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Modelling the Swiss Gas Market in a European Context

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The author of this report bears the entire responsibility for the content and for the conclusions drawn therefrom. The views expressed in this paper do not necessarily represent those of the SFOE.

Abstract

Natural gas plays an important role in most nations' energy systems especially with regard to the envisioned transition towards a less carbon intensive energy supply. This raises questions about the future development and security of Europe's and Switzerland's gas supply and the role of the restructuring of Switzerland's gas market in this context. Within this research project we evaluate how the Swiss market may evolve taking the potential European market developments into account. To that aim, we develop numerical models addressing the challenges of the European market development and of the Swiss Entry-Exit design debate.

The results for Europe indicate that due to the strong dependency on Russian imports, disruptions during the winter months can lead to load curtailment. Both the projected network extension (Southern Gas Corridor, Nord Stream 2, and new LNG terminals) and a coordinated strategic storage policy can help to reduce this shortage. However, the positive impact of an extended network also depends on the capability of the global gas market to provide flexible gas that can be reallocated towards Europe. The majority of demand curtailment can already by countered by a relatively modest amount of strategic storage (20% to 30%) if their use during crisis situations is coordination across European countries. The diverse model simulations show that the overall supply security for Switzerland is good and likely to remain high for the next decade.

The results of a Swiss model to investigate the possible consequences of an Entry-Exit system introducing regionally differentiated network charges compared to a system of Swiss-wide uniform fees show rather small impacts on prices and quantities. Consequently, the overall European market development, the coordination and connection between Switzerland and Europe, as well as a generally well-regulated network access are more important determinants for the restructuring of the Swiss gas market.

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Acknowledgments

Executive Summary

Natural gas plays an important role in most nations' energy systems, both as a supplier for heat demand – in Switzerland, gas covers about 14% of the final energy demand – and as a source of electrical power. In the context of the transition towards a less carbon intensive energy supply gas is often seen as an essential 'transition' fuel. This raises questions about the future development of Europe's and Switzerland's gas supply. Given the ongoing restructuring process, the projected reduction in indigenous European extraction, and the increased dynamics on the global natural gas market supply security is seen as a central concern. The ongoing Russian-Ukrainian conflict adds to this picture and has set the topic of supply security back on the agenda of the European Commission. In parallel, the Swiss natural gas market is currently facing questions concerning its own future design with an ongoing debate about different options of market openings

Against this background, we address in the present research project the question of how the Swiss market may evolve taking the potential European market developments into account. To that aim, we develop numerical models addressing the challenges of the Swiss and European markets. Given the different regional scope of the above identified aspects, we proceed in a two-step approach.

In the first part of the project, we formulate an optimization model of the European natural gas market, accounting for technical details on the supply side, as well as on the transport sector (both pipeline and LNG) and the storage one. Moreover, we ensure the linkage to the global market via aggregated consumption and production hubs. The model is used to evaluate the supply security of European countries using a set of scenarios of future market developments (i.e. the projected extension of the Southern Gas Corridor and Nord Stream 2), disruption cases (i.e. a Russian import shortage on the Ukrainian pipelines), and policy interventions to enhance supply security (i.e. strategic storage obligations and long term contracts).

The results indicate that the existing pipeline and LNG infrastructure in Europe and the expected increase in global gas production are sufficient to compensate the reduction in indigenous European gas extraction. However, given the strong dependency on Russian imports, the projected extension in terms of LNG terminals and the Southern Gas corridor are not sufficient to completely eliminate the threat of demand curtailments in case of Russian supply shocks during winter months. The extent to which Europe is able to counter supply shortages strongly depends on the capability of the global gas market to provide flexible gas that can be reallocated towards Europe.

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Policies based on a strategic storage obligation seem a cost-efficient method to meliorate supply security. A relatively modest amount of strategic storage of 20% to 30% already allows to cover the majority of demand curtailment for a four-month Russian supply shortage. However, to achieve an efficient crisis management, coordination across European countries is essential. As the storage capacity in relation to demand varies greatly across European countries, it is crucial to ensure collaboration among neighbors.

The overall supply security for Switzerland is good and likely to remain high for the next decade. In the diverse model simulations, Switzerland was never subject to critical demand curtailments. However, as Switzerland is not part of the European Union, cannot rely on domestic gas production, and does not possess own storage facilities, it should ensure a close linkage to secure access in critical situations. On the other hand, around 30% of the natural national gas consumption is made up by dual-fuel customers, which provides flexibility to the Swiss gas system.

In the second part of the project, we address the specific situation of the Swiss market. We design a model of the Swiss market representing the four main network areas and Swiss cross-border connections. We then use our model to investigate the possible consequences of an Entry-Exit system in Switzerland introducing regionally differentiated network charges compared to a system of Swiss-wide uniform fees. The results show rather small changes on price levels and quantity allocations. Owing to limited availability of data, the analysis is restricted to a highly stylized representation of the Swiss gas market. Whether the introduction of an Entry-Exit system would lead to local network constraints or problems during high demand conditions can therefore not be identified.

Given the limited impact of different Entry-Exit designs on market dynamics and the fact that network charges are small compared to wholesale prices, it is also likely that the overall European market development will have a bigger impact on the Swiss natural gas market dynamics. To that extent, the connection with Europe, a well-regulated network access, and incentives for consumers to switch suppliers are likely to be more important determinants for the restructuring of the Swiss gas market.

The results from the different scenario assessments lead to three basic implications for the Swiss natural gas policy. First, as the supply security assessments do not show a particular problem for Central and Western Europe, with respect to a Russian supply shock, there is no need for immediate action beyond the already projected reverse-flow extension of the *Transitgas* pipeline. Switzerland should maintain close contact with the EU to ensure a good cooperation in case of supply shocks.

Second, the different supply security assessments also indicate that a simple static evaluation method is insufficient to capture all the underlying dynamics. The stress tests conducted within the European Energy Security Strategy (European Commission, 2014a) and the risk scenario assessment by the ENTSO-G are already solid approaches in this regard, in particular in representing supply side dynamics. However, they usually fall short in obtaining the full market interactions, as they neglect the responsiveness of demand. Europe and Switzerland should therefore combine the more technical security assessments with global market assessments to obtain the needed linkage between both aspects.

Third, the opening of the Swiss natural gas market towards more competition will require a consistent market design. An Entry-Exit system is a well-fitting approach for network access and also in line with ongoing European developments. Yet, the question of its design (i.e. whether there is a uniform Entry-Exit fee or more zones) is likely not the main aspect for a successful market restructuring. The price impact of different network charges compared to the wholesale price level and the overall market dynamic is relatively minor. To transform the current market into a competitive framework, open for new entry and adaptable to new market developments, it will be crucial to have a solid network regulation that prevents cross-subsidies and ensures discrimination-free access to the network.

Zusammenfassung

Erdgas ist für die meisten Staaten ein wichtiger Energieträger, insbesondere zur Deckung des Wärmebedarfs und in der Stromerzeugung. In der Schweiz deckt Erdgas 14% der Endenergienachfrage, wobei die Haushalte mit rund 40% des Gaskonsums und die Industrie mit ca. 35% die grössten Anteile haben; die Stromerzeugung mit Erdgas ist in der Schweiz aktuell vernachlässigbar. Aufgrund der Zielstellung in der Schweiz und Europa die energiebedingten CO_2 Emissionen zu reduzieren, wird Erdgas wegen seiner geringen CO_2 Intensität und wegen seiner, im Vergleich zu anderen fossilen Brennstoffen, hohen Einsatzflexibilität häufig als wichtiger ‚Übergangsbrennstoff' angesehen. Entsprechend ist die mögliche Entwicklung der Erdgasmärkte und der Versorgungssituation der vollständig von Importen abhängigen Schweiz ein wichtiger Aspekt für die Schweizer Energiestrategie. Vor dem Hintergrund der Restrukturierung europäischer Märkte, den globalen Marktdynamiken um Shale Gas in den USA, den Nachfrageentwicklungen in Asien, sowie dem Konflikt zwischen Russland und der Ukraine ist Versorgungssicherheit von zentraler Bedeutung.. Zudem wird in der Schweiz aktuell über ebenfalls über eine Restrukturierung und Öffnung des Gasmarktes debattiert.

Vor diesem Hintergrund untersucht dieses Projekt zwei Themenaspekte. Erstens werden die Entwicklung der europäischen Erdgasversorgung und die daraus resultierenden Rückwirkungen auf die Schweiz analysiert. Zweitens wird die Schweizer Debatte zur Restrukturierung und Öffnung des Gasmarktes aufgegriffen und eine Abschätzung möglicher Auswirkungen erarbeitet.

Für den ersten Themenblock wird ein Modell des europäischen und globalen Erdgasmarktes entwickelt. Das Modell bildet Produktion, Transport (sowohl via Pipeline als auch Flüssiggas (LNG)), Speicherung und Verbrauch auf nationaler Ebene in Europa sowie aggregierter Ebene für nichteuropäische Gebiete ab. Mittels einer Szenarioanalyse werden dann unterschiedliche Netzausbauvarianten (Southern Gas Corridor, Nordstream 2), Versorgungsunterbrechungen (Russland-Ukraine) und mögliche Strategien zur Verbesserung der Versorgungssicherheit in Krisensituationen (Speichermanagement, langfristige Verträge) simuliert und analysiert.

Die Modellergebnisse zeigen, dass die existierende Netzinfrastruktur sowie die geplanten Ausbaumassnahmen ein generell hohes Versorgungsniveau sicherstellen und die Importmöglichkeiten den Rückgang der europäischen Produktion ausgleichen können. Allerdings besteht weiterhin eine hohe Abhängigkeit von russischen Importen –

insbesondere in Osteuropa – welche auch mit den geplanten Ausbaumassnahmen (neue LNG Terminals und der Southern Gas Corridor) nicht vollständig ausgeglichen werden kann.

Im Falle einer Unterbrechung der russischen Importe kann es daher auch weiterhin zu Versorgungsengpässen kommen. Ob und wie Europa darauf regieren kann hängt dabei jedoch auch sehr stark von den globalen Marktdynamiken ab: wenn global nur unzureichende Gasmengen verfügbar sind, welche in Krisenzeiten nach Europa umgeleitet werden können, helfen zusätzliche Importkapazitäten in Europa nur bedingt. Es ist daher wichtig nicht nur die technischen sondern auch die marktlichen Möglichkeiten und insbesondere das in Krisenzeiten verfügbare Gasangebot abzubilden.

Entsprechend der Modellergebnisse ist eine strategische Speichervorsorge eine kosteneffiziente Strategie, um Versorgungsengpässen begegnen zu können. Mit einer strategischen Speicherreserven von 20% bis 30% des Gesamtspeichervolumen könnte ein viermonatiger Versorgungsunterbruch der Russisch-Ukrainischen Verbindung grösstenteils kompensiert werden. Aufgrund der unterschiedlichen geografischen Verteilung des Speicherstätten in Europa, erfordert dies allerdings eine gute Koordination innerhalb Europas.

Für die Schweiz ist die Versorgungssituation gut und entsprechend der Szenarien auch weiterhin gewährleistet. In keinem der Modellläufe kam es zu Versorgungsunterbrüchen in der Schweiz. Da die Schweiz jedoch nicht Mitglied der EU ist und weder über eigene Produktion- noch Speichermöglichkeiten verfügt, sollte sie eine enge Koordination mit der EU sicherstellen. Da ca. 30% der nationalen Gasnachfrage durch Zweistoffkunden (z.B. Erdgas- und Ölbefeuerung möglich) erfolgt verfügt die Schweiz jedoch auch über ein gewisses eigenständiges Flexibilitätspotential.

