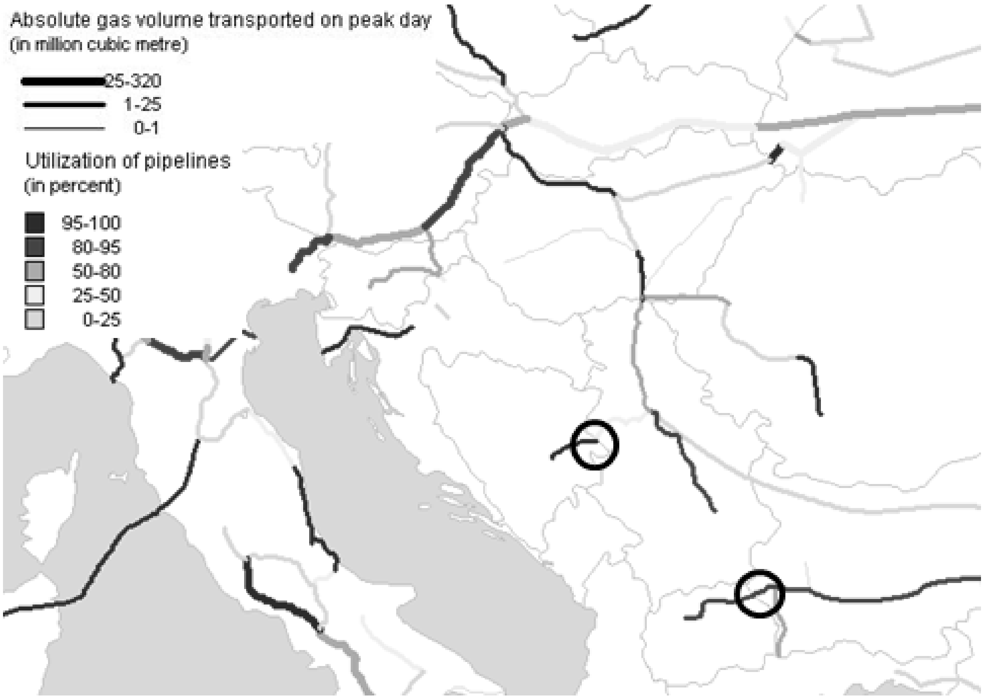
The previous section has shown that there are some bottlenecks in the Balkan region that cannot be impeded despite the inclusion of Nabucco and South Stream. These remain persistant on a peak day under the given demand and infrastructure assumptions (see Section 3.3). Figure 4 and 5 show the gas volumes transported within the South Eastern European pipeline system and the utilization of the different pipeline sections on a peak day for the Nabucco and the South Stream Scenarios. Despite the additional Caspian and Middle Eastern volumes being available to Eastern European countries along the route in the Nabucco Scenario, there is a lack of interconnector capacities to the adjacent countries. Hence, the disruptions cannot be avoided with the commissioning of Nabucco. These bottlenecks are indicated by the black circles in Figure 4. The only import pipeline from Bulgaria to FYROM provides an average daily capacity of 2.6 mcm/d which is not sufficient to meet Macedonian peak demand of 3 mcm/d. The same holds for the interconnector from Serbia to Bosnia and Herzegovina with 1.9 mcm/d compared with a peak demand of 2 mcm/d and the Serbian demand of 20 mcm/d which is significantly higher than the assumed cross-border capacity of about 13 mcm/d from Hungary and of about 4.3 mcm/d from Romania. Nabucco which is not crossing these countries thus cannot impede these disruptions.

Figure 4: Utilization of Pipelines - Nabucco Scenario




This is different for the South Stream Pipeline which is planned to be routed via Serbia and can therefore increase security of supply in this country (see Figure 3 and Figure 5). However, South Stream is only poorly utilized transporting only 3 mcm/d on the peak winter day from Bulgaria to Serbia which is just enough to meet Serbian demand and export some minor volumes to Bosnia and Herzegovina. As in the Nabucco Scenario there is a bottleneck on the interconnector from Serbia to Bosnia and Herzegovina and at the Bulgarian Macedonian border.

