Master Thesis

Risk assessment of the European natural gas network

Felix Schumacher

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Professors:

Prof. Dr. Božidar Stojadinović	ETH Zürich
Prof. Dr. Aldo Steinfeld (Tutor)	ETH Zürich

Supervisors:

Peter Lustenberger	Singapore-ETH Centre
Dr. Peter Burgherr	Paul Scherrer Institute
Dr. Matteo Spada	Paul Scherrer Institute

Summary

This thesis aims to investigate the European natural gas network and the potential consequences of earthquakes and technical failures on the network's flow capacity. A European natural gas network model is built from geo-information data. The structure of the model is defined by the interconnected natural gas transmission pipelines. Pipeline interconnections as well as pipeline dead-ends are either natural gas sources or sinks. Sources are natural gas entry points such as natural gas production sites, LNG-ports or system boundary crossing pipelines. For certain modelling scenarios natural gas storage facilities are additionally implemented as natural gas sources. Sinks are natural gas exit points where the natural gas is consumed. Natural gas compressor stations are uniformly distributed along the pipeline lengths, as no database with geospatial information about compressor stations' locations is found. The average distance between the compressor stations is assessed and evaluated within this thesis.

To consider geospatial differences of natural gas consumption, the natural gas consumption is allocated over Europe. Therefore, the natural gas consumption is subdivided into domestic/industrial and electricity production natural gas consumption. The natural gas consumption of power plants is defined by the carbon dioxide emissions found in emission databases and allocated to the geospatial location for each plant. The domestic/industrial consumption is derived from a geospatial population density map resulting in a raster grid map of natural gas consumption. The annual natural gas consumption by country is used to calculate the needed natural gas consumption per capita on a country level. To derive the natural gas consumption of a network's sink, the European land area is subdivided into demand areas. Demand areas are regions, containing only one sink, whose natural gas demand is covered by the corresponding sink. The demand areas are generated by applying a Voronoi algorithm with the natural gas sinks. The natural gas consumption of a natural gas sink is found by integrating the natural gas demand distribution over the sink's demand area.

The flow capacity of the natural gas network is measured by the maximum flow. The maximum flow of a network is defined as the maximum possible flow of a network from the sink to the source. In order to estimate the maximum flow of the European natural gas network, the network is converted from a multi-sink/source to a single-sink/source network. The conversion process assumes infinite natural gas source capacities and sink capacities, that are limited by the natural gas consumption of the corresponding sink. The accuracy of this network conversion process is analysed in this thesis. The applied network conversion is proved to generate reasonable results. The consequence of a network component's failure is defined as the relative maximum flow loss, caused by the corresponding failure.

In this thesis, risk is defined as the multiplication of the relative maximum flow loss by the failure rate of the component causing the flow loss. The failure rate caused by earthquakes (seismic failure) and the failure rate caused by non-seimic events (technical failure) are independent events and therefore computed separately. Seismic failure rates are calculated from a geospatial earthquake forecast map considering the component's seismic fragility. The technical failure rate is calculated from the ENergy-related Severe Accident Database (ENSAD). Its value is computed by dividing the number of component failures by the component's total exposure. In order to guarantee a high level of completeness, the database was updated during this thesis by collecting incident data in the investigated time window. The computed technical failure rate of natural gas pipelines was compared to published numbers of other studies. The technical pipeline failure rate is proved to be reasonable.

The risk assessment is carried out for natural gas pipelines with compressor stations and natural gas storage facilities. The seismic and technical risk is analysed separately. This thesis focuses on single component failure. Failures of multiple components at the same time are not investigated. All natural gas flows are calculated based on an annual average. Fluctuations (e.g. seasonal or daily) are not considered.

The maximum flow analysis of the natural gas network reveals that the highest maximum flow loss is found for the Transit Gas pipeline, crossing the Alps from Switzerland to northern Italy. Generally, the maximum flow loss caused by pipeline failure is reduced by using natural gas storage facilities as sources. Single storage failures do not cause any maximum flow losses, as the natural gas demand can be covered without natural gas storage facilities.

High seismic pipeline failure rates can be found in Turkey, followed by Italy and southern Greece. High seismic storage failure rates can be found in Italy and Romania. The seismic risk analysis reveals, that the highest seismic risk is found for a natural gas pipeline in south-eastern Turkey. The seismic pipeline risk is reduced by using natural gas storage facilities as sources in most of the regions in Europe. The seismic risk, however, can not be associated to natural gas storage facilities as the natural gas demand can be covered without natural gas storage facilities. Therefore, a failure of a natural gas storage facility does not cause any maximum flow losses.

High technical pipeline failure rates can be found for long pipelines (mainly offshore pipelines). The technical storage failure rate is higher than the seismic failure rate for all natural gas storage facilities. The technical risk analysis reveals, that the high technical risk pipelines are located all over Europe. The technical pipeline risk is reduced by using natural gas storage facilities as sources in most regions in Europe. The technical risk can not be associated for natural gas storage facilities as the natural gas demand can be covered without natural gas storage facilities. Therefore, a failure of a natural gas storage facility does not cause any maximum flow losses.

In this thesis pipelines with a high impact on the overall flow capacities of the network are identified. Furthermore, pipelines with a high exposure to technical and seismic hazards are found and the resulting risks for the pipelines are estimated. The reduction potential on the network's flow capacity and risk due to natural gas storage facilities is quantified. Additionally, the technical and seismic storage facility failure rate is computed. Those results could serve, with some caution, as a starting point to conduct evidence based decisions for structural and technical improvements of the European natural gas network towards a lower seismic and technical risk.