Im zweiten Themenblock wird die aktuelle Debatte über mögliche Ausgestaltungen einer Marktöffnung und die Implementierung eines Entry-Exit Systems in der Schweiz analysiert. Hierfür wird ein vereinfachtes Schweizer Marktmodell entwickelt, welches die vier Schweizer Netzgebiete sowie die Grenzübergänge abbildet. Mit dem Modell werden anschliessend differenzierte und einheitliche Netzzugangsgebühren analysiert. Dabei zeigen sich nur geringfügige Auswirkungen auf die die Marktergebnisse in der Schweiz. Allerdings ist aufgrund der sehr aggregierten Modellstruktur und der Nichtverfügbarkeit detaillierter Netzdaten die Aussagekraft des Modells limitiert. Ob die Einführung eines Entry-Exit Systems in der Schweiz zu Netzengpässen oder Probleme während Spitzenlastzeiten führen könnte, kann daher nicht abschließend beantwortet werden.

Die Ergebnisse der verschiedenen Modelluntersuchungen erlauben drei generelle Rückschlüsse für die Schweizer Erdgaspolitik. Erstens zeigen sich bei einer Unterbrechung der Russischen Importe keine gravierenden Versorgungsprobleme in Zentral- und Westeuropa. Daher sind keine weiteren Massnahmen zusätzlich zu den bereits geplanten Projekten (das Reverse-Flow Konzept für die Transitgas Leitung) erforderlich, um die Versorgungssicherheit in der Schweiz sicherzustellen. Allerdings sollte die Schweiz einen engen Kontakt mit der EU sicherstellen.

Zweitens zeigen die verschiedenen Versorgungssicherheitsanalysen, dass eine einfache statische Analyse oder auch eine auf rein technischen Parametern und Strukturen beruhende Analyse unzureichend ist, um die Dynamik während Krisenzeiten ausreichend abzuschätzen. Der Stresstests im Rahmen der Europäischen ‚Energy Security Strategy' (European Commission, 2014a) und die Risikoszenario-Bewertung durch die ENTSO-G sind diesbezüglich bereits solide Ansätze, insbesondere im Hinblick auf die Darstellung der angebotsseitigen Dynamik. Allerdings spielen auch nachfrageseitige Dynamiken und handelsbezogenen Marktmöglichkeiten eine wichtige Rolle. Die Schweiz sollten daher technischen Sicherheitsbewertungen mit einer globalen Marktbewertung kombinieren, um die erforderliche Verknüpfung beider Aspekte und damit eine umfassende Versorgungsanalyse zu gewährleisten.

Drittens erfordert die Öffnung des Schweizer Erdgasmarktes ein konsistentes Marktdesign. Ein Entry-Exit System scheint dafür ein gut geeigneter Ansatz zu sein und ist zudem in Einklang mit den Entwicklungen auf den europäischen Nachbarmärkten. Die genaue Ausgestaltung der zonalen Struktur des Entry-Exit Systems (eine oder mehrere Preiszonen) ist dabei jedoch wahrscheinlich nur von untergeordneter Bedeutung; die Preisauswirkungen verschiedener Konfigurationen sind im Vergleich zu den Grosshandelspreisen und europäischen Marktdynamiken vernachlässigbar. Die allgemeine Ausgestaltung der Netzregulierung, welche den Zugang regelt und Quersubventionierung verhindert, ist wahrscheinlich ungleich wichtiger für eine erfolgreiche Marktöffnung.

Résumé

Le gaz naturel joue un rôle déterminant dans les systèmes énergétiques de la majorité des nations, à la fois comme combustible dans la production de chaleur – en Suisse, le gaz couvre 14% de la demande finale d'énergie – et comme source de génération d'électricité. Dans le contexte d'une transition énergétique visant un approvisionnement en énergie moins intensif en carbone, le gaz est souvent vu comme un combustible de « transition ». Ce rôle soulève la question des développements et évolutions de l'approvisionnement en gaz en Suisse comme en Europe. Dans un contexte où la production européenne de gaz est prévue en baisse dans le futur et au vu des changements rapides sur le marché mondial du gaz, la question de la sécurité de l'approvisionnement en gaz est centrale. Le conflit entre l'Ukraine et la Russie a récemment renforcé les craintes dans ce domaine, remettant la question de la sécurité de l'approvisionnement au cœur de l'agenda de la Commission européenne En parallèle, la Suisse s'interroge actuellement sur une possible restructuration de son marché du gaz en menant différents débats autour de scénarios d'ouverture du marché.

Dans ce contexte, la présente étude s'attache à la question des perspectives de développement du marché suisse du gaz en relation avec celles du marché européen. A cet effet, nous développons des modèles numériques qui tentent d'adresser quelqu'une des grandes questions qui entourent les marchés suisses et européens. Vu l'ampleur du projet, nous optons pour une approche en deux temps.

Dans la première partie du projet, nous formulons un modèle du marché européen du gaz naturel basé sur des techniques d'optimisation. Le modèle prend en compte des détails techniques de la production, du transport (pipeline et GNL) et du stockage du gaz. De plus, nous assurons le lien avec le marché gazier mondial par une représentation schématisée des principaux hubs de consommation et de production. Le modèle est utilisé pour évaluer la sécurité de l'approvisionnement en gaz des pays européens à travers l'étude d'une série de scénarios de développements du marché (p.ex. : l'extension projetée des pipelines du Southern Gas Corridor ou du Nord Stream 2), des scénarios de crises gazières (p.ex. : avec l'interruption des livraisons entre Moscou et Kiev) ainsi que des politiques publiques visant à améliorer la sécurité de l'approvisionnement (p.ex : une réserve stratégique obligatoire de gaz ou contrats spécifiques à long terme).

Les résultats des simulations indiquent qu'au niveau européen le réseau existant de pipelines et l'infrastructure GNL semblent suffisants pour compenser la réduction attendue de production indigène de gaz. Néanmoins, au vu de la forte dépendance de l'Europe envers le gaz de Russie, les extensions prévues (nouveaux terminaux GNL ou Southern Gas

Corridor) ne semblent pas permettre d'éliminer complètement tous les risques de pénurie de gaz dans le cas d'une interruption des livraisons russes en hiver. L'Europe est tributaire du marché mondial et de sa capacité, ou non, à fournir du gaz de manière flexible pour contrer d'éventuelles pénuries.

Les simulations indiquent que des politiques publiques instaurant une obligation de stockage stratégique semblent une méthode efficace et efficiente pour améliorer la sécurité de l'approvisionnement gazier. Une réserve obligatoire fixée à 20% ou 30% des capacités de stockage permet, par exemple, de garantir l'approvisionnement en gaz malgré une interruption des livraisons à travers le canal Russie – Ukraine durant quatre mois. Il est à relever que, pour obtenir une bonne gestion de la crise, une excellente coordination des pays européens est essentielle. Les capacités de stockages étant réparties de façon hétérogène en Europe, il est crucial que les pays voisins puissent collaborer solidairement.

A l'échelon suisse, la sécurité de l'approvisionnement semble bonne et il est probable qu'elle le reste durant la prochaine décennie. A travers les différentes simulations effectuées, la Suisse ne s'est jamais retrouvée dans une situation où la demande nationale n'aurait pu être satisfaite. Il est néanmoins à noter que, la Suisse n'étant pas membre de l'Union européenne, étant entièrement dépendant des imports et ne possédant pas d'infrastructure propre de stockage, il est crucial pour le pays d'assurer sa bonne relation et intégration dans le réseau européée. La Suisse possède également un avantage en cas de situation critique, puisque 30% de sa demande en gaz est constituée de clients bi-combustibles, ce qui confère de la flexibilité au système.

Dans la deuxième partie du projet, nous analysons plus spécifiquement la Suisse en mettant sur pied un modèle représentant le marché suisse du gaz, ses quatre principales zones de réseau et son interconnexion avec ses voisins. Nous utilisons ensuite ce modèle pour étudier les possibles conséquences d'une introduction d'un système Entry-Exit, comparant notamment l'utilisation de charges de réseau propres à chaque région à celle de charges uniformes pour l'entier du pays. Les résultats indiquent qu'un tel système semble avoir un faible impact sur les niveaux de prix et sur la demande. En raison du peu de données disponibles, notre analyse est limitée à une représentation très schématique du marché suisse. La question de savoir si l'introduction d'un système Entry-Exit pourrait avoir de possibles conséquences sur les réseaux locaux, notamment en termes de congestion du réseau durant des périodes de forte demande, n'a pas pu être étudiée.

Partant du faible impact des différentes formulations du système Entry-Exit sur les dynamiques de marché et du fait que les charges de réseau soient relativement faibles en

comparaison des prix du marché de gros, il parait probable que les développements du marché gazier européen aient un plus grand impact sur le marché suisse du gaz. Dans ce contexte, l'interconnexion avec l'Europe, un accès au réseau garanti et régulé ainsi que des incitations aux consommateurs pour qu'ils profitent des opportunités offertes par une libéralisation sont des facteurs potentiellement plus impactant de la restructuration du marché suisse.

Trois implications concrètes pour les politiques gazières suisses semblent émerger des résultats des différentes études de cas. Premièrement, comme les évaluations de sécurité de l'approvisionnement n'indiquent pas de problème particulièrement criant pour l'Europe de l'Ouest et centrale en cas de crise gazière russe, il ne semble pas y avoir de mesures urgentes en termes d'infrastructure au-delà de la poursuite du développement du réseau, notamment le projet de « reverse flow » sur le pipeline Transitgas. La Suisse devrait s'assurer d'une proche connexion avec l'UE pour garantir une bonne coopération en cas de crise.

Deuxièmement, les analyses de sécurité de l'approvisionnement indiquent que de simples évaluations statiques sont insuffisantes pour capturer et représenter l'ensemble des dynamiques du marché. Les stress tests conduits dans le cadre la Stratégie européenne pour la sécurité énergétique (European Commission, 2014a) et les évaluations de risque de l'ENTSO-G sont des approches solides, notamment dans leurs représentations détaillées de l'offre. Néanmoins, elles sont souvent insuffisantes pour représenter l'ensemble des interactions du marché, puisqu'elles négligent l'adaptabilité de la demande. L'Europe et la Suisse devrait ainsi combiner les analyses techniques de sécurité de l'énergie à des évaluation plus globales du marché pour s'assurer une bonne évaluation des deux aspects. Troisièmement, l'ouverture du marché suisse du gaz à la concurrence requiert un choix cohérent de ses modalités d'organisation. Un système Entry-Exit semble une méthodologie adaptée pour assurer l'accès des tiers au réseau. De plus, ce système est en phase avec la pratique européenne en la matière. Néanmoins, il est à signaler que les modalités de son implémentation (par exemple la question de charges de réseau uniformes ou zonales) semblent n'être qu'un critère de succès parmi d'autre. L'impact des charges de réseau sur les prix finaux et les dynamiques de marché semblent n'avoir qu'un impact relativement mineur. La bonne régulation du marché, garantissant un accès sans discrimination au réseau et empêchant des subventions croisées sur le marché, est un facteur crucial dans le développement d'un marché compétitif, ouvert et adapté aux développements futurs.

1. Introduction

Natural gas plays a prominent role in most nations' energy systems, both as a supplier for heat demand and as a source of electrical power. Gas is further used in numerous industrial processes. In Switzerland, gas covers about 14% of the final energy demand. In the context of the envisioned energy transition, which shall help nations to comply with stringent climate targets, gas is often seen as an essential 'transition' fuel thanks to its low carbon content and to its flexibility for different applications.

In parallel, the Swiss natural gas market is currently facing questions concerning its future design. The Swiss Federal Office for Energy is currently elaborating a gas supply act. In this context, various options to open and reorganize the gas market are being explored[1]. The law will likely take some more years to materialize. Different options of market opening are up for debate. Regardless of the chosen design, the Swiss gas market is likely to extend the third-party network access – which is currently part of the association agreements ("Verbändevereinbarung") – adding to the general access guarantee via Article 13 of the Swiss Federal Pipelines Act.

