Security of natural gas supply for Europe in the special case of Austria under consideration of grid and storage expansion

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Abstract—This work analyses Austria’s security of natural gas supply by a two model approach. The first model is a Central European Model and the second a Local Model of the city Salzburg. By a sensitivity analysis the model shows Europe’s dependency on certain natural gas exporting regions. If an undersupply situation occurs the Local Model indicates the effect on Salzburg’s energy security. The investigation is divided into two scenarios. The first scenario considers Austria as an island concerning the natural gas supply under the consideration of 60% filled natural gas storages. The second scenario analyses the impact of supply disruptions of Europe’s main importers.

Index Terms—Austria, Central Europe, Linear Optimization, Natural Gas, Security of Supply, Sensitivity Analysis, Transmission Grid Expansion,

I. INTRODUCTION
Natural Gas is one of the most significant energy carriers for the European Union. Natural gas demand in the EU member states is expected to grow from 461 bcm per annum in year 2012, up to about 500 bcm per annum in year 2020 (Smith 2013; IEA 2013; EUROSTAT 2013). Another reason besides economic competitiveness is that natural gas is not producing as much carbon dioxide as coal by using it to generate electrical power. Electricity and heat generated by the combustion of natural gas is generally considered to have lower emissions intensity per unit electricity than that generated by burning coal. (Broderick and Anderson 2012)
To guarantee economic and technical competitiveness of the European Union, an undisturbed supply of natural gas is essential. The EU imports over 60% of its annual gas demand in the year 2013. For that reason the European Commission declared security of supply as one of the cornerstones in the European energy policy, alongside environmental objectives and economic competitiveness (Le Coq and Paltseva 2009; European Commission 2011).

Gas disruptions like the Ukraine-Russian gas conflict in 2009 have shown the vulnerability of the European natural gas supply. The disruption in natural gas supply during an extended cold period particularly affected Eastern and South-Eastern Europe. Reasons for undersupply in these regions were small natural gas storage capacities and a bad developed natural gas transmission grid (Kovacevic 2009). The non-existing connection of storages to main centers of consumption is another reason to cut off of natural gas supply (Betzüge and Lochnerprich 2009). As a consequence of this incident the European Parliament adapted the European Energy Policy to clearer and more transparent rules on security of supply (Fischer et al. 2012). Some countries like Austria increased the storage capacities and improved the transmission grid e.g. enabled reverse gas flow to Germany’s natural gas grid, to avoid situations like in January 2009 (EC, Control 2012).

In concern of the current Ukraine–Russian tensions resulting in the Crimean Crisis 2014, Europe’s Energy Policy is in urgent discussion. Figure 1 shows the dependency of European countries on Russian gas imports at present time. The dependence of South Eastern and Eastern European countries is evidence. Austria, a typical transit land is importing 60% of its annual natural gas consumption from Russia. Currently it appears as if European Member States try to diversify their natural gas supplier and reducing the dependence on Russian gas imports. This is only possible by a transmission grid expansion and increasing imported LNG (Zachmann 2014).

Most of today’s available literature analyzes Europe’s security of natural gas supply by investigating the impact of supply disruptions on the natural gas market (Abada and Massol 2011), or qualifies EU member countries by risk indices (Le Coq and Paltseva 2009). The problem of these methods is the missing quantification of supply disruptions via short-term simulations of gas flow. Motivated by supply
uncertainties of natural gas, as described above this work describes a Central Europe transmission gas grid model. It consists of the current natural gas storages and transmission lines. Thus it is possible to investigate the impacts of bottlenecks and supply disruptions, in the case of Austria, similar to the TIGER model of (Lochner 2011; Dieckhöner 2013). A second task of the model is to show the sensitivity of supplier countries and transmission routes. Furthermore it shows the change in security of supply caused by additional transmission capacity. The focus remains on possibility and impact of natural gas supply disruptions to Austria. A weakness of the transmission grid view is the lack of information at local level, concerning natural gas shortage.

