Challenges in Measuring Security of Supply in Changing Electricity and Natural Gas Systems

By Samarth Kumar, Dirk Hladik and Philipp Hauser

INTRODUCTION

Ensuring Security of supply (SoS) in the energy sector is an important goal for policymakers as a shortfall can have significant societal and economic implications. On the one hand, the promotion of renewable energy sources (RES) in energy systems leads to a fluctuating power production in electricity systems and increases the importance of flexible conventional generation capacities, e.g., natural gas (NG) power plants. On the other hand, to reduce CO_2 emissions there is a need to decarbonize the energy system. Technologies like power-to-gas try to link the electricity and NG sector. These developments bring new challenges to measuring SoS, e.g.:

- fluctuating electricity production
- uncertain development of NG demand
- balancing uncertainties due to the linkage of NG and electricity systems

However, SoS itself is an umbrella term used to cover a broad range of issues to ensure uninterrupted and economic supply of energy for end utility. Against this backdrop, this paper attempts to structure different drivers for SoS. In order to increase the share of RES in the entire energy system, sector coupling is being promoted. We also look at what this could entail for measuring SoS.

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CLASSIFICATION OF SECURITY OF SUPPLY DRIVERS

The future SoS in energy system is strongly impacted by developments in many dimensions: politics, technology, markets, environment, etc. Some of these developments can be quantified by using historical data and probabilities. If it is possible to do so, we call them risks. For other developments, it might not be possible to quantify them, as there exists no probability of occurrence or assessment of consequences. Hence, we call them uncertainties. Figure 1 shows the classification of the terms *uncertainty, systematic risk* and *specific risk* that can be used to cluster drivers for the assessment of the future level of SoS.

Both uncertainties and risks influence the future performance of SoS of an energy system. An example for *uncertainties* is policy decisions concerning regulation or climate change effects. A common methodology to assess the future level of SoS taking uncertainties into account is creating scenarios that depict ranges of developments. The model results should not be interpreted as a forecast for future, rather they give an idea of cause-and-effect relationships in complex energy systems.

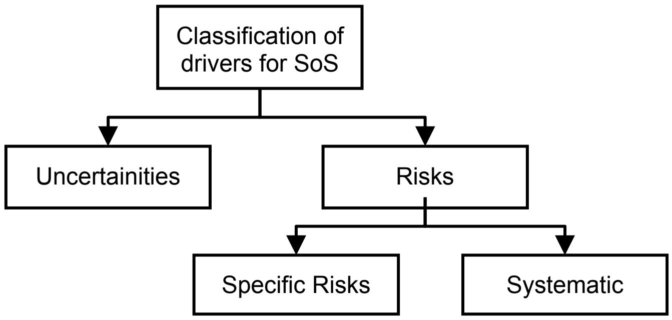

Figure 1: Classification of SoS drivers (own illustration)

In contrary, the usage of *risks* in energy models enables decision-makers to quantify the impact of their measures. In our classification, we distinguish between two kinds of risks. The first group is clustered in *specific risks* that summarize event related risks and occurs e.g., in case of a single event. In some publications, this risk is also called unsystematic risk as it is individual for each player in the market. In general, specific risk refers to risk originating from a particular condition, event or incident.

The second kinds of risks are grouped as *systematic risk*. In finance, systematic risk is also known as the market risk that influences all market participants. Using this definition, systematic risk also occurs in energy systems; e.g., a systematic risk in natural gas markets could be a decreasing NG demand that influences traders, importers and producers simultaneously.

The next step of our analysis is to investigate indicators that enable modellers to quantify specific and systematic risks. In the academic literature there exist a large number of overviews that focus on SoS indicators (e.g., Jansen et al. (2004), Kruyt et al. (2009), Ang et al. (2015)). Due to multi-dimensionality and the broad scope of SoS, it is not possible to create a strict allocation of risk and uncertainties to indicators and vice versa. Rather, the risk classification and the indicators used depend on the stage of the energy chain and the intended use of the indicators. Hence, this classification also renders itself to interpretations. For example, what might be classified as a specific risk for the gas market, might be considered a systematic risk for the electricity market. This flexibility also enables developing understanding of how risks are perceived by different players. This method of classification helps in clarifying the type of risk and the kind of intervention needed for mitigation of the same.