Moreover, from a European perspective, three ongoing processes impact the future gas market development: First, the European market is still undergoing a liberalization process leading to the reorganization of European national markets and, therefore, impacts trading within Europe. Second, as numerous European producers slowly exhaust their reserves, Europe is increasingly reliant on imported gas. Last, the globalization of the natural gas market offers a more diversified European supply portfolio, notably through the surge of the liquefied natural gas (LNG) market. At the same time, the increasing worldwide demand and the North American shale gas boom alter international natural gas trade flows.

In addition to open questions on market design and market dynamics, supply security is a major concern for natural gas markets. The ongoing Russian-Ukrainian conflict set the topic of supply security back on the agenda of the European Commission, and potential substitutes for Russian imports are being discussed, notably for the South-Eastern part of Europe. For Switzerland, as the country is completely dependent on imports and is an important transit route between Northern Europe and Italy, the European supply situation also has strong implications.

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[1] See http://www.bfe.admin.ch/themen/00486/00488/06662/index.html?lang=de for further information

Against this background, we address in the present research project the question of how the Swiss market may evolve taking the potential European market developments into account. To that aim, we develop numerical models addressing the challenges of the Swiss and European markets. Given the different regional scope of the above identified aspects, we proceed in a two-step approach.

In the first part of the project, we design a model of the European natural gas market which includes the transmission pipelines, the LNG and the storage system, endogenous European supply, and is linked to an aggregated global gas market. Our model has an aggregated representation with one node per country and a cross-border network topology; it uses welfare optimization and represents a perfectly competitive market. The model endogenously determines supply, demand, imports, and trade flows in Europe. We use the model to evaluate the supply security of European countries highlighting the role of storage to counteract short-term supply disruptions.

In the second part of the project, we address the specific situation of the Swiss market. We design a model of the Swiss market representing the four main network areas and Swiss cross-border connections. We then use our model to investigate the possible consequences of an Entry-Exit system introducing regionally differentiated network charges compared to a system of Swiss-wide uniform fees. Given the limited data availability for the Swiss gas network, the analysis represents a highly aggregated assessment, and is thereby focused on the basic effects resulting from the introduction of an Entry-Exit system.

Three scientific papers are based on the main results obtained within this project. The first paper focuses on the European model and market assessment. The second paper tackles in detail the question of supply security indicators and proposes a novel methodology, which is suitable as an evaluation tool to compare different policy or infrastructure approaches. The last paper provides the assessment of the Swiss market.

The report at hand summarizes the insights of these three papers. It is structured as follows: chapter 2 presents our assessment of the European market which focuses on a comprehensive evaluation of the overall supply security and combines the content of the first two papers. We conclude the chapter by summarizing the results and highlighting their implications in the particular Swiss context. Chapter 3 then presents the model of the Swiss market used to analyze the proposed Entry-Exit systems. Finally, chapter 4 summarizes the findings of both project parts formulating key policy conclusions.

2. Switzerland within the European Natural Gas Market: Market Developments and Supply Security[2]

Switzerland's gas market faces a peculiar situation. As the country has no domestic resources, imports have to cover the entire demand leading to a strong dependency on European market trends. In addition, the absence of large-scale gas storage facilities leads to a similarly important interrelation in case of supply shocks or other critical system conditions. This background raises the question of whether Switzerland is likely to face severe supply problems in the coming years. On the positive side though, one must note that around 30% of the Swiss gas consumption is made up by dual-fuel users, who are less sensitive to gas shortages.

Given this context, the present study seeks to address the aforementioned question by developing a numerical model of the European natural gas market dedicated to analyze possible future developments and different security of supply assessments. Specifically, we simulate projections of the European natural gas market in 2030 and study how supply security is affected by major infrastructure projects (additional pipelines, new LNG terminals) and storage policies.

The remainder of this chapter is structured as follows. In the next section a short literature review provides an overview on recent discussions on supply security in the European natural gas market. Section 2.2 then describes the developed model and its parametrization. Subsequently, a three-stage assessment is provided: first, we sketch general future market developments to provide a reference for the supply security evaluations; second, we perform a case study on the disruption of Russian supplies with a special focus on storage; third, a more comprehensive assessment of Europe's supply security is provided. Section 2.6 summarizes and concludes.

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[2] This Chapter is based on two research papers: Abrell, J., Chavaz, L., Weigt H. (2018) 'Infrastructure and policy – Dealing with supply disruptions on the European natural gas market' and Abrell, J., Chavaz, L., Weigt H. (2018) 'Assessing the supply security - A compound indicator' available on the project webpage, see https://fonew.unibas.ch/de/projects/

2.1. Introduction

Disruptions in natural gas deliveries have become a prominent concern in Europe. As natural gas reserves are geographically concentrated in a few countries and since its supply is vulnerable to network constraints, the market is exposed to supply insecurity. Furthermore, recent geopolitical events have exacerbated this concern. These events notably include the disputes between Russia and Ukraine in 2006 and 2009, as well as the political and economic sanctions imposed by the European Union (EU) against Moscow in response to the Ukrainian crisis in 2014. With more than 15% of the gas consumed by Europe transiting through Ukraine (IEA, 2015a), the relation between Eastern Europe and Russia is crucial for the European energy security.

Against this background, the European Union launched the Energy Security Strategy (EC, 2014b) seeking to achieve a twofold goal: first, ensuring short-term resilience of the natural gas network in cases of supply interruption and, second, reducing the dependency on unstable routes and suppliers in the long term. The development of the European pipeline and LNG infrastructures is one of the key measures to achieve a secure supply. In parallel, Moscow aims at reducing its own dependency on Ukraine for its exports towards Europe, thus promoting alternative infrastructure projects.

Numerous studies evaluate supply security of energy markets and, in particular, the European natural gas market. Richter and Holz (2015), for instance, investigate two short and one long-term Russian export disruption scenarios using the Global Gas Model (developed by Egging et al., 2010 and Holz et al., 2013, see below). They highlight the importance of LNG to replace Russian imports, and identify the most important pipeline extensions to secure the European supply. Dieckhöner et al. (2013) use the TIGER model (Lochner, 2011) to evaluate different demand and infrastructure scenarios, in particular the Nord Stream 2 and the Nabucco pipeline. They conclude that, despite remaining bottlenecks in the system, the European natural gas market will be well integrated by 2019. Paltsev (2014) analyzes possible developments of Russian gas exports until 2050 using the EPPA model, a computable general equilibrium model of the world economy. Regarding exports to Europe, he states that the need for additional pipeline connections is only justified by a Russian diversification of export routes reducing its dependency on Belarus and Ukraine.

Stress tests imposed by the European Energy Security Strategy accompany these studies. These tests quantify the impacts of (short-term) supply disruption of either Ukrainian routes or Russian exports in total for a duration of one or six months (European Commission, 2014a). The related report underlines the large share of demand which cannot be satisfied in

the most severe scenarios, notably in Eastern Europe. As a conclusion, the Commission suggests additional measures to enhance the security of supply (SoS) focusing among others on network enhancement, storage optimization, and, in particular, the need for storage usage coordinated across member states.

In addition, ENTSO-G recently published the first European Union-wide study on the simulation of gas supply and infrastructure disruption scenarios. The study is based on a detailed technical model of the European gas system. They identify 17 risk scenarios for the European gas system. Their results underline some of the main dependencies in Europe, e.g., the vulnerability of Bulgaria, Romania and Greece to a disruption of the Russia-Ukraine route or the weakness of Finland and the Baltic states to interruption of Russian supplies.

The present study embeds into the above-mentioned references analyzing disruptions of Russian gas supply. We then develop a more systematic SoS indicator summarizing technical and political risks of supply disruptions.

2.2. Model and Data

We develop a numerical model representing the European natural gas market embedded into the global market to assess potential developments and evaluate its supply security. The present research effort draws on an abundant literature studying natural gas systems. We use a partial equilibrium framework to represent the behavior of different actors. The model comprises technical details of the production sector, natural gas storage, and the transmission system including the pipeline and LNG transport system. Furthermore, industry and household demand is separately modeled.

In the following section, we shortly present the mathematical model structure and the underlying dataset.

2.2.1. Model Formulation

Our model is based on partial equilibrium settings that we subsequently reformulate as a welfare optimization problem. We notably draw on Abrell and Weigt (2012), Egging et al. (2010) and Neumann et al. (2009) for our model formulation. The resulting model is furthermore related to other European gas models, i.e. the NatGas (Zwart and Mulder, 2006) and TIGER (Lochner, 2011) models (see Holz (2009) for a detailed review of optimization, equilibrium or other classes of models applied to the natural gas market).

The model depicts the action of the various market participants along the natural gas supply chain:[3]

- **Producers** extract natural gas, and sell it on the wholesale market given extraction costs and production capacity constraints.

- **LNG operators** buy natural gas in a country which possesses liquefaction infrastructure, transport it overseas on a carrier and re-sell it to a country with a regasification infrastructure. They are constrained by the liquefaction and regasification capacities of the respective countries.

- **Pipeline operators** transport natural gas across borders accounting for transport costs and capacity restrictions of pipeline.

- **Gas storage** operators arbitrage between different time periods buying and selling gas from and on the wholesale market with capacity constraints on withdrawal, injection and the total amount of storage.

- **Demand:** our model distinguishes between demand for natural gas stemming from the domestic, the industrial and the transformation sectors. Domestic usage of gas is mainly driven by heating, industrial demand by heating and process gas, while the transformation sector uses gas for electricity generation and district heating. All three types of consumers are characterized by distinct demand elasticities.

For the present work, we assume that all market actors are perfectly competitive allowing us to aggregate the overall cost and benefits into a single welfare objective:

$$
\begin{aligned}
max\, W = \\
\sum_t^T \sum_n^N \left[\sum_i^I \left(\frac{1}{2*b_{nit}} D_{nit}^2 - \frac{a_{nit}}{b_{nit}} D_{nit} \right) - \left(\begin{array}{c} \gamma_n^x X_{nt} + \delta_n^x X_{nt}^2 \\ + \sum_{\tilde{n}}^N \left(\frac{c^{liq}}{1-\beta^{liq}} + tc_{\tilde{n}n}^{lng} + c^{reg}\left(1-\beta_{\tilde{n}n}^{lng}\right) \right) FL_{\tilde{n}nt} \\ + \sum_{\tilde{n}}^N tc_{\tilde{n}n}^{pipe} FP_{\tilde{n}nt} + c^{sto} SO_{nt} \end{array} \right) \right]
\end{aligned}
$$

Total welfare is represented by two blocks: The first term represents the gross consumer surplus, defined by the area below the respective demand functions. We assume a linear demand-price relation defined for each of the three sectors *i* (domestic, industry, transformation), country *n* and month *t* of the form: $D_{nit} = a_{nit} + b_{nit} P_{nt}$

The remaining terms reduce this surplus by the costs of production (X), of LNG (FL) and pipeline transport (FP), and of storage (SO). Production costs are defined as a quadratic

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[3] According to the perfect competition premises, all actors take prices as given.

function. LNG costs are composed of liquefaction cost (c^{liq}), route dependent transport cost (tc^{lng}), and regasification cost (c^{reg}) accounting for the related losses of gas (β) needed for the process chain. Pipeline transport is assumed to be subject to a constant cost factor (tc^{pipe}) depending on the pipeline length. Finally, storage is subject to a generic cost factor on the stored gas volume (c^{sto}).