For this reason the next step is a detailed investigation of a predefined urban region, to determine impacts of natural gas breakdown to residential and industrial consumers on a local level. For natural gas shortage concerns both heat and electricity production, the Local Model consists of multiple energy carriers (natural gas, electricity, fuel oil, biomass and renewable energy sources). The energy sector’s components are predefined and consist of producers, consumers and transmission lines. If natural gas supply breaks down, the Local Model quantifies the effect on energy consumers. This effect depends on redundancy of the consumers energy supply. For example a natural gas supplied consumer with an additional wood fired furnace is able to use the second heating system instead of the primary. If the consumer has no secondary heater and installs an electric heating appliance, the simulation shows the effect on the electric grid. The analysis of the Local Model indicates effects of natural gas supply at the consumer level and specifies emergency plans.

II. METHOD

This work’s security of supply analysis consists of two separate simulations, as shown in Figure 2.

1) The Central European model describes the sensitivity of existing transmission lines. The model consists of predefined load nodes connected by transmission lines. Natural gas imports to Central Europe (e.g. Russian and Norwegian imports) are modelled by exogenous sources, connected by transmission lines as well. Each node is represented by a consumer load and natural gas storage capabilities. To show the sensitivity of sources or lines the element is disconnected and the impact on nodes is examined. If an impact is affecting security of supply, results are the input parameter of the local simulation. This model is a linear optimization model modelled by eTransport.

2) In addition to the Central European Model the Local Model identifies shortage effects on certain energy carriers at local level. In this work the city Salzburg in Western Austria is modelled. As pictured in Figure 2 the model consists of producers, transmission capabilities and consumers. If natural gas input is changing the effects on consumer of different energy carriers is shown. In comparison to the Central Europe Model, the Local Model is modelled as a linear optimization problem in the optimization software GAMS

A. eTransport

eTransport is developed by SINTEF a Norwegian research organization, headquartered in Trondheim. It is a tool for planning energy infrastructure. By adding components, e. g.
sources, plants, consumers the model optimizes energy system minimal total costs (investment and operational costs) due to a predefined planning horizon. Mathematically, the model uses a combination of linear programming (LP), mixed integer programming (MIP) and dynamic programming (DP). (SINTEF 2012; Bakken et al. 2007)

eTransport is modelled as a multiple energy carrier simulation tool, but in this work only uses the natural gas infrastructure. It consists of lines (pipes), sources, loads, storages and markets. A detailed component explanation is done by (Bakken et al. 2007). For security of supply aspects the power of a load \( j \) can be described by

\[
P_{j\text{,Load}}(t) = c_{j\text{,NaturalGas}}(t)P_{j\text{,supply}}(t) + c_{j\text{,Undersupply}}P_{j\text{,Undersupply}}(t). \tag{1}
\]

The costs for regularly delivered natural gas \( c_{j\text{,NaturalGas}}(t) \) are defined by the countries market price and costs for undersupply natural gas \( c_{j\text{,Undersupply}} \) is predefined. Undersupply power is a fictive model variable to fulfill the “supply is equal to demand” equation. If natural gas infrastructure cannot provide the node’s load, undersupply power is consumed. Because natural gas is a storable energy carrier, storages are implemented as well. Storage \( i \) can be described by the storage equation

\[
E_i(t) = E_i(t-1) + P_{i\text{,in}}(t-1) - P_{i\text{,out}}(t-1). \tag{2}
\]

Storage disarms the effects of disruptions or line breakdowns, since natural gas flow can be maintained.

![Figure 3 Central Europe model in eTransport](image)

**B. Central European Model**

This model considers Europe’s natural gas infrastructure. As mentioned above the Central European Model is modelled by eTransport. This tool enables the modeler to use predefined components to construct the model. Figure 3 shows the Central European Model as an abstracted illustration of Figure 2. The focus of this work is on the investigation of Austria’s security of supply. For that reason Austria is modelled very well and the surrounding states are represented aggregated sources, sinks and transmission lines. This simulation does not consider any demand changes e.g. by an elasticity of demand. Due to this fact a shortage of natural gas does not affect the natural gas demand.

Furthermore it has not implemented any market model. The prices of the modelled countries are exogenous variables from (Directorate General for Energy 2012). The interface of exporting countries is modelled by markets as well.

The model’s input data bases on the 2012 data of (GSE; ENTSOG 2012).