DRIVERS FOR SECURITY OF SUPPLY IN ELECTRICITY AND GAS SYSTEMS

Electricity Markets and Grids

In the context of rising RES generation shares, nuclear phase-out in Germany as well as liberalised and increasingly connected electricity markets in Europe, new challenges for maintaining a high level of electricity SoS arise. Additionally, the interactions between electricity markets (markets) and electricity grids (grids) are complex and thus there are a number of common risks which we would like to highlight in this section. Central aims of that relationship are on the one hand the physical grid ability to fulfill the market results and on the other hand the provision of market price signals for appropriate spatial generation capacity investments in order to optimally use existing transmission capacities. Regarding the grids, generation adequacy should be able to measure the overall adequacy of the system covering congestions, voltage drops and frequency problems of the grid.

Uncertainties for the markets and grids are often related to policy and regulation developments as well as societal or even climate issues. The following exemplified uncertainties might be considered:

- Extreme weather condition due to climate change (markets and grids)
- Regulatory and government policies (markets and grids)
- Technological breakthrough (markets and grids)
- Impacts of future market coupling activities (markets and grids)
- Delays in grid enforcement projects due to technical reasons or public unacceptance (grids)
- Inappropriate market zones with high spatial imbalances leading to internal congestions (grids)

These uncertainties are hard or nearly impossible to quantify for the future due to limited available data. Hence, they are often treated with scenarios and appropriate sensitivities or cases analysis (Poncela-Blanco et al., 2016). Scenarios are often depicted through the share of RES in the energy mix, demand or efficiency development paths, decommissioning of certain power plants or radical penetration of a particular technology. For example, to model impacts from policy changes different policy scenarios are deployed for instance the EUCO scenarios from the European Commission (EC) to consider different energy efficiency targets (EC, 2017).

Besides uncertainties, it is important to consider *systematic risks in electricity systems*. These risks occur mainly in markets, not in grids, due to the extensive regulation. Systematic risks can emerge from one of the following:

- Missing money
- Fuel supply risk

The missing money problem refers to lack of financial incentives for companies to keep generation capacity operation and/or invest in new required generation capacity. An interruption in fuel supply can affect multiple power plants and hence cause adequacy issues.

The indicators used to measure these systematic risks are not direct measures for SoS but rather proxies to quantify the risk and the change of risk. Commonly used methods to evaluate these indicators are: surveys and collection of market data for the current system and then calculating the value of the indicator using model-based analysis for the future. These risk factors are commonly measured through deterministic indicators for instance the VoLL - Value of Lost load (European Commission EC, 2016), the NEID - net import of energy carrier (Kruyt et al., 2009), the HHI - Herfindahl–Hirschman Index (Sovacool and Mukherjee, 2011) or the electricity prices trend (Winzer, 2012).

Furthermore, there are several *specific risks in markets and grids.* These risks can be quantified with probabilities due to the availability of historical data that can be used to calculate probabilities for the future. The specific risks in the electricity market can originate from following conditions:

- Extreme weather condition and fluctuation in RES (markets and grids)
- Terrorist attacks (markets and grids)
- Planned and unplanned plant unavailability (markets)
- Exceeding thermal limits or other technical restrictions because of high spatial imbalances or human / operational failures (grids)
- Outage or malfunction of technical components (grids)

As opposed to uncertainties, *extreme weather condition* here refers to extreme weather situations as seen in the past. Probabilities for *extreme fluctuation in RES* are derived from long-term weather data collection in high spatial and temporal resolution. *Plant unavailability* can occur due to maintenance (planned or unplanned) or due to exogenous factors like *terrorist attacks* etc. The mentioned specific risks for the grids are often encountered by preventive operational measurements like considering security margins for thermal limits or employing the n-1 criterion. However, these risks are getting more important in the future because of further increasing RES-shares, transmission capacity gaps and integrating new electricity users, e.g., e-vehicles and heating pumps, that could also bring further volatility into the system.

All of these risk drivers can result in supply interruptions either due to lack of capacity to meet the load under a certain set of conditions or inability to match the change in the demand with changes in the supply. Since these kinds of risks can be geographical- or country-dependent, cross border flow can play a critical role in ensuring SoS but may also lead to unintended loop flows which can cause new challenges. In general, we can sum up that all of these factors lead to a higher level of stochasticity in the system, mainly driven by the RES share. Hence, it becomes important to assess these risks using probabilistic approaches. Probabilistic approaches commonly used can be categorised into two types: analytical and Monte Carlo simulations. Typical probabilistic indicators are the Loss of load probability (LOLP), the Energy not Served (ENS), Energy index of reliability (EIR resp. P95) (EC, 2016) or the Total Loss of Power (TLP) (Poncela-Blanco et al., 2016).