The problem is completed by a set of constraints representing the extraction capacities of producers:

$$\mathbf{cap_n^X \geq X_{nt}}$$

The technical capacities of pipelines:

$$cap_{n\tilde{n}}^{pipe} \geq FP_{nnt}$$

LNG regasification and liquefaction infrastructure:

$$cap_n^{reg} \geq \sum_{\tilde{n}}^{N} (1 - \beta^{reg})\left(1 - \beta_{\tilde{n}n}^{lng}\right) FL_{\tilde{n}nt}$$

$$cap_n^{liq} \geq \sum_{\tilde{n}}^{N} FL_{n\tilde{n}t}$$

Technical restrictions on storage use (injection capacity, withdrawal capacity, and maximal working gas capacity):

$$cap_n^{in} \geq SI_{nt}$$

$$cap_n^{out} \geq SO_{nt}$$

$$cap_n^{sto} \geq STO_{nt}$$

A storage balance further links the current and previous month storage levels:

$$SI_{nt} - SO_{nt} = STO_{nt} - STO_{n,t-1}$$

We define the nodal market clearing as follow:

$$X_{nt} + \sum_{\tilde{n}}^{N} (1 - \beta^{reg})\left(1 - \beta_{\tilde{n}n}^{lng}\right) FL_{\tilde{n}nt} + \sum_{\tilde{n}}^{N}\left(1 - \beta_{\tilde{n}n}^{pipe}\right) FP_{\tilde{n}nt} + SO_{nt}$$

$$= \sum_{\tilde{n}}^{N} FP_{n\tilde{n}t} + \sum_{\tilde{n}}^{N} \frac{FL_{n\tilde{n}t}}{1 - \beta^{liq}} + SI_{nt} + \sum_{i}^{I} D_{nit}$$

This clearing condition represents the basic flow conservation constraint, stating that the quantity of gas produced, imported or taken out of the storage at a node (left hand side) has to be equal to the quantity that is exported, injected into the storage and directly consumed at the node (right hand side). The model also accounts for the gas losses occurring during LNG liquefaction (β^{liq}), regasification (β^{reg}) and transport ($\beta_{n\tilde{n}}^{lng}$) as well as during pipeline transport ($\beta_{n\tilde{n}}^{pipe}$)

Furthermore, the model accounts for long-term contracts between producers and consumers. Albeit a current trend towards a reduction in their duration (see e.g. Neumann and von Hirschhausen, 2015), these contracts still represent an important share of the European gas imports. Neumann et al. (2015) provide the most thorough database on long-term contracts. These bilateral relationships are implemented as minimum exports over the year as follows:

$$\sum_{t}^{Y} FP_{n\tilde{n}} \geq expMin_n^{pipe}$$

where $expMin_n^{pipe}$ represents the yearly amount of export stipulated in the contract. The same is implemented for the LNG exports:

$$\sum_{t}^{Y} FL_{n\tilde{n}} \geq expMin_n^{lng}$$

2.2.2. Model Data

Our model represents the European natural gas market and its transmission system (see Figure 1). European countries[4] and worldwide main producers are represented as single nodes. Non-European countries are aggregated to regional hubs (e.g. South America). Overall, the model covers roughly 98% of the total world production and consumption. The model, thus, allows a focused assessment of the European market, while incorporating the global market dynamics and trends.

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[4] By European countries we mean the following ones: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom

Figure 1: Stylized model representation of the European natural gas system
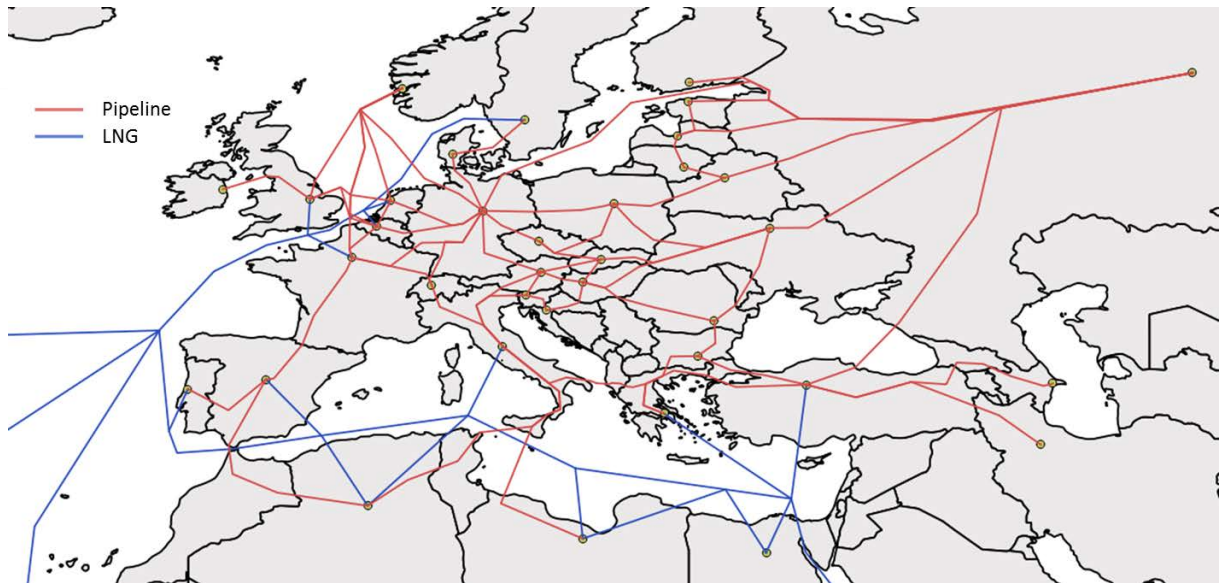
The European cross-border pipeline ***infrastructure*** is derived from ENTSOG (2015), which provides the technical capacity of each pipeline. Multiple pipelines linking two countries are summed to a single synthetic one. The existing European pipeline infrastructure already compromises several reverse flow connections which are included in the respective cross-border connections. The capacities of the future projected pipelines are derived from the respective companies' websites.[5] Eikon (2015) provides comprehensive data on technical characteristics of all regasification and liquefaction plants. Finally, worldwide storage facilities are obtained from Gas Infrastructure Europe (2015a) and Eikon (2015). The cost of pipeline transport are based on OME (2002) and Egging et al. (2008). LNG transport cost are derived from the delivery prices on Eikon (2015), while liquefaction and regasification costs are taken from Cayrade (2004). Assumptions regarding pipeline and LNG losses are found in Neumann et al. (2009) and Egging et al. (2008).

Data on the ***production capacities*** of each country is further required for our model. Since reliable information is hard to come by in this domain, we approximated them based on the production patterns. For the countries for which the monthly production is available on Eurostat (2015) or JODI (2015), we assume that each month's production represents 94% of the respective monthly capacity[6]. For the rest of the countries, it is assumed that capacity is

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[5] Nord Stream: http://www.gazprom.com/about/production/projects/pipelines/ built/nord-stream2/, SGC https://www.tap-ag.com/the-pipeline & https://ec. europa.eu/energy/sites/ener/files/documents/pci_7_1_1_en.pdf
[6] This is a fairly common, yet rather arbitrary practice. As it is difficult to come across reliable data on production capacity, most authors assume the capacity based on past production data adding a margin on top.

constant throughout the year, and that each country's highest monthly output represents its extraction capacity. The extraction cost function is derived from OME (2002), Seeliger (2006) and Egging et al. (2008).

Yearly **consumption** is provided by IEA (2015b). For IEA member states, disaggregated data on consumption of specific sectors is used (domestic, industrial and transformation). For the domestic sector, we generate synthetic monthly profiles by averaging all European countries' domestic consumption patterns, gathered from Eikon (2015). Profiles of transformation users are obtained from Eurostat (2015) and JODI (2015), while industrial profiles are calculated by subtracting domestic and transformation ones from the total demand. For the Non-European regional hubs a single consumption sector is implemented.

The linear demand function is calibrated for each node, consumption sector and month based on historic data. Given a reference point – defined by the monthly demand level and the related average spot price – and an assumption about the demand elasticity in this point the two parameters *a* and *b* for the demand curve can be defined. We assume a price elasticity of demand of -0.2 for the domestic sector, of -0.4 for the industry and of -0.5 for the transformation one.[7] Thus, while the reference point varies for each month the demand elasticity is assumed to be same in each month in this reference point.[8]

As we use a linear demand function the respective elasticity is not constant across the whole demand range. The reference price for this elasticity estimate is based on historic spot prices from nine major European and international trading hubs (e.g. Henry Hub in the USA), which are obtained from Eikon (2015). Daily prices are averaged for each month, and each node is linked to the nearest hub.[9] Countries mostly reliant on LNG exports (e.g. Japan) and not linked to a pipeline trading hub are linked with their regional price of landed LNG, which is also obtained from Eikon (2015). Export countries are assumed to have prices corresponding to the opportunity cost of exporting gas to their main customer.[10]

Compared to the other existing gas models referenced in Section 2.2.1 our model approach shows the following similarities and differences: Like the World Gas Model (WGM)

E.g. Egging et al. (2008) use a 10% margin on past data. The 6% in our model are also chosen based on the desire to obtain a close fit of production levels to observed market patterns (see Section 2.2.3).

[7] For the sake of comparison, Egging et al. (2008) use following assumptions: 0.25 for the residential sector, 0.4 for industrial demand and 0.75 for power generation

[8] Given the linearity assumption the elasticity in a given point of the demand curve is defined by $\varepsilon_i = P_{nt}/b_{nit}D_{nt}$. Given the reference price P^{ref} and the reference Demand D^{ref} the slope b can be calculated for a given elasticity level and used to derive the intercept a of the function. As P^{ref} and D^{ref} vary for each also the slope and intercept will vary for each month albeit the elasticity is the same.

[9] Note that despite having the same reference price the different nodes in the model still obtain individual prices representing the national price level in the different scenario runs.

[10] E.g. as Algeria exports a large share of its gas towards Spain, the domestic consumer price in Algeria is assumed to be the one in Spain minus the transport costs to export it from Algeria to Spain.

by Egging et al. (2010) and the TIGER model by (Lochner, 2011) our approach needs to rely on several simplifications. Our depiction of the gas network is similar to the level of detail of the WGM. As we aggregate cross-border pipelines and ignore inner-country pipelines the network representation is inferior compared to the TIGER model. For the supply side, we simplify the formulation of the WGM while preserving its main specifications. We notably aggregate all players into a single representative agent. On the demand side, we use the same formulation as the WGM thereby having a higher detail than the TIGER model. Finally, as we assume perfect competition we transform the equilibrium model structure into an equivalent optimization formulation for computational reasons. Therefore the final model outlet has many similarities to Neumann et al. (2009).

2.2.3. Model Calibration

In order to test the suitability of our model for a scenario assessment of the European market, we compare the results of our simulations to historic market outcomes. There are important limitations and shortcomings of the model which need to be considered when comparing the model results with real world observations.

Owing to its aggregated formulation, our model does not account for pipeline congestion occurring within countries. We assume that the inland transport capacity is sufficient to satisfy the demand. This likely leads to an overestimation of trading potential and a more equalized price level across European countries as only cross-border constraints will limit exchange. Furthermore, the assumption of perfect competition is likely to lead to a lower price level (and a subsequent higher demand level) compared to real market outcomes. The European gas market is frequently depicted as a game dominated by a few Cournot players (see e.g. Boots et al., 2004). To capture the impact of those potential deviations we adjust the model parameters. As the underlying cost structure is one of the most uncertain parameter assumptions (due to limited pubic available data for different production sites) the main calibration parameters are markups on those production costs. Within this model calibration priority was given to a match of quantities and global flow patterns and not on a match of model prices with market prices. Consequently the resulting price levels are not directly comparable to real world wholesale price levels and the scenario results should not be seen as market forecasts.

Table 1 displays some of the European market's key values alongside to the corresponding model results. The achieved calibration is far from perfect. Some results are close to reality, for instance for producing countries like Russia, Iran or Libya, while others

like Algeria or Nigeria extract more than in reality. One further notices that the LNG share in Europe is significantly underestimated. Overall, our model tends to overestimate demand and supply levels. The European demand exceeds its real value by approximately 7%, while the domestic production is overestimated by roughly 5%. While interpreting the results of our upcoming scenario analyses, one must bear in mind these calibration results. Therefore, the focus of the scenario analysis should be put on the obtained general dynamics and interdependencies and less on absolute values.