**C. Local Model**

The Local Model is modelled in GAMS and solved by OSICplex. First the input energy carriers

\[
e_i = \text{[elec, gas, oil, bio, sun, undersupply]} \tag{3}
\]

transport energy carriers

\[
e_j = \text{[grid, heat, gas, oil, distribution, bio distribution]} \tag{4}
\]

and consumer energy carriers

\[
e_d = \text{[ele, demand, Demand, DH, gas, demand, oil, demand, bio demand]} \tag{5}
\]

over the time \( t \in [0, T] \subseteq \mathbb{R} \) are defined. The energy carrier “undersupply” is a modelling magnitude. The model’s input is the input power \( P_{in}(e_i, t) \) which defines the height of an energy carrier at the time \( t \). A transformation between these energy carriers is enabled by transformation matrices \( \eta_{primary}(e_i, e_d, t) \) and \( \eta_{secondary}(e_i, e_d, t) \). Primary power plants power (e.g. combined cycle power plants, heating power plants, photovoltaic panels …)

\[
P_{primary, pp}(e_i, e_d, t) = f_{primary}(e_i, e_d, t) \circ \eta_{primary}(e_i, e_d, t) \tag{6}
\]

and secondary power plants power (e.g. furnace, electric devices, heating devices …)

\[
P_{secondary, pp}(e_i, e_d, t) = f_{secondary}(e_i, e_d, t) \circ \eta_{secondary}(e_i, e_d, t) \tag{7}
\]

are defined by variables

\[
f_{primary}(e_i, e_d, t) \in \mathbb{R} \quad \text{and} \quad f_{secondary}(e_i, e_d, t) \in \mathbb{R} \tag{8}
\]

The power plant power is a transformation between the energy carriers e.g.

\[
P_{secondary}(e_i, t) = P_{primary}(e_i, e_d, t)P_{in}(e_i, t). \tag{10}
\]

The input energy carrier has a predefined price \( p_{primary}(e_i) \) as well as the secondary energy carriers \( p_{secondary}(e_d) \). The analysis is a minimum optimization problem with the objective
\[
\min C = \sum_{\alpha} \left( p_{\text{primary}} \left( \sum_{t} \sum_{\alpha} P_{\text{primary},PP}^t \right) \right) + \sum_{\alpha} \left( p_{\text{secondary}} \left( \sum_{t} \sum_{\alpha} P_{\text{secondary},PP}^t \right) \right)
\]

(11)

D. Combination of Central Europe Model and Local Model

As mentioned above the Central European Model describes the performance of the Central Europe’s transmission grid by alternating the input e.g. supply disruption of Russian gas, break of transmission lines. The two models have a defined observation period. The Central European Model’s observation period \( T_{\text{max,CE}} = 365 \text{d} = 1 \text{year} \) (beginning on 1 January) and at the Local Model’s \( T_{\text{max,L}} = 90 \text{d} = 3 \text{months} \).

The Locals Model’s simulation period lasts three winter months. This time is characterized by the annual peak load of consumption. Figure 4 shows the model’s interactions.

- First an impact is defined and is set as the Central Europe’s input parameter. If the impact has no influence to the Austrian nodes the next impact is investigated (comparable to incident 1 at Figure 4) and if the impact results in a considerable effect at an Austrian node, the results are the input of the Local Model (comparable to incident 2 at Figure 4).
- By changing the input parameters, the Local Model shows the effect of wide supply disruptions on a more detailed local level. At this level the impact has no influence (comparable to incident 2 at Figure 4) or has an influence (comparable to incident 3 at Figure 4). The impact on the local level can be the breakdown of heating systems or the electrical grid. The simulated area of this work is the city Salzburg in Western Austria.

Benefit of this investigation method is the indication of transnational supply disruptions on a local level, without picturing Central Europe at a highly detailed level. Another difference is concerning the time resolution. While the Central European time resolution is 1d that of the Local Model is 1h.

E. Definition of Scenarios

For this work, two scenarios, concerning the security of supply are defined.

- **Scenario 1** describes a natural gas supply disruption at all supplying nodes to Austria. In this case Austria is a natural gas isolated island, with full storages. The effected nodes according to (ENTSOG 2012) are Baumgarten, Arnoldstein, Weitendorf, Burghausen, Murfeld and Oberkappel. Baumgarten is the major transit gas for Russian natural gas imports to Central Europe.
- **Scenario 2**, sensitivity analysis in regard of supply regions. In these scenarios three import regions are considered. As the model’s input the whole natural gas import of this country or region is stopped. The case of undersupply shows a country’s dependence on a certain natural gas exporting region.