Gas Market and Gas Networks

As Germany and Europe have limited NG resources the European energy sector depends on reliable NG imports from non-European suppliers, e.g., Russia, Algeria and Qatar. NG is used for both sectors, power and heat. Additionally, it is used as raw material in the chemical industry, e.g., for producing hydrogen. Following the liberalization process in the electricity system in Europe, the unbundling of market actors leads also to an uncertainty of regulation. Against this backdrop, the awareness of SoS in NG markets is very high in European energy policy in order to ensure a stable electricity system, the production of heat for households in cold winter days and uninterrupted industry processes. There are several risks and uncertainties for the NG system that endanger the SoS. According to our definition, the following are the examples of *uncertainties in NG systems*:

- geopolitics
- resource deposits
- climate change

The following are the examples of *systematic risks*:

- NG price developments
- development of world NG demand

and finally, examples of *specific risks*

- The shortfall in NG supply
- terrorist attacks on critical infrastructure

As with electricity systems, there are several studies that investigate uncertainties in the NG markets. Due to a lack of probabilistic data, many studies use scenarios to cover uncertain paths. A popular application is the assessment of resources, e.g., recent analysis investigates the resource deposits of shale gas in Europe (cf. Riedel et al., 2017). Furthermore, transport conditions in the context of geopolitical strategies are subject to a variety of uncertainties. While Hecking et al. (2015) and Richter & Holz (2015) analyzed different scenarios according to time and volume of interruption price reaction, stress tests were modelled by the European Commission (2014). Systematic risks to geopolitics are addressed by Berk et al. (2017) who analysed Turkey's role in NG systems. Also, Dieckhöner (2012) analysed different pipeline projects to ensure the supply to Europe. The development of NG demand is a crucial uncertainty for the coming years and is analysed by Biresselioglu et al. (2015).

Recent efforts in the field of energy system analysis aim to include risks and uncertainties in energy models in order to improve deterministic model approaches and enable more reliable decisions. SoS indicators support these attempts, as they provide an opportunity to quantify risks and uncertainties in NG markets. Up to now, mainly static indicators are applied to asses SoS and diversification. Cabalu (2010) used the indicator *Gas intensity* that describes the ratio of total NG consumed in a region to gross domestic product (GDP) of a region. This measure is interpreted as an index and exists also for other units like electricity, emissions, oil etc. *Net gas import dependency* is an indicator that describes the ratio of net gas imports to the total energy consumption of a country or region. *The Ratio of domestic gas production to total domestic gas consumption* focuses on diversification of gas import sources. A measure to evaluate stability in gas-exporting countries is the calculation of *Geopolitical risk* using a politic rating. These ratings give quantifiable data for selected gas-producing countries and are provided by World Bank's Governance Indicators or the Gas Supply Security Index (GSSI). In general, the availability of data is quite well for calculating these indicators. However, until now these indicators follow a deterministic approach and therefore a need exists to extend these to probabilistic approaches.

RELATION BETWEEN SECURITY OF SUPPLY IN ELECTRICITY AND GAS SECTORS

Some aspects classified as risks or uncertainties that were discussed earlier influence both the electricity and gas systems. For example, a cloudy cold period in winter times leads to higher heat and NG demand and lower RES feed in. However, until now, the link between both systems is weak and hence the mutual influence is limited. According to the aim of reducing the usage of fossil primary resources, it is proposed to increase this interaction in the future. Hence, same risk factors (e.g., weather conditions) can influence both systems simultaneously and a coupling could increase the danger of a supply interruption. Thus dealing with a systematic risk in electricity markets, e.g., diversification of fuel supply for power generators, could lead to a specific risk in NG markets, e.g., higher fluctuation of NG demand.

In an energy system that was based primarily on fossil fuels, the flow of energy has been unidirectional. This means the fossil fuels (primary energy as oil, coal or NG) is transformed to final energy as heat or electricity. Figure 2 shows the schematic representation of the energy flow, black arrows show the flow of energy in a system based primarily on fossil fuels, red and green arrow show new flows being created by renewables and sector coupling. Each state can be associated with uncertainties and risks that need to be analysed. In the system based primarily on fossil fuels, the final risk to the disruption of end-utility could be obtained by combining the risks at each stage.