Table 1: Comparison of model results with market observations

	Market data 2013	Model results
Main non-European producers (bcm)		
Algeria	81.5	107.9
Azerbaijan	16.2	18.1
Iran	164.0	161.5
Libya	11.0	13.3
Nigeria	36.2	47.9
Russia	742.6	746.3
European demand & production (bcm)		
Total demand	594.8	635.0
Domestic prod.	307.7	322.0
European shares		
LNG	7.4%	2.1%
Domestic prod.	45.1%	50.7%
Russian pipe.	35.5%	36.3%
Others	11.9%	10.9%

The model results are based on the calibrated model run with markups on the underlying production costs levels in the exporting countries to obtain a close match of production and transport patterns with observed levels.

2.3. Long-term Market Evolutions

As a first application of our model, we develop projections of the European natural gas market in 2030. The focus lays on the impact of infrastructure as we sketch different pathways for the evolution of European gas infrastructure and evaluate their effect on the market.

For this analysis, we conduct a ceteris paribus approach with respect to underlying cost and price levels and alter production, demand and infrastructure assumptions (i.e. we project the calibrated model with the base year 2013 into the year 2030). The demand and

production data are updated based on the *New Policies* scenario of the World Energy Outlook (IEA, 2015c), while the infrastructure assumptions are specified for each pathway. Aside from the relevant projects, we do not assume any further network extension. As we use the 2013 price and cost assumptions for all scenarios the obtained results show the impact of altered infrastructure changes on the resulting marker dynamics..

We investigate the following three infrastructure pathways:

1. *As-is 2030*: assuming that the current infrastructure remains unaltered
2. *Main Projects*: the infrastructure is completed by some of the currently discussed infrastructure projects:
   o The Southern Gas Corridor (SGC): a three-part project consisting of the South Caucasus Pipeline (SCP), the Trans-Anatolian Pipeline (TANAP) and the Trans-Adriatic Pipeline (TAP) connecting Azerbaijan to Italy through Turkey and Greece. Some portions of the SGC have already been built.
   o The Reverse Flow project: opening of a South-North route from Italy to Germany and Belgium thanks to transformation of the existing pipelines.
   o Several additional LNG regasification terminals planned in Europe, notably in Croatia, France, Spain or Sweden.
   o Currently projected developments of the storage infrastructure (e.g. in Germany, France or Italy).
3. *Nord Stream 2*: same as *Main Projects* with the addition of the Nord Stream extension, a project which shall double the capacity of Russian exports towards Germany. First agreements for the construction have recently been reached by the commercial partners. It is, however, heavily debated, and Eastern European countries like Poland have engaged in a political and legal battle to fight the project.

2.3.1. As-is 2030

This first pathway can be interpreted as a benchmark to identify the impact of changes in demand and supply on the market, without any change in the infrastructure. Compared to the 2013's levels, the IEA foresees a slightly growing demand level in Europe (a 1% increase). On a global scale however, both the worldwide demand and production levels are believed to be expanding by more than 30%, mainly owing to the surging demand in Asia and Africa. On the supply side, many European producers are slowly exhausting their gas reserves. Their production is thus forecasted to shrink: -12% for Norway and up to -38% for the United Kingdom or Germany. In reaction to this, our simulation yields on the one hand an increasing

share of LNG imports in European consumption (amounting to roughly 10% of the total demand compared to 2% previously). On the other hand, the share of Russian gas is also rising and takes a value of 40%.

The increasing importance of LNG can also be noticed in the seasonal structure. The impact of gas demand in heating leads to a large difference of consumption between summer and winter months. Currently, this seasonal flexibility is predominantly supplied by storage, while some European producers (mainly Netherlands) and Russia provide complementary supply. The results of the *As-is 2030* simulation indicate the rise of LNG as a flexible supplier, allowing to compensate for the declining production of European suppliers and to reduce the Russian imports (see Table 2).

Due both to the diminishing domestic production and to the enhanced global demand, the average price level in continental Europe is upward tending, slightly increasing by 6%. On the contrary, the price spread between summer and winter is reducing. This is explained by the fact that, in both cases, the maximum price is determined by LNG imports.

Table 2: Contribution to seasonal demand spread

	Baseline 2013	As-is 2030
Own extraction	22.8%	15.0%
Storage	57.1%	54.5%
Russia	20.1%	11.3%
LNG	0.0%	19.3%

The results are in relation to the total demand of all modeled European countries.

2.3.2. Main Projects

The infrastructure projects that we consider in the *Main Projects* pathway have the common overall effect to enhance the import and transport capacity of the European natural gas market. This expanding supply induces an increased demand of roughly 1% compared to the *As-is 2030* level. Moreover, the SGC pipelines undermine the prevalence of Russian exports (37% of market share), as Azerbaijan enhances its supply to Turkey or to Greece. Surprisingly, the simulation results do not indicate growing LNG imports, although several regasification terminals are added to the European infrastructure. This is primarily explained by the cost disadvantage of LNG compared to the additional import alternatives comprised in *Main Projects*.

The SGC further leads to a partial reallocation of the Russian flows towards Western Europe, owing to the rising independence of the Southern-Eastern parts of Europe. Overall,

a more abundant and cheaper gas supply in Europe results from the new infrastructures. Hence, the average price is slightly reduced compared to *As-is 2030*. It is further to be noted that, in the simulation, the last branch of the SGC linking Greece to Italy and the Reverse Flow project (from Italy towards Germany and Belgium) are both strongly underused. This highlights the fact that, in the simulation's results, there seems to be sufficient transport and export capacities to supply Western Europe at cheaper costs than through this additional route.

2.3.3. Nord Stream 2

The extension of the Nord Stream pipeline enhances the availability of cheap Russian gas in Western Europe, thus resulting in a 2% increase in demand with respect to *As-is 2030*. The added export capacity permits Moscow to increase its market share in Europe, accounting for approximatively 40% of the demand. Hence, the Nord Stream 2 project countervails the negative impacts of the SGC for Moscow. Germany further adopts a pivotal position on the European market by re-dispatching Russian gas towards the rest of the continent. Finally, Nord Stream 2 causes a reduction of the usage of the route over Ukraine (-21% of shipped quantity), thereby depriving the transit countries (e.g. Slovakia, Hungary or Austria) of substantial transit fees. Furthermore, the LNG share in Europe is decreasing, as it is replaced by the more economical alternative of Russian gas.

The price effect of *Nord Stream 2* case is stronger than in the *Main Projects*. The average price reduction compared to the *As-is 2030* case amounts to -6%. The price level returns to its Baseline 2013 level.

2.3.4. Comparison and Conclusion

Comparing our three different pathways with the 2013 simulated results and corresponding market observations, we note the strong reduction of domestic European supply in 2030 (Table 3). How this reduction will be compensated for notably depends on the gas infrastructure. In all pathways, we observe an increase in the LNG share. However, compared to the market results of 2013 this raise may be overestimated in our simulations as we obtain significantly lower LNG shares in our baseline calibration. Nevertheless, LNG is likely to remain an important supplier for Europe, especially for southern countries.

Russian imports remain important for Europe's natural gas market in all scenarios. In the *Main Projects* case, where the Russian market share is the lowest of all scenarios, it remains at a level which is comparable to today's market. The question of how to cope with this

dependency is therefore likely to remain an important element of Europe's energy policy in the next decade.

Table 3: Supply Shares

	Market data 2013	Baseline 2013	As-is 2030	Main Projects	Nord Stream 2
Own Extraction	45.1%	50.7%	37.6%	37.2%	36.8%
Russia	35.5%	36.3%	40.2%	37.4%	40.2%
Other pipes	11.9%	10.9%	12.9%	16.3%	16.1%
LNG	7.4%	2.1%	9.3%	9.0%	6.9%

The results are in relation to the total demand of all modeled European countries.

Even though our model yields very rough price calibration and significantly underestimates prices (see Table 4), the development of the price levels in the various pathways still allows us to obtain insights on potential market dynamics. Overall, we observe a tendency towards price increase in the future which can be explained by the reduced domestic supply and higher dependence on imported gas.

Table 4: Market Prices

	Market data 2013	Baseline 2013	As-is 2030	Main Projects	Nord Stream 2
Av. Euro. price [€/mcm]	0.218	0.154	0.163	0.160	0.154
Max price [% of average]	116%	121%	117%	115%	115%

The results refer to average of all modeled European countries.

Against this fact, the additional infrastructure projects result in greater availability of gas on the market, and thus in lower prices; Nord Stream 2 has the largest price impact of all pathways due to the assumed low-cost level of Russian supplies. The reduction in the seasonal price spread is mainly explained by the fact that the same suppliers set the prices in summer and winter, as Europe is more dependent on foreign supplies throughout the year.

As a summary, one can conclude that the forecasted reduction of domestic natural gas production in Europe implies a diversification of the supply sources. The role of Russia will remain central, but in addition to LNG, the projected pipeline projects in Southern-Eastern Europe might help Europe on its ways towards a higher diversification of supply sources. Overall, the gas infrastructure seems to be sufficient to satisfy Europe's gas needs under average market conditions even without further additions. We do not observe significant price differences within Europe beyond transport costs differentials.

2.4. Evaluation of Supply Security

As one notes from previously presented long-term market evolutions, a key feature of the European gas market today and in the future is its dependency on Russian imports. Whether this dependency represents a threat to the security of gas supply depends on the (im)possibility to compensate a shortage of Russian supplies by other imports. To provide an assessment of this threat, we extend our model with a shock scenario structure: we induce a complete shutdown of the Russian-Ukrainian pipeline, one of its most prominent import routes.

The timing of the crisis is chosen to represent a worst-case scenario, so that the transit is disrupted during the four winter months (December to March). To grasp and measure the European market's short-term resilience, we use the average market conditions (Section 2.3) as reference by fixing the demand in the crisis conditions to this 'normal' market demand; in other words, we assume a total inflexible demand during the crisis simulation. This transfers the model into a cost minimization version (D_{nit} becomes a parameter). To ensure a feasible model solution even in cases when supply is insufficient, we introduce a 'lost load' variable with prohibitive costs. Thereby, we are able to identify and locate supply shortages in Europe.

In addition, we countervail the perfect foresight assumption that is necessarily part of an optimization model by fixing all variables of the time periods before the crisis to their respective values of the normal market case. The formulation therefore translates into an unforeseen market shock in which consumers must consume their pre-defined quantity of gas, since they have no alternative for short term switching or other demand reduction measures. To cope with the shortage of gas supply, the model can resort to alternative imports and transport routes to ensure stable gas supply if they are available. This fixed demand assumption is likely to overestimate the effect of a supply shock as in reality, one might expect consumer to adapt their consumption to the crisis, at least partially. [11]

In the next section, we will first present the basic results of a supply interruption under different market conditions. Subsequently, we will assess the impact of specific policy approaches to improve supply security.

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[11] Short term fuel switching options provided by dual-fuel consumers which are an important provider of potential flexibility in Switzerland are also neglected for this scenario assessment.

2.4.1. Impact of a Russian Supply Disruption

In order to obtain insights on the impact of different market conditions and infrastructure projects on the supply security level in Europe, we apply the aforementioned scenario of disruption to our three market pathways and to the base case calibrated model (*Baseline 2013*).

Baseline 2013 represents the shock under current market conditions. Due to the crucial importance of the Ukrainian route, an interruption of the Russian supply has far reaching consequences for the whole of Europe. Several countries strongly reliant on the Ukrainian transit endure lost load due to insufficient gas supply, among others Ukraine, Bulgaria, Croatia, Italy, Greece or Turkey (Table 5). Roughly 13% of the European demand during the four crisis months cannot be satisfied. However, also Russia's yearly output is significantly reduced (by 20%) owing to the lack of available alternative export routes. Hence, one observes a double dependency between Russia and Europe.