Figure 5: Utilization of Pipelines - South Stream Scenario



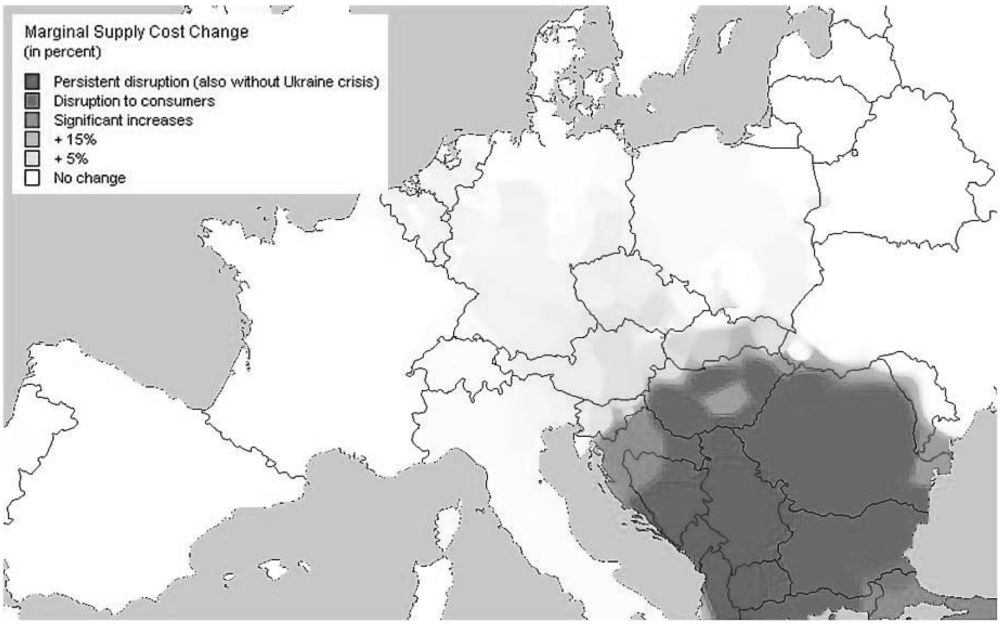

## 5. Results: Effects of a hypothetical Ukraine crisis on European supply security

As currently about 80 percent of Russian gas to the European Union is transited via Ukraine, a supply disruption on this route seems to be most threatening for the European gas supply. The effects of the inclusion of the Nabucco or the South Stream pipeline in the model's infrastructure on the locational marginal cost price estimators are therefore simulated and evaluated for a supply disruption of four weeks of gas imports via Ukraine. The analysis of the simulation results is carried out as a comparison of the three different infrastructure scenarios presented in Section 3.3.

### *5.1. Change of marginal supply costs during crisis*

A comparison of the different infrastructure scenarios shows the effects the different pipeline projects could have on marginal supply costs during such a crisis. These marginal supply cost changes result of a simulation with a halt of gas supplies via Ukraine in comparison to a scenario without such a crisis. Considering a peak winter day the simulated four week halt of gas supplies via Ukraine leads to disruptions to consumers and significant effects on marginal supply costs in large parts of South-Eastern Europe. Figures 6, 7 and 8 depict these marginal supply cost changes for the three different infrastructure scenarios presented in Section 3.4. The black area indicates persistent disruptions to consumers that occur on a peak winter day in 2020 even without a Ukraine crisis simulation plus disruptions that only occur during such a transit halt. The regions in grey show marginal supply cost increases resulting from the crisis. For the Baseline Scenario presented in Figure 6, given the planned pipeline infrastructure expansions, a peak day scenario itself would already cause disruptions in a no-crisis-simulation . These persistant disruptions occur in Serbia, Bosnia and Herzegowina[4] and the Republic of Macedonia (FYROM). In addition, during a Ukraine crisis simulation consumers in Romania, Bulgaria and Hungary are also cut-off gas supplies (area in black colour in Figure 6). Significant marginal supply cost increases can be observed in Croatia, Slovenia and Slovakia. Germany, the Czech Republic and Austria are confronted with slighter marginal cost changes. Western Europe which is supplied by Norwegian and Algerian pipeline gas as well as LNG imports is basically not affected by the crisis.

