

# CONSEQUENCES OF NATURAL GAS SHORTAGE ON SUPPLY CHAINS IN AUSTRIA

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## ABSTRACT

**Purpose:** The scarcity of natural gas as a significant threat became highly evident since the beginning of the Russia-Ukraine conflict. It is essential to understand the impact on national supply chains (SC) in case of import restrictions or any other disruptions. A holistic approach is vital to identify the most affected sectors or businesses. Additionally, it is necessary to investigate and understand indirect consequences caused by cascading effects in SCs.

**Methodology:** The study modelled the natural gas dependency of SCs in Austria, from the national interconnection hub to gas customers in a business context, and visualized it through a graph to enhance awareness of interdependencies. Based on the graph, a simulation was designed to mimic the potential reaction to a shortage of specific nodes in the SC.

**Findings.** The dataset included nodes, edges, and characteristics based on natural gas usage (as a material source for production or for the operation of machines or heating) to enhance the understanding of the SC. The simulation identified the interdependencies and nodes most strongly affected.

**Limitations of the research:** This study has limitations because it is focused on a national and, therefore, geographically limited context. Although the simulation did not consider the available storage volumes in the natural gas network, it showed significant interdependencies between sectors.

**Practical implications:** The research indicated that there was insufficient information and data available to monitor potential natural gas shortages and their effects on national SCs at the state level.

**Originality/Value:** This study provides an initial holistic overview of the natural gas SC in Austria to increase awareness of existing dependencies. The simulation improved the understanding of the aftermath of a shortage, supporting the estimation of impacts, complementing existing practices in managing system infrastructure, and ensuring a continued national supply. Engaging in discussions with domain experts further increased the validity of the approach.

## Keywords

Impact estimation, Interdependencies, Simulation, Natural Gas Shortage, SC

## Introduction

Due to its essential role in various sectors of the economy, a shortage of natural gas can pose a significant threat and cause severe disruption to national businesses. Natural gas is a vital energy source used for generating electricity, industrial processes, heating, and as a feedstock for petrochemicals. Manufacturing, agriculture, and transportation industries heavily depend on a consistent supply of natural gas. Any shortage leads to surging energy prices, rising operational costs, reduced profitability, and potential production cutbacks or shutdowns. Furthermore, the scarcity of natural gas can unveil interdependencies among sectors as SC disruptions in one industry can affect others through a cascading effect. For example, a shortage of natural gas could have an impact on power generation, which in turn could have an impact on communication networks, and essential infrastructure, thereby amplifying the economic and societal consequences (Dujak et al., 2019).

As a result, the accessibility of natural gas is closely linked to the stability and resilience of the economy. To be more holistic, this accessibility is an issue of raw material resilience and at the core of the EU Commission's "Raw Materials Initiative - Securing Europe's Supply of Goods Needed for Growth and Jobs" (European Commission, 2008) and the Communication "Commodity Markets and Raw Materials: Challenges and Solutions" (European Commission, 2011). As early as 2008, the Commission recognized

the strategic importance of the Raw Materials Initiative. It also formulated the desirability of defining an appropriate policy in this direction. Subsequently, the framework for issues such as sustainable access to raw materials inside and outside the EU, resource efficiency, and recycling was established. The demand for raw materials has increased both in the EU and in many of its member states – also in Austria, which serves as the research geographic context. Processes of extraction, processing, reuse, and recycling have evolved. In order to respond to changing conditions and at the same time be in line with international strategies and goals. Austria's efforts to continue to play a leading and stable role in Europe in the field of raw materials and the raw materials and basic materials industry entails the following: international planning and supporting activities in order to strengthen the resilience of the raw materials sector along the value chains and to reduce future supply risks (European Commission, 2008; European Commission, 2011; BLMFUW, 2011).

SCs within a country can be significantly affected by a shortage of natural gas. Numerous industries depend on natural gas for various purposes, including manufacturing, heating, and transportation. With reduced availability and rising prices caused by a shortage, businesses could experience difficulties in obtaining the needed energy supply, resulting in production delays, higher operational costs, and potential disruptions in logistics and distribution processes. Such a situation can trigger a ripple effect, affecting interdependent industries such as manufacturing, electricity, transportation logistics, agriculture, petrochemicals, and retail (Zamanian, 2020).