With the forecasted levels of production and consumption in the *As-is 2030* case, Europe seems less vulnerable to supply disruptions (Table 5). The overall lost load amounts to 9%, which represents a reduction of -28% in absolute terms of missing supply compared to the *Baseline 2013*. At a first glance, this might seem counterintuitive as both European and worldwide gas demand are increasing, while the import infrastructure stays constant. The *As-is 2030* scenario does, nonetheless, introduce large production capacity extensions, notably for Middle-Eastern countries. These growing LNG import potentials provide Europe with additional flexibility, which represents an essential asset in overcoming such a crisis. Europe is able to import 16 bcm of additional LNG, whereas in the *Baseline 2013* almost no supplementary LNG import was possible as the global production capacities were already fully utilized.

The projected infrastructure investments of the *Main Projects* case result in growing availability of import alternatives to replace the missing Russian gas. Thereby, the overall level of lost load is further reduced (Table 5). The two main beneficiaries of the new infrastructures are Turkey and Greece, who directly profit from the SGC and no longer suffer missing supply. Thanks to the SGC, Italy benefits from increasing export from Greece. In addition, newly implemented LNG import capacities help Croatia and Sweden to improve their supply situation.

The extension of the *Nord Stream* generates growing Russian exports towards Germany, who supplies part of the missing gas from Ukraine by re-exporting to Poland, Czech Republic

or Austria. As a result, the pipeline significantly impacts the European security of supply. Ukraine and Romania are the sole countries enduring supply disruption (Table 5).[12]

Table 5: Lost Load in the different market scenarios during crisis

	Baseline 2013	As-is 2030	Main Projects	Nord Stream 2
Bulgaria	54%	11%		
Croatia	65%	58%	15%	
Greece	78%	21%		
Italy	19%	8%	9%	
Romania				22%
Slovakia	69%	44%		
Slovenia	38%	100%		
Sweden		38%	7%	
Turkey	24%	13%		
Ukraine	66%	62%	59%	60%
Average Europe	13%	9%	7%	6%

The results are given as percentage of the respective demand during the four crisis months. Countries not listed in the Table have no lost load.

Examining the change in flow patterns during the crisis (Figure 2, Figure 3), it becomes visible that the interruption of the Russian-Ukraine pipeline tends to lead to shortages along two main routes. The first one runs though Ukraine-Slovakia-Austria-Czech Republic and Italy; the second from Ukraine-Romania-Bulgaria to Greece and Turkey. To cope with the missing gas, several alternatives are exploited.

In all cases, one notices 'reverse' flows patterns (gas flowing from Western towards Eastern Europe). The main source for these flows is increasing Norwegian exports channeled through Germany. In some cases, additional supply from Northern Africa can be obtained, either towards Italy[13] or as LNG exports to Spain. In *Main Projects* and *Nord Stream 2*, new infrastructures are used to import additional Russian gas via Turkey that is re-directed towards West. This is especially helpful for the Balkan countries which have sparse alternatives of supply.

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[12] *Nord Stream 2* causes higher lost load than *Main Projects* for Ukraine and Romania due to feedback effects from the pipeline extension. The crisis assessment is based on an uninterrupted market simulation providing the respective load levels. The extension of the Nord Stream connection reduces the natural gas flow over the Russian-Ukrainian route, increases the availability of transport capacity, and thus yields shrinking prices for several Eastern European countries under normal market conditions. Furthermore, Romania and Ukraine display a less pronounced price spread between winter and summer, which reduces their incentive to store gas. The overall higher demand level and reduced storage levels following the introduction of the Nord Stream 2, mean they are more prone to supply disruptions. Therefore, there exists a counterproductive effect of an increased supply for the energy security of some regions.

[13] Nonetheless, as the shock occurs at the peak time of gas consumption in Europe, spare production capacity is a scarce resource. The growing pipeline flows from Algeria and Libya towards Italy in the *Baseline 2013* case are only made possible thanks to a reduction of their LNG exports.

Throughout the shocks, two general trends can be observed. First, the increase in the availability of production capacity forecasted by the IEA, notably in the Middle-East, results in enhanced gas security in Europe. Second, infrastructure projects further have a strong positive impact on the European short-term SoS.[14]

Figure 2: Flow reallocation during the four crisis months

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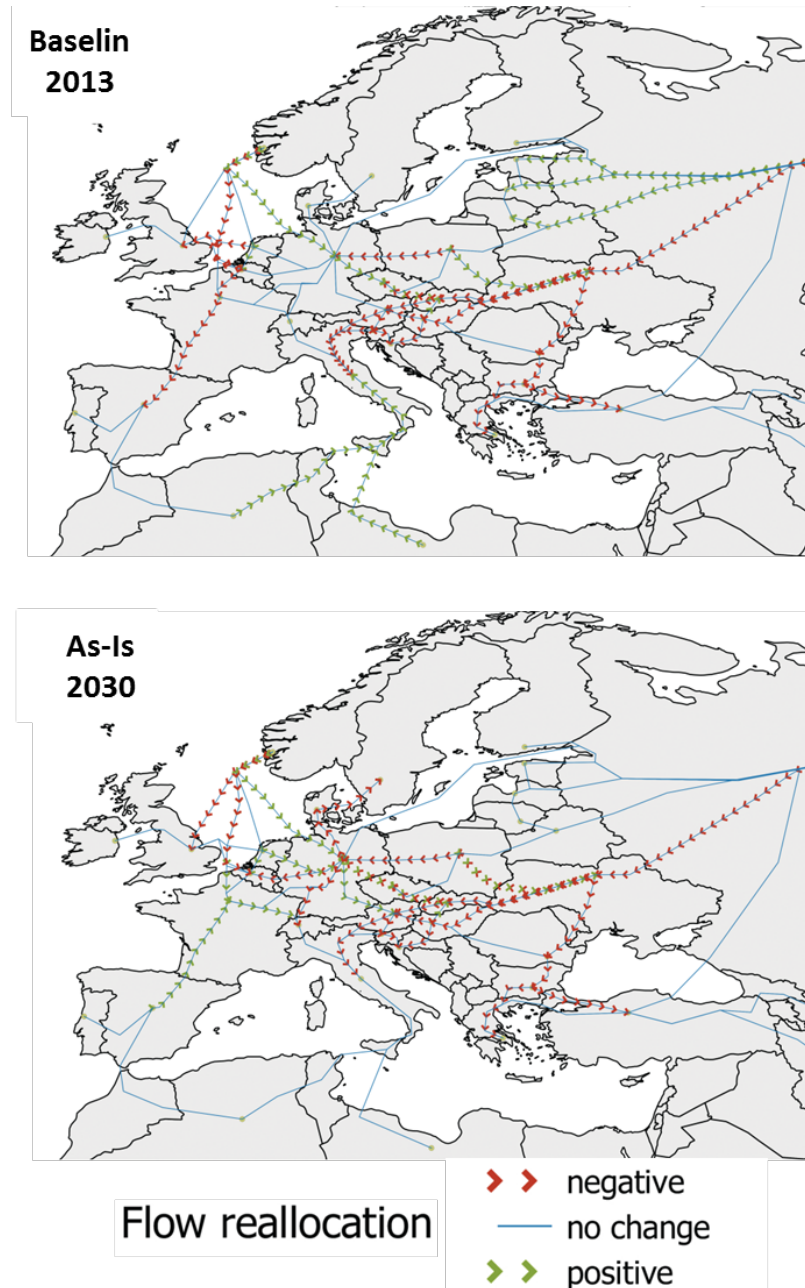
[14] The extension of Nord Stream can also create a trade-off for the current transit countries of other Russian pipelines (e.g. Poland), between the loss of transport fees and an enhanced European security of supply.

Figure 3: Flow reallocation during the four crisis months
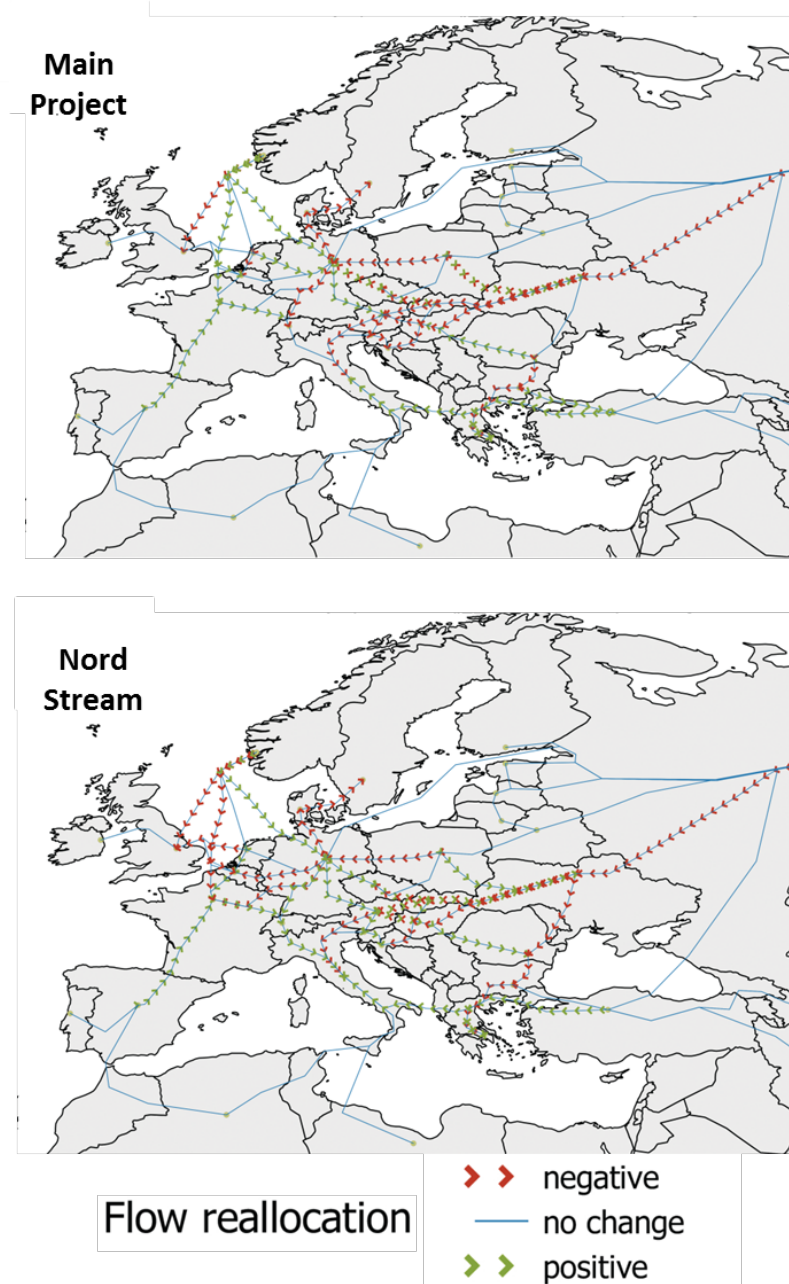
2.4.2. Impact of Supply Security Policies

As shown by the above assessments, the average European market conditions do not show significant supply constraints or extensive congestion problems, but the dependency on Russian gas can be a trouble source in case of deliveries interruption. The currently discussed extension of the gas infrastructure might help to weaken, at least partially, this

threat, while the Nord Stream 2 would enlarge it. Nonetheless, given the fact that the main challenge consists rather in managing specific extreme conditions than in structural problems of market, one may think about alternative approaches that may also provide additional supply security without the need for costly infrastructure investments.

Against this background, we extend our assessment by simulating the impact of specific policies targeting a more secure supply; namely:

1. *Strategic Storage:* Imposing an obligation to maintain a specific storage level for emergency situations.

2. *European Storage Coordination:* As not all countries can rely on own or sufficient storage capacities, coordination among countries during the crisis is key. This policy seeks to tackle this question by assessing the difference between cases where countries can or cannot share their strategic storage with each other.