Figure 6: Marginal Supply Cost Changes - Baseline Scenario, 4 Weeks Ukraine Crisis in Comparison to No-Crisis

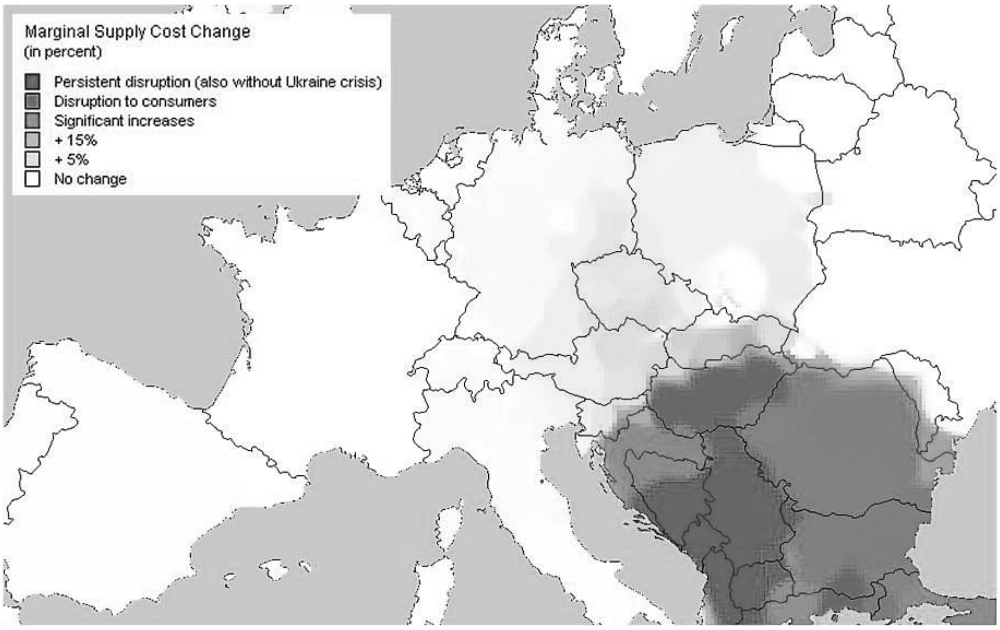



Introducing the Nabucco pipeline (see Figure 7) does not reduce the persistant disruptions that result in Serbia, Bosnia and Herzegowina and the Republic of Macedonia (FYROM). However, during the simulated Ukraine crisis, disruptions in Bulgaria, Romania and parts of Greece can be avoided. The situation in these countries is mitigated so that only marginal supply costs increases instead of consumer cut-offs result from the crisis. However, the improvement of market integration with Nabucco leads to slight marginal supply

[4]The Bosnian natural gas company BH-Gas has already shown interest in an extension auf its gas supplies through connections to major pipeline projects. It has asked Turkey's Bota to help it connect to the planned Nabucco and TAP pipelines in an effort to diversify its gas supplies (Balkans.com Business News (2010)).

cost increases in Poland and Northern Germany in comparison to the Baseline Scenario. It is again cost-efficient within this modelling framework to accept these slight increases on the one hand and to prevent disruptions to customers in other regions on the other hand.