However, with the changing paradigm in energy systems, especially through increasing generation from RES, sector coupling and e-mobility, this unidirectionality would become less valid. As shown in Figure 2 the flow of energy is no longer strictly unidirectional. Energy can enter the system at different stages as in the case of RES connected to distribution grid or rooftop solar. Power to Gas (PtG) is a set of technologies used to convert electricity, primarily at times of high RES generation, to produce fuels like hydrogen or methane. These technologies can result in 'upstream' flow of energy thereby transferring the risks and uncertainties as well. Furthermore, technologies like PtH (Power to Heat) and electric mobility can result in an 'across' sector flow of energy. This results in the more interdependent and interconnected system thereby transferring the risk elements from one sector to another.

As discussed earlier, there is an increasing need to consider stochasticity in the electricity system. Furthermore, sector coupling can result in a spillover effect of stochasticity on security in the gas sector. On the one hand, this might reduce dependence on foreign fuel, thereby decreasing fuel associated risk. On the other hand, the variable nature of RES generation introduces reliability issues. Hence, there is a need to rethink methodologies and indicators used in measuring SoS as the energy system undergoes a transformation to a more interconnected and interdependent system. When analysing energy security in the long-term, researchers and policymakers would benefit from considering a more holistic approach to measuring SoS. As done by Bai et al. (2016), for electricity and NG sector, modellers would benefit from using a combined modelling approach considering different sectors.

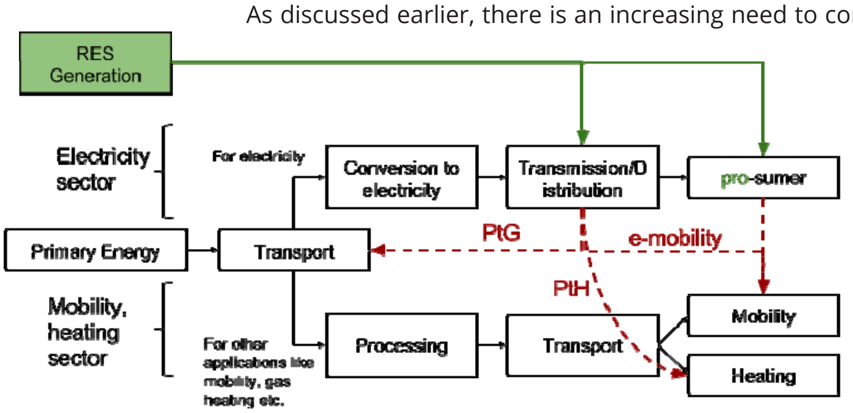

Figure 2: Schematic representation of energy flow (own illustration)

SUMMARY AND CONCLUSION

We started by classifying the different aspects of SoS into specific risks, systematic risks and uncertainties, and applied it to electricity and gas sectors.

In the electricity sector, various sources of uncertainties like political decisions, extreme weather events etc. are recognised. Due to lack of data and inherent unpredictability in these factors, they can only be studied through scenarios. These scenario-based analyses cannot be interpreted as forecasts for the future but rather provide a causal understanding of the uncertainties. Systematic risks occur mainly in the electricity market caused by the missing money problem or fuel supply interruptions. They are often measured indirectly with deterministic indicators. A wide range of indicators can be found for measuring specific risks for the electricity markets and grids. Overall, it is recognised that as a result of an increase in stochasticity in the electricity system, use of probabilistic indicators is becoming more relevant.

In NG systems many efforts aim to decrease risks of supply interruptions and increase the SoS. Beside technical risks, mainly geopolitical uncertainties drive the need to evaluate the SoS in this field. As recent indicators are static and do not cover system dynamics, new indicators are needed that take into account probabilistic aspects.

Finally, we discuss the relation between SoS in gas and electricity sector. Here it is recognised that due to aspects like sector coupling, distributed generation, electric mobility, etc. the unidirectional nature of the measuring SoS is changing. This introduces new challenges in measuring SoS meaningfully. As coupling of energy systems is driven by the fluctuating RES feed in, future works would benefit from considering time dependency and sector coupling.

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