Companies that operate within interconnected networks aim to focus on managing a system, which comprises various economic actors, including suppliers, partners, allies, or customers (Iansiti and Levien, 2004). Within these networks, resilience is the ability to absorb risks by acting and using the resulting new knowledge to one's advantage (Lengnick-Hall et al., 2011). SC networks are highly vulnerable since disruptions can lead to costly downtime. Such failures can be caused by influencing factors such as technological change, crises, and shortages of raw materials. Adapting resilience to the value chain can prevent damage and at the same time open up new opportunities (Schrems, 2021). For these reasons, the improvement of the resilience of SC networks in the face of crises is all the more important. Value chain resilience refers *“to the capability of planning and designing the SC network in advance to anticipate unforeseen events and respond to them dynamically, while retaining control over the structure and functioning of the SC. The goal after such events is to achieve a robust operational state that is, if possible, more favourable than the pre-event scenario, resulting in a competitive advantage”* (Ponis and Koronis, 2012, p. 921). In the context of resilience, visibility is a crucial aspect because it provides the necessary insights and information for organizations to effectively anticipate, mitigate, and respond to disruptions. When managing SCs, visibility refers to the ability to track and monitor the movement of goods, information, and resources across various stages of the SC network.

Given that SCs undergo continuous change and visibility cannot be assumed, it is crucial to find approaches to investigate, simulate and analyse network vulnerabilities using a standardized process and methodology. Moreover, a standardized approach facilitates not only temporal comparisons between analysis of the same SCs but also comparisons between analysis of different SCs. Modelling the components involved (e.g., SC partners, critical infrastructures, and individual subsystems) and their interdependencies helps analyse and assess vulnerabilities. This type of abstraction also represents the dependencies between different areas, which are traditionally considered separately, and then estimates and visualizes potential impacts and cascade effects (Wei and Wang, 2010). This research illustrates this process, and aims to develop associated risks in scenarios within the context of natural gas shortage in the country of Austria.

The remainder of the paper is organized as follows. In section 2, the literature review describes the natural gas issue in the national context and the SC literature on risk management, disruptions, and resilience. Section 3 introduces the methodology and the steps taken to model the natural gas dependency of SCs in Austria based on scenario and data description and data analysis. Sections 4 and 5 present the findings

and discussion while section 6 concludes the paper with theoretical and managerial implications and future research avenues.

### **Literature Review**

Alongside oil and coal, natural gas is one of the most important energy sources worldwide, accounting for 23.5% of global primary energy consumption in 2022 (Statista, 2022). In addition to the use of natural gas for heating, natural gas is used for electricity generation and industrial production processes (Emenike and Falcone, 2020), which is why the industrial sector, in particular, is an important customer, including in Austria (FGW - Fachverband der Gas- und Wärmeversorgungsunternehmen, 2022). Natural gas supply is ensured by a supply consisting of numerous nodes responsible for individual components in the SC, which increases operational complexity. In addition, long lead times, insufficient communication between nodes and dependencies due to single source constellations further add to the complexity of the natural gas SC (Emenike et al., 2022). Adding to that, various events disrupted the natural gas SC, such as the most recent Russian invasion of Ukraine in 2022 (Chen et al., 2023). Reoccurring events like those show why resilience is needed in the natural gas SC.

Risk management created several strategies to minimize the negative consequences of disruptions. However, in response to the increasing frequency of interruptions, these consequences cannot be avoided entirely by risk management as these strategies focus only on known risks. This is why resilience in SC is needed to tackle prior unknown risks regarding the probability of occurrence and magnitude (Kayikci, 2021). Former literature in SC management defined resilience as the ability to bounce back after disruptions (Kamalahmadi and Parast, 2016). In particular, the former definition of resilience is no longer suitable for complex systems with numerous components since these systems and their components may often not be comparable to their prior states after a disruption. Therefore, the capacity to withstand, adapt to, and transform in the face of short-term disruptions and long-term changes is the definition used for this paper (Béné et al., 2016; Wieland and Durach, 2021).

Resilience thereby becomes an essential factor in the natural gas SC. As mentioned earlier, the availability of the natural gas SC is frequently impaired by disruptions. Not only the Russian invasion of Ukraine but also natural disasters disrupt the SC, such as Hurricane "Michael" in October 2018, which affected 400,000 consumers (Li and Hao, 2022). Primarily due to the extensive usage of natural gas in various SCs, it is necessary to build resilience. Previous studies found that resilience can be achieved mainly through a buildup of storage facilities, supplier diversification or the establishment of alternative suppliers (Zamanian, 2020), decentralization of SC structures, or optimization of transportation pipelines, to mention a few. However, it is necessary to analyze various risks and their impacts to implement and establish these resilience factors in the long term (Emenike and Falcone, 2020).