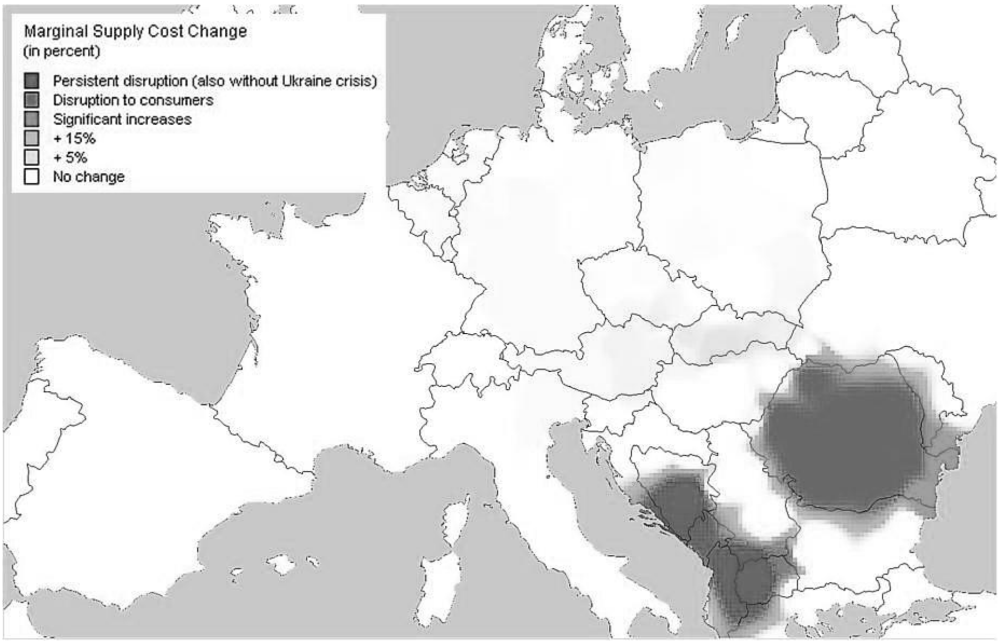
Figure 7: Marginal Supply Cost Changes - Nabucco Scenario, 4 Weeks Ukraine Crisis in Comparison to No-Crisis




The inclusion of the South Stream pipeline (see Figure 8) leads to an elimination of persistant supply disruptions in Serbia. Moreover, the crisis-induced disruptions that occured in the Baseline Scenario in Bulgaria, Greece and Hungary are avoided and marginal supply cost increases are reduced significantly in Slovakia, Croatia, Austria and Germany. South Stream's immense capacity allows for additional gas being transported to South-Eastern Europe in case of disrupted supplies via Ukraine and therefore mitigates marginal supply cost increases significantly. In comparison to the Nabucco Scenario however, gas supplies to Romania are still disrupted due to the assumed route of South Stream bypassing Romania.[5]

[5]Interestingly to mention in this context is that Gazprom and Romania have started negotiations on Romania joining the South Stream pipeline network. A feasibility study will be worked out. However, it is not yet clear if this could result in a different route excluding Bulgaria. (Euractiv.com (2010))

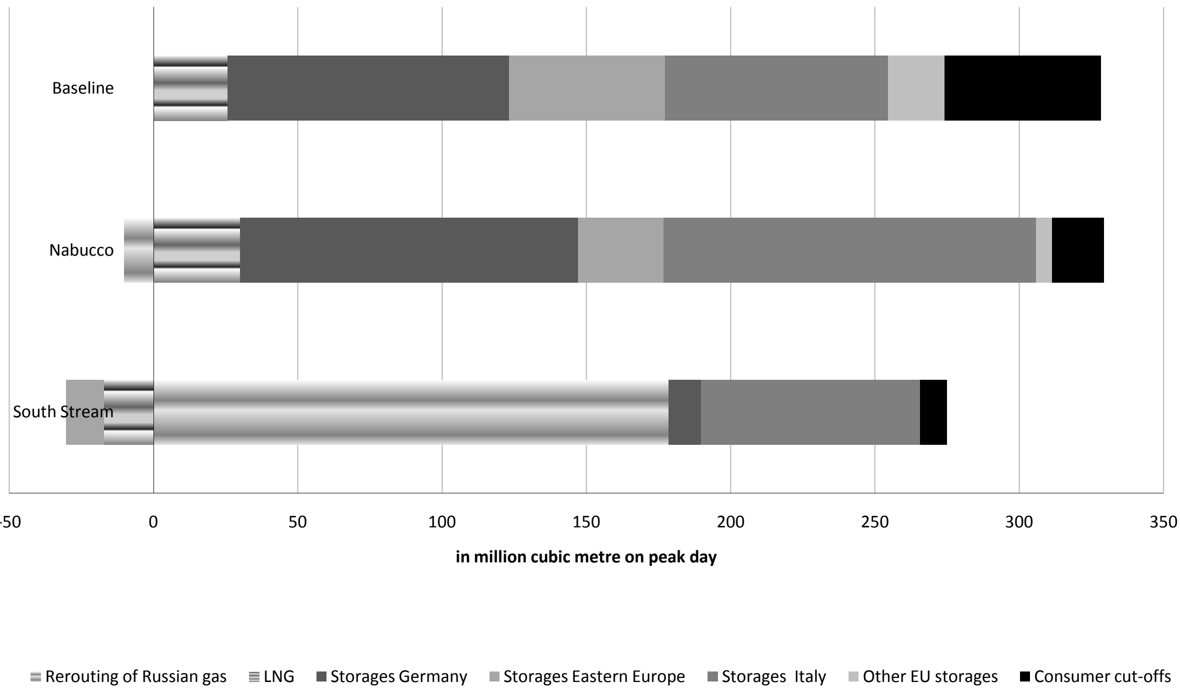
Figure 8: Marginal Supply Cost Changes - South Stream Scenario, 4 Weeks Ukraine Crisis in Comparison to No-Crisis