III. RESULTS

A. Scenario 1

As mentioned above scenario 1 shows the capability of Austria’s natural gas storages. This scenario is defined by a disruption at all boarder nodes at 1 January. To disarm the scenario, the model has implemented a reconnect to Europe’s gas grid during the second half, beginning with the summer months. The storage capacity are according to storage management statistics of (E-Control 2014) at 60% of the nominal capacity. Furthermore this scenario is divided into three cases.

a) Simulation without the natural gas storages 7Fields and Haidach. This unavailability can be explained by the connection topology of these storages. The geometrical position of these two storages is Austria, but they are technically connected to Germany’s natural gas grid.

b) Same parameter as scenario 1a in addition to a load reduction of 5, 10 and 30%.

c) With a connection of the natural gas storages 7Fields and Haidach. As explained before these two storages are connected to Germany’s natural gas grid. In spring 2014 7Fields is connected to Austria’s natural gas grid too (APA 2014). Haidach will connected 2014 to Austria as well (E-Control 2011).

1) Scenario 1: Central European Model’s Results

The results of scenario 1a show an undersupply of Austria’s consumers after 100 days. The 100 days supplying the consumers are in the winter season, the annual peak demand. Up to this date Austria’s gas supply is theoretically maintained. In reality first high pressure lines fail and afterwards lines with lower pressure. The reason is because high pressure lines need the high working pressure for operation. For that reason small consumers are supplied much
longer than consumers connected at a high pressure level e.g. business and industry consumers.

The reduction of load in *scenario 1b* causes an extension of the natural gas supply. By reducing the load of 5% undersupply starts 111 days. A reduction of 10% is delaying the undersupply to 122 days, while a reduction of 30% delays the beginning of undersupply to the summer months. Because grid reconnection reinitialized in the summer, the 30% load reduction enables Austria to manage with the supply disruption. As mentioned in scenario 1a this results are only theoretically and in reality high pressure consumers are undersupplied much earlier.

A direct connection of the natural gas storages 7Field and Haidach to Austria’s natural gas grid in *scenario 1c*, defuses the model’s situation very well. 7Fields has a working gas volume of 1.17 bcm and Haidach a working volume of 2.64 bcm. Because 7Fields and Haidach represent 51% of Austria’s total natural gas storage capacity, the connection of these storages to Austria’s natural gas grid raises Austria’s security of supply significantly. In scenario 1c no situation of undersupply appears.

2) *Scenario 1: Local Model Results*

The Local Model’s results are only significant in scenario 1a, because this case results in a situation of undersupply.

Effects appear especially in Salzburg district heating and natural gas distribution grid. Salzburg’s installed capacity of natural gas fired combined heating power plants (CHPP) is 205.5MW and oil fired capacity of 115.5MW. Biomass fired power plants of 9.4MW are installed too. By using alternative fired power plants (oil und biomass) the situation of natural gas shortage can be disarmed. Not supplied heating energy is 1.65GWh/week by a total district heating demand of 21.1GWh/week. This situation occurs during the annual peak loads in winter and transition period months. A solution is the installation of additional oil or biomass fired CHPP or heating plant with a nominal power of 49.5MW.

The situation for natural gas consumers is much heavier, because the entire supply is broken down. To ensure a supply of heating additional electric heating devices can be installed in times of shortage. This shifts the problem to the electrical grid. The electrical grid’s peak load power raises of 120% and weekly energy demand raises of 80%. The impact of increased electrical energy flow and power encumbers the electrical grid is not a part of this works model.