3. *Long-Term Contracts:* As a significant share of international gas trade is conducted via bilateral long term agreements those contracts could in principal entail a supply guarantee priority during emergencies. Based on the exiting long term contract structure we evaluate the impact if those would include a priority supply for the contract holders.

In following section, we will shortly present the different policies and simulate their impact using the same model framework as for the Russian supply disruption assessment.

2.4.2.1. Impact of Strategic Storage

Storage is a prominent flexibility provider, both to cover fluctuations of seasonal demand and in case of supply disruptions. Recognizing its importance, several European countries have put in place a strategic storage policy. For instance, Italy imposes a minimum storage level of 4.6 bcm of gas. In Hungary, gas suppliers are required to store 10% of the total demand. A detailed overview of the national policies can be found in European Commission (2015).

Our first policy assessment simulates the implementation of a strategic reserve obligation at the European level. We define the obligation as a fixed percentage of each country's storage capacity. The storage obligation must be held throughout the year and can only be used in case of a crisis. If the strategic reserves have been used to overcome a crisis, they must be refilled at the latest five months after the end of the crisis. To evaluate the policy's impact on SoS, we loop the Russian crisis scenario over different level of storage obligation.

On the one hand, this policy augments the possibility to recourse to gas in storage in case of a crisis. The impact on the European market should, thus, be positive. On the other

hand, the obligation reduces the available capacity for commercial storage, and might, therefore, hinder seasonal arbitrage. Hence, the direction of the overall impact is unsure.

Using the *Baseline 2013* as starting point, Table 6 highlights the basic dynamics of the storage obligation: more stringent storage obligations lead to higher level of storage and, thus, to more available alternatives to cope with the missing Russian exports. The stored gas is used for both, national demand and shared with neighboring countries. For storage obligation above 40%, Europe is capable to cope with a four months disruption of Ukrainian transit with only marginal lost load. The crisis is overcome without any supply disruption at levels of mandatory reserves above 70%.

Table 6: Impact of the storage obligation policy on Europe (Baseline 2013)

Storage obligation	Avg. Storage Level	Withdr. base [bcm]	Withdr. crisis [bcm]	Lost Load [bcm]	LL / Demand	Increase Cons. Exp.	Increase Prod. Profit
0%	66%	66.4	68.2	39.4	12.90%	-	-
10%	71%	64.1	76.7	29.1	9.60%	1.3%	2.3%
20%	76%	60.7	86.6	16.5	5.50%	2.9%	6.5%
30%	79%	54.2	85.5	11.4	3.80%	5.8%	16.1%
40%	83%	47.1	85.5	7.5	2.60%	9.2%	28.4%
50%	88%	41.1	83.5	4	1.40%	12.1%	37.1%
60%	91%	35.6	81.9	0.5	0.20%	14.9%	47.0%
70%	96%	30.8	78.9			17.9%	58.0%
80%	98%	25.7	69.3			21.2%	70.6%
90%	100%	14.2	58.8			26.3%	89.2%

Average storage level in % of maximum storage capacity at beginning of winter period; Total sum of withdrawals from storage (in bcm) in the base and in the crisis case during a year; Total sum of lost load during the crisis months (in bcm) and the ratio of lost load over demand during the crisis months (in %); Increase in consumer expenses compared to the no-obligation case; increase in producer profit compared to the no-obligation case.

However, this increase in security comes at a price. There exists a crowding out effect which occurs when imposing a more stringent policy: the larger the storage obligation, the smaller the remaining storage capacity available for seasonal arbitrage. This effect is highlighted in the second column of Table 6, where one notes the decreasing trend of storage withdrawals during winter season in the base case. The radical formulation of the policy, in which storage operators are forced to maintain a minimum level throughout the year, leads to significant limitation of the storage usage.

In addition to reduced withdrawals in winter, the policy causes operators to buy more gas on the market during the filling season to fulfil their obligation. Both effects lead to higher average gas prices on the European market in the non-crisis conditions. Owing to our policy

formulation, increasing prices are seen before the winter season (need to fulfil the winter storage requirement) as well as in the peak winter time (the diminishing withdrawals must be compensated elsewhere). This price increase leads to higher expenses for consumers and higher profits for producers (see last two columns from Table 6).

Overall, the effect of strategic reserve policy could be summed up as follow: on the one hand, it brings along substantial benefits in terms of energy security. The strategic storage is used as a buffer, which helps to cope with unforeseen circumstances and severe crises. On the other hand, however, the policy induces certain costs. First, the cost of filling up the strategic storage must be paid. As this would represent a regulatory measure, the associated costs are likely to be passed on to consumers. Second, the strategic reserve restrains the commercial usage of storage, thus foregoing potential seasonal arbitrage. Third, stringent filling obligation lead to market-wide reactions: growing demand, higher prices, and larger price spreads on the market. This negatively impacts the consumers. The question is then on the value attached to the supply security. Looking at Table 6, one notices that a level of storage obligation of 20% already halves the missing supply, while causing an increase of 3% of consumer expenses. Depending on the valuation of supply security, this might be considered an acceptable compromise.

Turning to the three infrastructure pathways–*As-is 2030*, *Main Projects*, and *Nord Stream 2*–the basic insights remain valid. The storage obligation leads in all cases to enhanced security of supply in terms of a reduction of the lost load (Table 7). Each infrastructure setting yields a more flexible gas supply, which translates into smaller impact of the pipeline shutdown. Nonetheless, the strategic storage policy helps to overcome the supply disruptions in a similar way as it did for the *Baseline 2013*.

One of the main drawbacks of the strategic reserve policy is that it prevents the flexible use of storage and, therefore, leads to higher prices preventing inter-seasonal arbitrage. As the infrastructure scenarios result in additional flexibility of supply on the European market, this effect is less pronounced than in the *Baseline 2013* case (Table 6 and Table 7). However, since the level of lost load is also lower than in the *Main Projects* and *Nord Stream 2* cases, the question remains open whether the additional benefit in terms of better supply during crisis conditions is worth the additional cost.

Our results also lead to the additional question of whether a storage policy is a more cost-efficient solution to address Europe's supply security concerns than investments in infrastructure. The overall benefit of the two infrastructure cases is a decrease in the lost load level of about 2 to 3 percentage points. The same improvement can be obtained by imposing

a 10 or 20% storage obligation which leads to about 1 to 2% higher consumer prices (Table 7).[15] Naturally, further factors play into the investment decision, yet from a pure supply security perspective, investment in new infrastructure may not represent the most cost-efficient solution.

Table 7: Impact of storage obligation in 2030 cases on Europe

Storage obligation	Lost Load			Increase in Consumer Expenses		
	As-is 2030	Main Projects	Nord Stream 2	As-is 2030	Main Projects	Nord Stream 2
0%	9%	7%	6%	0%	0%	0%
10%	6%	4%	5%	1%	1%	0%
20%	5%	3%	4%	2%	2%	1%
30%	4%	3%	3%	4%	3%	1%
40%	3%	2%	2%	6%	5%	2%
50%	1%	1%	1%	8%	8%	3%
60%				9%	10%	3%
70%				11%	12%	6%
80%				14%	14%	9%
90%				17%	16%	11%

Ratio of lost load over demand during the crisis months (in %); Increase in consumer expenses compared to the no-obligation case (in %).

As a final remark, one must note that our results depend on the underlying assumptions. In the Appendix, we provide a set of different sensitivities addressing the way how we model the costs of storage and how we define the strategic storage rules. The assumptions do change the obtained numerical values but do not fundamentally alter the benefits of the policy or the general conclusions. As increases in strategic storage obligations always lead to an increase in supply security the question is, how stringent the policy should be formulated, and hence, how large the disadvantages of the policy on the consumer's wallet will be. A more flexible implementation (i.e. gradually freeing up strategic storage over winter months) seem to lead to smaller negative impacts.

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[15] However, a direct comparison of those price increases with the needed investment costs (i.e. for the Southern Gas Corridor a total investment volume of US$40 billion is assumed, https://www.tap-ag.com/the-pipeline/the-big-picture/southern-gas-corridor, for Nord Stream 2 cost in a similar range like Nord Stream 1 of €40 billion can be expected, https://www.nord-stream.com/download/file/documents/pdf/en/2013/11/nord-stream-by-the-numbers_177_20131128.pdf) is complicated as non supply security related aspects of the investments need to be taken into account.

2.4.2.2. Impact of European Coordination

In the previous analysis, we assumed that all European countries jointly participate in the policy and exchange their strategic gas reserve in an optimal way for the European welfare. Yet, one notes strong divergence among storage capacities among European countries. While Austria can approximately cover its entire annual consumption with a full storage, Germany, France or Italy have capacity for around one quarter of their annual demand in storage. And countries like Greece and Switzerland have no domestic storage and would depend on the provision by neighboring countries. In a crisis case, countries with limited storage capacity rapidly exhaust their entire stored gas and subsequently have to rely on additional supply by their neighbors. Hence, cooperation between the European players seems a key feature of a strategic storage policy.

To assess the impact of this cooperation, we compare two different cases: a cooperative and a non-cooperative one. In the latter, gas in strategic storage may only be used for one's own needs, whereas in the former, the strategic reserve might be shared with one's neighbors.

To implement this approach in our model, we need to limit the usage of gas to a countries own lost load in the non-cooperative case even if there is more gas in the storage than there is demand shortage. To achieve such a restriction we use an additional virtual model run that entirely forbids the use of strategic storage reserves to identify the amount of lost load a country has to cope with. This value can then be set in relation to a countries strategic storage reserves.[16] If a country's strategic reserve is short it has to rely on increased imports or suffers lost load. Contrary, if a country has surplus storage capacity it will use its storage to compensate the demand shortage but not provide surplus stored gas for neighboring countries. It is to be noted, that for all runs, the commercial storage (i.e. the non-strategic storage) can be freely used and shared.

The general importance of cooperation for an efficient crisis management is highlighted in Figure 4 by comparing the welfare effects of the different settings for the Baseline 2013 case. One notices the large differences between the two crisis cases. The non-cooperation

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[16] Technically the approach is implemented as a three step model: First, the base case market results are obtained with the respective storage obligation in place. Second, a crisis run is carried out without the possibility to use the strategically stored gas. This run defines the levels of lost load for each country. This lost load is then compared to the strategic storage volume and a netted demand position is defined (i.e. if the storage volume is bigger than the lost load, the demand is fully reduced by the lost load value; if the volume is smaller than the lost load the demand is only reduced by the storage volume) as well as the remaining strategic storage volume is identified. In a third run, the crisis case with adjusted demand level is simulated. Depending on the case either with free exchange of the remaining strategic storage volume (cooperation case) or exclusion of the remaining volume (non-cooperation case).

can cause a reduction in total welfare of up to 28%. Since strategic reserves cannot be shared, their potential is not fully used. Several regions suffer lost load, although their neighboring countries might have remaining stored gas.