### **Methodology**

To determine the consequences of a gas shortage in Austria in the form of a simulation model, it was first necessary to map dependencies in the network into a graph. By using a stochastic approach (König et al., 2019), it was thus possible to map the critical partners and systems to create awareness of the dependencies. Not only could this create visual mappings, but it also served to formalize a mathematical layer. To integrate the behavioural patterns of the respective organisations and components within the SC under consideration into the dependency graph model, the individual nodes in the graph are based on the mathematical model of a probabilistic Mealy automaton. A probabilistic Mealy automaton is an abstract concept of a machine with finitely many states; this machine can compute an output for an input (from a predefined set of symbols) based on its current state.

The simulation of dependency effects starts with one or more initial events that affect one or more nodes. The respective nodes behave according to their current state, and a state change is triggered in the node based on the transition function and the transitions defined in it. This state change generates an output

event, which is then formally sent out via the node's outgoing edges to all neighbouring nodes that depend on the initial node. In this way, the dependence graph represents the cascade effects and their further propagation in each simulation step. Simulating a sufficient number of times can produce a comprehensive overview that highlights the partners in the SC who are most impacted by an incident and the crucial points in the SC where such an incident could occur.

The initial event is assumed to be a shortage in the supply of natural gas. This shortage appears in the natural gas SC to Austria, but has its origin beyond Austria. For the model, therefore, the event "natural gas shortage" is used, which affects the node in the natural gas SC in Austria that is connected to the international network. Due to dependencies in the network, these states propagate throughout the network with time delays as individual natural gas storage and distributors were considered.

The initial stages, as well as the transition functions, were defined using qualitative and quantitative primary and secondary data in several sub-steps. In the first sub-step, the most important industrial natural gas consumers in Austria were identified based on published emission figures of companies in specific industries. An analysis of annual and sustainability reports enabled the additional concretization of these figures. In the second sub-step, these data were further expanded with qualitative and quantitative primary data. The secondary data research was sourced from reports, databases, and statistics, and the data collected through semi-structured interviews and collaborative workshops spanned five months, from January to May 2022. In the form of direct exchange rounds with companies and representatives of industry organizations (e.g. the Austrian Chemical Industry Association) as well as the preparation and implementation of an Austria-wide survey concerning the dependence of Austrian companies on natural gas and the recording of effects of supply interruptions or complete natural gas supply stops, further important insights were gained, which were taken into account in the simulation.

**Findings**

From a state perspective and in the case of a potential supply disruption in natural gas supply, that has not yet taken place, the available pre-emptive measures include both general preparedness measures established by the government, as well as specific preparations undertaken in response to any indicative signs of impending disruption. The primary precautionary measure involves close monitoring and observation of the national market, particularly the key SCs. This involves, most importantly, the acquisition and analysis of data and information from Austria's pivotal industries to detect any inconsistencies or disruptions in the affected value chains as early as possible, and if necessary, address them with diplomatic measures.

The following table (Table 1) displays an overview of interconnected industries in a natural gas shortage consideration – gathered from the empirical work and secondary data analysis – and emphasized the intricate network of dependencies that support a nation's economic stability.

Industry	Narrative description
Manufacturing	Manufacturing Industries, such as those related to chemicals, plastics, and metals, heavily rely on natural gas as an energy source and as a raw material. Shortages can cause production stoppages, which can affect the availability of essential goods.
Electricity	Natural gas is commonly used by power plants to generate electricity. Shortages may result in decreased power generation, which can have an impact not only on households, but also on critical infrastructure such as hospitals, data centres, and communication networks.
Heating and Cooling	Residential, commercial, and industrial heating systems depend on natural gas. Any shortages can affect comfort and cause operational disruptions, particularly in cooler regions.
Transportation Logistics	Natural gas is utilized as fuel for vehicles, especially in certain commercial fleets. The shortage can cause disruptions in the SC and an increase in transportation expenses.