*5.2. Change of gas flows during crisis*

The compensation of the missing Ukraine transits implicates gas flow changes. For each of the three infrastructure scenarios these compensated or disrupted volumes are presented in Figure 9. The net length of the bars, i.e. positive minus the negative part, indicates the sum of missing Ukraine transits. These aggregated volumes differ by reason that the utilization of the Ukrainian routes varies depending on the major pipeline available to supply the European market. South Stream takes over some of the volumes that are transported via Ukraine in the Baseline Scenario. Thus, in the South Stream Scenario less volumes, i.e. about 77 mcm/d less than in the Baseline Scenario, need to be substituted in case of the occurence of a supply disruption via Ukraine given that with South Stream Ukraine transits were already lower than in the Baseline Scenario. Further rerouting of Russian gas volumes then takes place during the crisis on the South Stream pipeline and only a small proportion of storage withdrawal in Germany and other European countries is necessary to substitute the missing Ukrainian volumes. Rerouting here terms the volumes that have been transported via Ukraine in a no-crisis-simulation and are transported on another route from Russia in a crisis-simulation. South Stream supplies to the South-Eastern European market are cheaper for that region than withdrawals from storages and LNG imports. For this reason and due to several bottlenecks in South-Eastern Europe, 15 million cubic meter (mcm) less LNG are imported in the Krk terminal, Croatia and 13 mcm less gas is withdrawn from Eastern European storages on the peak day during the simulated Ukraine crisis.