### Table 1: Storage capacity, annual demand according to (ENTSOG 2012; IEA 2012)

<table>
<thead>
<tr>
<th></th>
<th>AT</th>
<th>DE</th>
<th>IT</th>
<th>SK</th>
<th>HU</th>
<th>SL</th>
<th>FR</th>
<th>BeLux</th>
<th>NL</th>
<th>CH</th>
<th>CZ</th>
<th>PL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Capacity in bcm</td>
<td>7.5</td>
<td>20.4</td>
<td>14.9</td>
<td>2.8</td>
<td>6.1</td>
<td>0</td>
<td>12.6</td>
<td>0.7</td>
<td>5.1</td>
<td>0</td>
<td>3.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Annual Demand in bcm</td>
<td>8.5</td>
<td>81.0</td>
<td>76.4</td>
<td>6.5</td>
<td>10.8</td>
<td>0.8</td>
<td>42.1</td>
<td>22.0</td>
<td>47.3</td>
<td>3.3</td>
<td>8.6</td>
<td>17.6</td>
</tr>
<tr>
<td>Rate Storage Capacity to Annual Demand in %</td>
<td>87.7</td>
<td>25.2</td>
<td>19.6</td>
<td>42.3</td>
<td>56.5</td>
<td>0</td>
<td>30.1</td>
<td>3.2</td>
<td>10.7</td>
<td>0</td>
<td>36.5</td>
<td>9.2</td>
</tr>
</tbody>
</table>
degree of undersupply is that these countries are primarily connected to Russia and the natural gas storage capacities are poorly developed. The Western Central European countries are not affected in that scale, because the natural gas grid is connected to different production areas and the storage capacity is well developed.

Scenario 2b shows the results in case of a supply disruption of produced in the North Sea area. Figure 5 shows the results too. In comparison to the scenarios 2a East Central European countries are not affected as well, because these states are primarily delivered by Russian natural gas. North European Countries have to work with heavy supply problems. Especially Belgium and Luxembourg are concerned by a degree of undersupply of 73%. In Austria this situation is not as bad as 2a.

LNG and North Africa supply disruptions in scenario 2c only affect Italy (see Figure 5) but have no influence on other Central European countries.

2) Scenario 2: Local Model Results

In case of natural gas undersupply in Austria, scenario 2a and 2b the results of Local Model results are the same as in Scenario 1. Due to that reason a separate representation is not shown here.

IV. CONCLUSION

This work shows a security of natural gas supply analysis. The benefit of the techno-economic model in this work is a robust security of supply analysis. By a sensitivity analysis it is possible to analyze the impact on a countries natural gas supply. The model contains Central Europe and consists of two submodels. First a Central European Model characterizes Europe’s natural transmission grid. Austria is modelled at a high detailed level. Secondly a Local Model describes undersupply situations in the western Austria city Salzburg. The benefit of the two model approach is a very detailed investigation of a transnational impact on the natural gas supply. The investigation is divided into two scenarios.

The first scenario considers Austria as an island concerning the natural gas supply under the consideration of 60% filled natural gas storages. Without a demand reduction natural gas supply Austria’s natural gas demand can be ensures about 100days. By reducing the load this period extends till the summer months. The third case anticipates the two natural gas storages Haidach and 7Fields are connected to Austria’s natural gas grid. Down to the present day 7Fields is connected in spring 2014 and Haidach will be connected during this year. This enhanced storage capabilities increases Austria’s security of supply sustainable. The Local Model shows undersupply situations in district heating as well as in the gas grid connected customers. Furthermore it investigated the effect on the electrical grid, by the shift of heat load with electrical heating devices.

The second scenario analyses the impact of supply disruptions of Europe’s natural gas exporting regions. Cutting off from Russians natural gas mainly concerns the East European countries Poland, Slovakia and Hungary. Switzerland is affected too, because of missing natural gas storage capabilities. North Sea gas imports affect the states Belgium and Luxembourg, France, Netherland, Germany and Switzerland. North African and LNG imports do not affect Europe’s at all, only Italy has 27% degree of undersupply.

To ensure future security of supply in Central European States it is necessary to diversify the supply countries as well as the energy mix’s composition. A reduction of natural gas consumption in residential heating has high potential, too. Another important transnational challenge is the implementation of the Ten Year Network Development Plan (TYNDP) according to (ENTSOG 2013). This plan includes future pipeline and storages projects in order to satisfy Europe’s raising energy demand and diversify the origin of natural gas.

The model introduced in this work will be used for further investigation. It is intended to expand the model by the missing European countries as well as a benefit analysis of the TYNDP.

V. REFERENCES