Agriculture	The use of natural gas in the agricultural sector is fundamental for processes such as the production of fertilizers and crop drying. Shortages can impact both the production and distribution of food.
Petrochemicals	The petrochemical industry utilizes natural gas as a feedstock for the production of materials such as plastics, chemicals, and synthetics. Shortages of natural gas can result in decreased availability and increased costs of these products.
Construction	The use of natural gas in the construction industry includes heating, hot water, and drying processes. Shortages can impact project timelines and costs.
Retail	Due to manufacturing and distribution disruptions caused by the shortage, retailers might face challenges securing products. In the upstream process view, food production may be affected by fertilizer availability.
Finance and Technology	Disruptions can have economic impacts on financial markets, investor confidence, and overall economic stability. A stable energy supply is also critical for the operations of data centres and tech industries meaning that shortages of natural gas may cause power interruptions, which can impact digital services and operations.

*Table 1 - Interconnected industries in natural gas shortage settings*

To analyse and evaluate vulnerabilities between interconnected industries within the given natural gas SC, it was important to model the various players involved, from the origin national interconnection hub to gas customers in the business context including their interdependencies. This data generation and analysis approach facilitated the representation of dependencies among different areas that are traditionally analysed separately.

In a nutshell, the developed data set covers nodes, edges and entails characteristics based on natural gas usage (as a material source for production; for the operation of machines, or heating) for an enhanced interpretation of the SC. The simulation allowed to identify who is most strongly affected. Based on this analysis, actions are proposed that increase the resilience of the gas SC against shortages.

The simulation component utilized in the study and underlying context is constructed based on an abstract depiction of the natural gas SC (for example a generic and theoretical outline of Austria's national gas network). This rough representation models the relevant organizations and components along with their interdependencies through a directed graph called the "dependency graph". It generally consists of the following components: nodes and directed edges.

Nodes represent the various parts of the SC relevant for analysis. This includes SC partners, critical infrastructure, industrial customers, and diverse actors related to them. Additionally, the term nodes encompass actors, goods, and abstract components, such as an attacker.

The SC model developed describes the various functional states of a node in the SC. A representation consisting of three possible states could be defined as:

- State 1 signifies the situation when the node is functioning as expected without any issues.
- State 2 refers to the node functioning with certain limitations.
- State 3 represents severe problems where the node is no longer operating.

The behavior of a node in response to an event (e.g. a threat or a disruption problem), depends on its current state, which is defined by the transition function. In general, an incident or external influence causes the node to transition to a particular state as defined by the transition function. For instance, the occurrence of "power failure" causes a node to change from state 1 (fully functional) to state 3 (non-functional), as per the transition function. Nevertheless, the new state of the node depends on not only the initial problem but also its current state. In addition, the availability and the expected damage in nodes are included in the interpretation to provide a consistent overview of the situation of the entire SC.

Directed edges describe the dependencies between nodes and indicate the direction in which resources or goods are exchanged. They mainly represent the national natural gas pipelines including the respective branch pipelines. They also include supply pipelines representing the connection between a branch point and an industrial customer or a specific region. The authors opted for this abstracted representation of edges due to the networks' complexity and lack of data.

It is key for the approach, that the direction of directed edges also indicates the direction in which the effects of an incident can propagate within the dependency graph. This means that a disruption in one node can escalate along edges and have effects on another node and potentially lead to further problems there.

The developed graph enabled the visual processing of relationships within the natural gas SC. Additionally, formal (mathematical) capture of these relationships is possible. The graph primarily facilitated an initial analysis of the natural gas SC concerning its critical nodes. These could be nodes that have a large number of outgoing edges, thereby, supplying many organizations, or evolved as neuralgic points, which represent the only supplier in a specific part of the natural gas SC under consideration. Certain industrial consumers (such as those related to critical infrastructure) were explicitly identified in this graph. As this diagram is a formally described directed graph, further analysis of highly complex and strongly interwoven SCs can be achieved through certain metrics from graph theory, such as the inner and outer degrees of nodes.

The analysis of an incident in the natural gas SC followed two steps: First, the local reaction of each node is described by changes in state. Second, if the state of a node changes, it informs all its neighbours about it. Neighbouring nodes in turn react to the received message about state changes of the predecessor node and in turn, send messages to their neighbours. In this way, the propagation of a problem through the entire network is simulated and cascading effects are explicitly taken into account. The effects of shortage in the natural gas network were estimated based on a simulation of cascade effects (König et al., 2023). For the simulation, the nodes were divided into different types and qualitatively described for their potential states to make their change and the probability of this change from one state of the node to another comprehensible.