Figure 9: Compensation of Interrupted Gas Flows via Ukraine

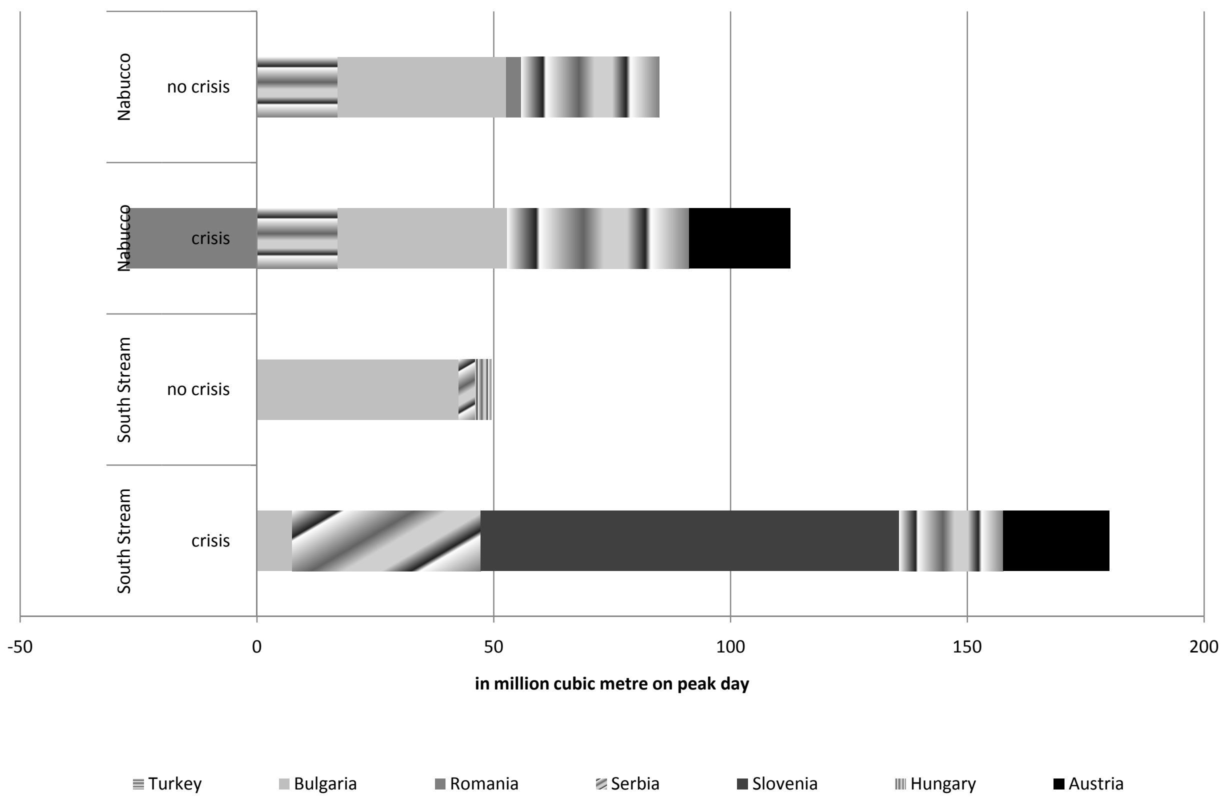



On the contrary, gas volumes transported via Nabucco do not have a crowding-out effect on Ukraine transits in a no-crisis-simulation. Thus, the missing Ukraine volumes are much higher during a crisis-simulation. These are mainly compensated by storage withdrawals in Eastern Europe and Germany but also in Italy and other European countries. Germany providing the largest storage working gas volumes in Europe with more than 25 billion cubic metre (bcm) provides additional volumes during the crisis. These volumes are transported to the East. In the Nabucco Scenario, in the simulated crisis on a peak day 10 mcm less are rerouted from Russia, i.e. transported on another route but the Ukraine route which is on Blue Stream in this case. The simulated Ukraine crisis causes a bottleneck on the interconnector from Turkey to Bulgaria which results in this decrease of Blue Stream flows.

Consumer cut-offs on the peak day during crisis are both reduced by South Stream and by the Nabucco pipeline. In the Baseline Scenario 54 mcm were cut-off on a peak day and only 18 mcm with Nabucco being included. South Stream's extensive capacity further reduces the disruptions to 9 mcm on the peak day.

Figure 10 shows the gas volumes on Nabucco and South Stream transported to the European market sorted by countries where these volumes are withdrawn and consumed. Based on the cost-minimizing simulation of a peak day scenario without crisis, Nabucco brings more gas to the European market than South Stream which only transports natural gas to Bulgaria and minor gas volumes from Serbia to Hungary. In contrast, Nabucco volumes mainly supply Bulgaria and Hungary but also Turkey and minor volumes are withdrawn in Romania.

Figure 10: Withdrawal of Gas Volumes Along the Route




During the halt of Ukrainian transits Nabucco gas supplies to Bulgaria and Turkey remain the same as in the no-crisis simulation. Moreover, additional volumes are transported to Hungary and Austria on the Nabucco pipeline. These additional volumes are mainly injected in Romania indicated by the negative green bar as Nabucco is already completely utilized in a simulation without a crisis from the start of the pipeline. As some volumes are consumed in Bulgaria, capacity is then available in Romania. The gas volumes injected into the pipeline are withdrawn from storages in Romania to mainly reduce disruptions in Hungary and mitigate marginal supply cost increases in Austria. Furthermore, some supplies to Austria are routed back to Hungary through reverse flows due to a lack of capacity on the direct way.

South Stream being only poorly utilized in a no-crisis-simulation thus offers generous redundant capacity during a crisis-simulation.[6] During a halt of gas supplies via Ukraine, gas transported on South Stream more than triples on a peak demand day which demonstrates the extent of redundant capacity available. South Stream then provides less volumes for the Bulgarian market, but significant volumes for the Serbian, Slovenian, Hungarian and Austrian market. Referring to the mitigating effects these extra volumes have on the marginal supply costs and on disruptions to consumers, the large-scale capacity of the South Stream has a significant impact on security of supply in terms of transit country risks and strongly reduces the dependence on Ukraine. However, based on cost-minimization, even in a peak-day scenario, South Stream is only poorly utilized if other transport options from Russia are available.

## 6. Conclusion

The Nabucco and South Stream Pipeline are projects often discussed in the context of European gas supply security. The results of the simulations with the TIGER model show that security of supply in Eastern Europe increases with the inclusion of Nabucco and South Stream. Nabucco reduces marginal supply costs in many Eastern European countries and South Stream prevents disruptions to consumers in Serbia that occur on a peak winter day in 2020 in the Baseline scenario. But, bottlenecks in some Balkan countries on the peak winter day cannot be avoided by neither Nabucco nor South Stream. These occur due to a lack of sufficient interconnector capacity on this day.

For both projects the gas supplying countries are not yet clear. For Nabucco these could be Caspian and Middle Eastern countries and for South Stream either own Russian or Caspian supplies sold by Russia. Thus, to draw a conclusion on the aspect of source dependence of these two projects is not possible. But the model simulations of a four week supply disruption via Ukraine implemented with the TIGER model shed some light on the aspects of transit and facility dependence in this context.

Generally, the inclusion of Nabucco and South Stream in model simulations of a Ukraine crisis both increase security of supply and lead to a reduction of disruptions to consumers and to less price increases, especially in South-Eastern Europe. Nabucco prevents disruptions in Bulgaria and Romania and South Stream in

[6] This is due to the assumptions of capacities in Ukraine still being available to supply the European market. Accounting for future major Russian production region being in the Yamal Peninsula and in the Barents Sea and the length of the route, the Brotherhood route is more cost-efficient because South Stream would either be physically supplied by more expensive Caspian volumes or would face a much longer distance from Russian production locations.

Hungary, Serbia and Bulgaria but not in Romania. However, not all disruptions within the European market can be avoided by these pipeline projects again due to intra-European bottlenecks. Persistant disruptions remain in Bosnia and Herzegovina and FYROM. A connection of South Stream to Romania or (reverse flow) capacity from Hungary to Romania could mitigate disruptions to consumers there. The same holds for a connection of Nabucco to the Serbian market or a better integration of the Hungarian and Serbian market. Moreover, due to the significantly lower capacity of Nabucco, additional LNG volumes imported in Croatia would be needed to eliminate disruptions in the two latter countries which could only be further transported if bottlenecks in Croatia were removed. Effects in Western Europe are rather small.

The model reslts based on cost-minimization have shown that South Stream is only poorly utilized even on a peak winter day in a no-crisis simulation. Mainly just Bulgaria is supplied. South Stream thus offers redundant capacity in a crisis-simulation to reroute Ukraine transits during the simulated halt of supplies via Ukraine. In the crisis simulation South Stream is highly utilized which supports that it would be built by reason of bypassing Ukraine.

Both pipeline projects enable an diversification of supply routes and if implemented should help to contribute to secure gas supplies. However, only Nabucco would reduce the dependency on Russian gas, if adequate alternative suppliers in the Middle East and Caspian region were available to provide gas for the pipeline, and would thus support a diversification of supply sources.

To sum up, Nabucco and South Stream do not only provide additional large-scale pipeline capacity in South-Eastern Europe but they also increase security of supply by extending supply options and mitigating the effects of potential supply disruptions via Ukraine in this region.