The initial event is assumed to be a shortage in the supply of natural gas. This arises in the SC to Austria but originates outside of Austria. For the model, therefore, the event "natural gas shortage" is used, which affects the node in the natural gas SC in Austria. The importance of the key network node (natural gas import node in the Eastern part of the country) evolved immediately. The simulated shortage corresponded to a reduced flow rate and interruptions or delays in the gas supply and changed the states of nodes in close connection with the key network node. With multiple runs, state transitions naturally changed, resulting in a distribution over all possible states at the end, which allowed a conclusion about the average impairment of a node.

## **Discussion**

At the beginning of the underlying research investigations, there was significant emphasis on the natural gas supply topic, including the SC and the "natural gas as a product". Since the onset of the COVID-19 pandemic, there have been consistent bottlenecks and supply issues. However, the situation regarding natural gas supply had been surpassed by reality, metaphorically speaking, and further escalated by the Russia-Ukraine conflict.

To identify dependencies among industrial customers and sectors, it was necessary to record affected companies and their industry classification. To define real dependencies and document the actual use of natural gas as a "product", it was necessary to link the natural gas consumption of these companies with its actual use. The research process of analysing data on the dependencies, production, and application areas of natural gas not only focused on individual business models and product specifications but especially on the interdependencies of companies and their partners throughout the SC. This study also took into account how natural gas is used and applied in other companies and industries in this specific

Austrian SC context. The approach allowed the team of researchers to consider the use and application of the product and to set the database for the simulation and the rough representation models.

Natural gas distribution networks can be described as systems consisting of hundreds or thousands of kilometres of lines and production facilities, including pipelines, storage and distribution centers, compressor stations, valves, and regulators. The developed model in this research does not include any detailed analysis of individual network elements or their configuration. The simulation's primary aim, including the data model developed within the scope of the study, is to illustrate the potential impacts of disturbances, to display transitive dependencies and cascading effects resulting from such disturbances, and thus gain a deeper understanding of the natural gas SC in Austria.

### **Conclusion**

The research contributed to the European natural gas SC literature and evidently showed that there was insufficient data and information available for monitoring potential natural gas shortages and their effects on national SCs at the specific state level.

A first step of a holistic overview of the natural gas SC in Austria was provided to raise awareness of existing dependencies. The key contribution was an analysis of a rough representation of a natural gas SC about potential cascading effects due to natural gas shortages or supply interruptions. Simulations increased the understanding of the aftermath of a shortage to support existing best practices to protect infrastructures and the supply of businesses. Discussions with domain experts increased the validity of the theoretic approach.

It was problematic that the extent of natural gas required for the production of downstream products could not be recorded due to the limited data from basic statistics, and could only be estimated through technological inferences. By collecting more data through expert discussions, workshops, and a nationwide survey directly addressed to companies, deeper insights into the overall natural gas system were gained and a more solid basis for further analysis steps was established. The analysis steps involved surveying critical actors in the overall national natural gas network, identifying relevant industries affected by natural gas shortages, and presenting cascade effects in connection with supply bottlenecks.

To conclude, the outlook for both the national and European natural gas markets is expected to remain uncertain. This is due in part to the ongoing situation in Russia and Ukraine, which has damaged Russia's reputation as a dependable natural gas supplier. There is considerable evidence to suggest that the natural gas markets will remain highly competitive until at least 2023 and 2024, and likely beyond. Therefore, it is necessary to develop comprehensive strategies and viewpoints that provide an overview of the entire natural gas system. To achieve this aim, it is crucial to have shared data, a transparent understanding of the interconnectivity of individual economic sectors, and comprehensible mechanisms for decision-makers. These measures will help in handling the times of natural gas and other energy sources' disruptions and shortages, assessing their criticality, and reducing dependencies.

The study's limitation concerns a national and thus regional limited context. Although the simulation does not consider available storage volumes in the natural gas network, the interdependencies of sectors were drastically shown – irrespective of the gas usage. In this study, the industries and companies identified by their consumption of natural gas were aligned and demonstrated by their individual significance and systemic importance. Yet, a comprehensive evaluation of natural gas dependency and criticality necessitates additional factors. Future research might delve into this issue as at present, the criticality of a company is primarily determined by its industry's criticality.

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