Stern (2002) addresses the problem of attributing costs to events that have a low propability to happen but a high impact on supply and the difficulties for policy makers to balance costs and risks and find measures to cope with these events. This paper presented an approach of how to analyze such events. However, the attribution of relevant costs appart from relative marginal supply costs changes and of a propability to the occurence of such events are not evaluated. Moreover, further research needs to be done to give an overall evaluation of the efficiency of a potential investment in the Nabucco and South Stream pipeline projects.

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## Appendix A. Main equations of the TIGER model

The TIGER model optimizes the European natural gas dispatch given the infrastructure components, i.e. long-distance transmission pipelines, storages and LNG import terminals, minimizing the total costs of gas supply. The **Objective Function**

$$
\begin{aligned}
C = & \sum_{t,n,n_1} [(T(t,n,n_1) + T(t,n_1,n)) \cdot ocp(n,n_1)] \\
& + \sum_{t,pr} [P(t,n,pr) \cdot pc(t,pr)] \\
& + \sum_{t,st} [ST(t,st) \cdot ocst(t,st)] \\
& + \sum_{t,r} [LNGSt(t,r) \cdot ocLNGst(t,r)] \\
& + \sum_{t,r} [LNGR(t,r) \cdot rt(r)] \\
& + \sum_{t,n} [DD(t,n) \cdot dc(n)]
\end{aligned}
\tag{A.1}
$$

is minimized over the vector $X = (T, P, ST, LNGSt, LNGR, DD)$.

Gas supply and demand need to balanced. At each node, gas supply, that could either be storage withdrawal, pipeline supply, LNG import or production, needs to be qual to gas demand. Thus, the **Node Balance Constraint** holds for $t$ and $n$:

$$
\begin{aligned}
& \underbrace{\sum_{dr} d(t,n,dr)}_{\text{demand}} = \\
& \underbrace{\sum_{n_1} T(t,n_1,n) + \sum_{pr} P(t,n,pr) + LNGR(t,n) + DD(t,n)}_{\text{inflow at node}} \\
& \underbrace{- \sum_{n1} T(t,n,n1) - \sum_{st} [StCh(t,n,st) + stif \cdot StI(t,n,st) + stwf \cdot StW(t,n,st)] - LNGL(t,n)}_{\text{outflow at node}}
\end{aligned}
\tag{A.2}
$$

## List of symbols

### Sets

$n$: (start) node

$n_1$: (end) node

$dr$: demand region

$pr$: production region

$st$: storage number

$stif$: storage injection factor

$stwf$: storage withdrawal factor

$r$: LNG regasification terminal number,

### Parameters

$d(t, n, dr)$: demand at node $n$ in period $t$

$ocp(n, n_1)$: operating costs of pipeline between $n$ and $n_1$

$ocst(t, st)$: operating costs of storage $st$ in period $t$

$ocLNGst(t, r)$: operating costs of LNG storage at regasification terminal $r$ in period $t$

$pc(t, pr)$: production costs in production region $pr$ in period $t$

$rt(r)$: regasification tariff at LNG import terminal $r$

$dc(n)$: disruption costs at node $n$,

### Optimization Variables

$T(t, n, n_1)$: gas volumes transported from $n$ to $n_1$ in period $t$

$T(t, n_1, n)$: gas volumes transported from $n_1$ to $n$ in period $t$

$P(t, n, pr)$: production at node $n$ in production region $pr$ in period $t$

$St(t, st)$: gas volumes in storage $st$ in period $t$

$StCh(t, n, st)$: storage volume change (net of in- and outflow) from period $(t-1)$ to period $t$ at storage $st$ at node $n$

$StI(t, n, st)$: storage compressor consumption for injection

$StW(t, n, st)$: storage compressor consumption for withdrawal

$DD(t,n)$: demand disruption at node $n$ in period $t$

$LNGR(t,n)$: LNG volumes regasified at node $n$ in period $t$

$LNGSt(t,r)$: stored LNG volumes at regasification terminal $r$ in period $t$.

The marginal supply costs estimator at a certain node $n$ at time $t$ is the dual variable associated with the Node Balance Constraint. The dual variable reflects the increase of the Objective Function's optimal value by marginally increasing demand in the Node Balance Constraint. The dual variable is thus interpreted as the shadow price of supply.