Figure 4: Impact of strategic storage and cooperation on system welfare (billions USD$_{2013}$)
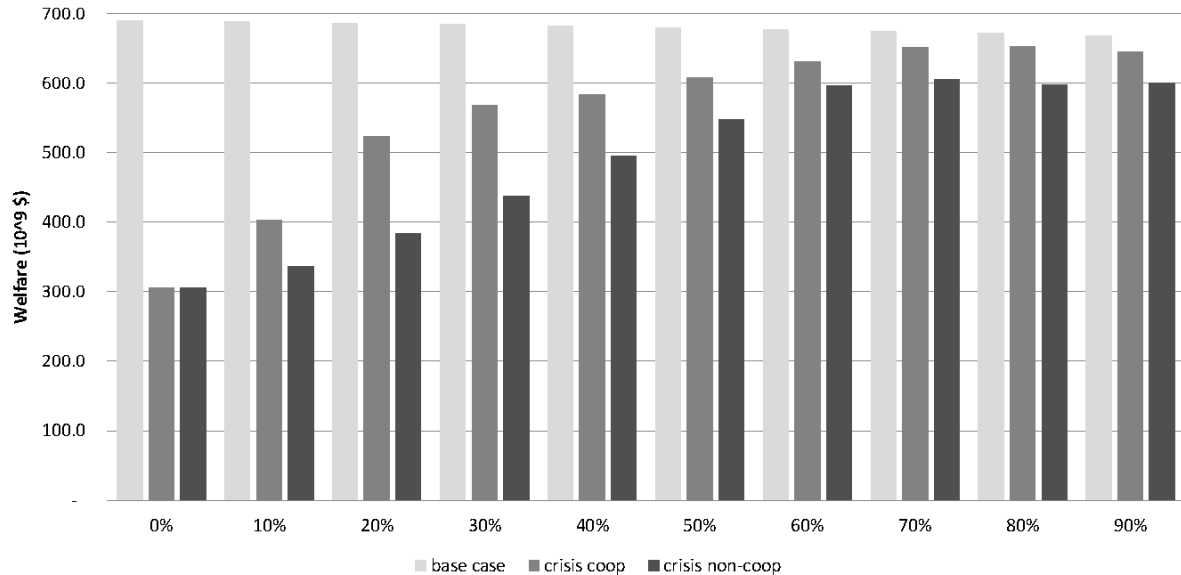
Total system welfare for Europe. The absolute value of the crisis case is strongly impacted by the assumed costs of lost load (10'000 $/bcm)

The differences between the two cases first increase until the 20% storage level (peaking at a difference of 28%), shrink afterwards until 60% and 70% (going as low as 5%), and increase again for the 80% and 90% case (to ca. 10% difference). To explain this pattern, one must consider the trade-off caused by the policy. A larger strategic reserve leads to enhanced availability of gas to cope with the crisis, while it also reduces the quantity of commercially stored one. In the context of this scenario analysis, this trade-off is even more important, as a distinction between commercial and strategic storage is made (as for the non-cooperative case the usage of strategic reserves is restricted). Hence, the impact of this trade-off is different in the cooperative and the non-cooperative settings. In the cooperative case, only the increased availability of stored gas is relevant, since both, strategic and commercial storage, can be freely used and shared. On the contrary in the non-cooperative case, only commercial reserves might be distributed among neighbors.

Therefore, increasing the strategic storage has a twofold effect on the supply security in the non-cooperative case; positive on the one hand (more gas in storage for one's own needs) and negative on the other hand (less commercial storage to be shared). The direction

of the overall impact depends notably on the storage occupancy before the policy implementation. Provided a country has already a rather filled storage, the strategic storage obligation will mainly result in a crowding out of the private reserves. Hence, a more stringent reserve obligation could make the neighbors worse off. On the contrary, if the storage of a country is fairly empty, the policy will increase its total reserve level. This is in turn directly beneficial for the country's supply security. Although the strategic reserves cannot be shared in the "non-cooperative" case, it might still have a positive indirect effect on the neighbors, as it reduces the demand for gas in case of crisis.

To visualize this interaction Figure 5 shows the impact of the storage obligation on the free available storage volume in Europe. The crowding out effect starts rather slowly, thus the positive impact of the policy dominates. Each iteration yields a larger pool of reserves to be shared in the cooperative case; however, in the non-cooperative one, this pool is diminishing. Hence, the difference between the two cases is growing. From 30% onwards we observe a decreasing growth in the total pool of storage (i.e. a reduced growth in the overall benefits of the policy). This leads to the decrease in the difference between the two cases. For high storage obligations, the available commercial storage is plunging (for instance because Germany reaches its storage capacity). Hence, the sharing of the reserves is drastically reduced. Each country must then be self-sufficient, and the nation with insufficient storage capacities might endure lost load again. This explains why the difference is growing for very high obligations.

Figure 5: Total commercial storage availability in November by storage obligation iteration
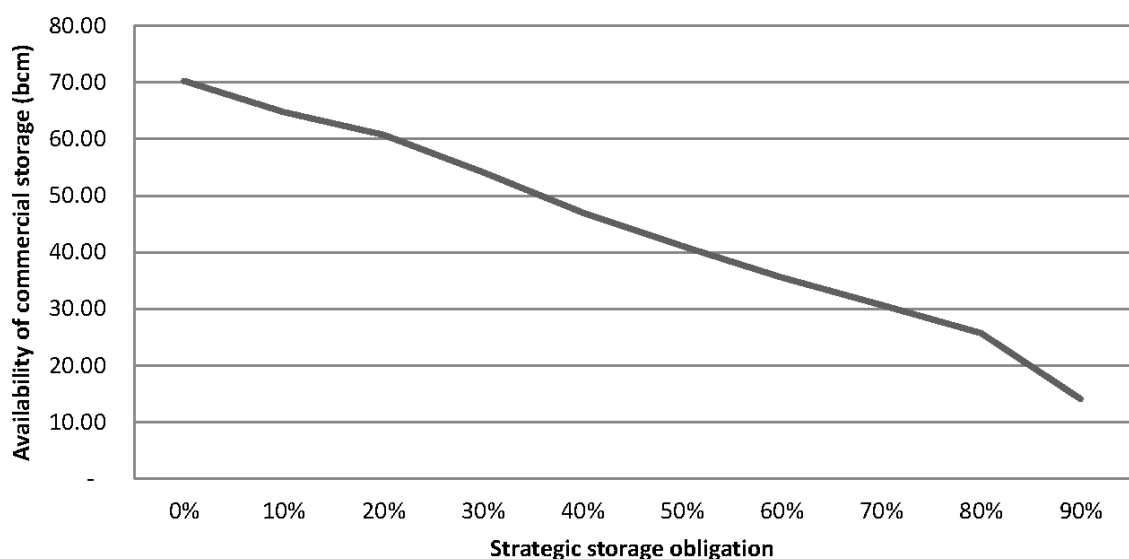
Lastly, looking into country specific effect we can identify which countries benefit most from a cooperative policy (Table 8). Since Greece does not hold gas storage capacity, it suffers severe supply disruption in the non-cooperative set-up; whereas in the cooperative case, the country can fully satisfy its demand at high level of storage obligation. The same observation is valid for Croatia or Italy, who both possess significant storage capacities, yet covering only a limited part of their yearly demand (roughly 20% in both cases). For a country with a relatively large storage like Ukraine, one notices that the impact of the cooperation is more restricted, yet still positive. Other countries with little storage capacities, like Switzerland, are less impacted as they rely less on gas from Russia.

Table 8: Lost load over demand during the crisis for selected countries in the non-cooperative and the cooperative cases

Storage obligation	Cooperative Case				Non-Cooperative Case			
	CRO	GRC	ITA	UKR	CRO	GRC	ITA	UKR
0%	65%	78%	19%	66%	65%	78%	19%	66%
10%		78%	9%	68%	66%	78%	19%	68%
20%		35%		43%	64%	78%	17%	53%
30%		17%		34%	67%	60%	14%	47%
40%		33%		21%	70%	63%	6%	33%
50%		48%		23%	74%	68%	3%	17%
60%		26%			77%	50%	1%	7%
70%					82%	50%		
80%					86%	50%		
90%					91%	36%		

Note: Switzerland does not suffer lost load

Summarizing the findings, we can conclude that European coordination is a highly valuable aspect of a security of supply policy. Without proper exchange and coordination on measurers during supply shortages the needed countermeasures need to be scaled up significantly to achieve a similar effect, with some countries not being able to achieve a comparable effect at all.

2.4.2.3. Impact of Long-term Contracts

In addition to infrastructure investments and storage operation, bilateral supply contracts can further represent a form of supply insurance in case of an overall market shortage. As stated in Section 2.2.2, we use the database of Neumann et al. (2015) of long-term contracts in Europe. These contracts were historically prominent for the European gas market covering the vast majority of gas imports in many countries. Nowadays, their relevance is challenged by the rising importance of sport markets. Despite these changes, they remain a significant part of gas importers' portfolio, especially when speaking about the security of supply. One

can consider long-term contract as a more 'secure' source of supply as it ensures the quantities of gas delivered as long as parties stick with the terms of contract.

Given this reasoning and the fact that long-term contracts still cover a large share of European consumption, we investigate the impact of these contracts on the European security of supply. To that extent, we compare two different cases. In the first one, countries do not have to stick with contracts during a crisis (disruption of the Russian-Ukrainian pipeline). Hence, they do not face any consequences if they fail to deliver the promised gas. On the contrary, in the second one, exporters have to stick with the contract and pay a financial penalty in case of failing to deliver. To simulate this, we introduce a differentiated cost of lost load for the share of demand covered by long-term contracts. Defaulting on these consumers will thus be more expensive than on other ones.

Table 9 displays the resulting average lost load in percent of demand for the European countries which must endure missing supply during the crisis. Comparing the case with and without penalty, one notes the clear impact of the long-term contracts on security of supply. The introduced financial incentive dissuades exports to default on their long-term commitments. Thereby, the countries which had a high share of contracts are better off than others. Greece, Italy or Portugal, Turkey are all freed from their lost load problems, while even the Ukraine can reduce its missing gas share.

On the other side, the countries which do not possess long-term contracts are penalized by the new situation. From a system point-of-view, it is now optimal for exporters to default on these countries, rather than on others. Thus, the missing supply problem is shifted toward Eastern European countries like Bulgaria, Croatia, Slovakia or Slovenia. Even Romania suffers lost-load despite a share of 16% of long-term contract. On the Western end, Great-Britain and Ireland also both see enhanced problems supply security which is mostly due to a reallocation of Norwegian gas and LNG for countries with long-term contracts.

Some countries are, in turn, unaffected by the policy, as they do not face shortages in supply in any of the cases. This is for example the case of Switzerland.

Summing up, one notices that a financial penalty for breach of contract, discouraging exporters to default on their long-term contract, might be a powerful tool to enhance one's security of supply. The question of whether the parties in a long-term contract will accept such a clause and of whether, in the absence of such a penalty, the exporters will favor its long-term clients over others remains to be answered.

Table 9: Impact of long-term contracts on lost load

Country	Long-term contracts share	Lost Load without contracts	Lost Load with contracts
Bulgaria		40%	100%
Croatia		42%	60%
Great Britain			13%
Greece	63%	9%	
Hungary			5%
Ireland			87%
Italy	62%	14%	
Portugal	58%	37%	
Romania	16%		69%
Slovakia			100%
Slovenia		23%	100%
Spain	27%	9%	5%
Sweden			49%
Turkey	54%	20%	
Ukraine	39%	62%	52%

Ratio of lost load over demand during the crisis months (in %)

2.4.3. Conclusion

Summarizing the assessment of the European supply security situation we can derive three main insights for Europe's energy policy:

First, the dependency of Europe on Russian supplies does pose a threat of undersupply in case of supply interruption, and one may think about measures to tackle this threat. The projected extension of the Southern import corridor might help to reduce, at least to some extent, this dependency, especially for Southern-Eastern Europe. Similarly, a strategic storage reserve in the range of 20% to 30% of storage capacity can cover a large share of potential supply shortages. Furthermore, long-term contracts can enhance the supply security of the contracted party, if they ensure supply during general shortage conditions. Which of those policy options (or which mix) is to be favored also depends on the different aspects that the measures provide for the involved parties under regular conditions. To that extent, the strategic storage reserve only provides benefits in case of crises, not in normal condition. On the other hand, investments and long-term contracts can also possess positive impacts on the market under normal conditions. These effects need to be considered.

Second, the capability of the European gas market to counter short-term supply disruptions strongly depends on the global market conditions. This is most evident with the under-usage of LNG terminals in some cases, as the global market does not necessarily provide the export capacities needed. Thus, the value of import infrastructure always

depends on the possibility to activate alternative exporters in case of changing supply conditions. Consequently, a purely infrastructure-oriented security assessment can underestimate the threat of supply shortages.

Third, the results clearly indicate the benefit of a coordinated European effort to counter short-term supply disruptions. Purely national approaches will lead to suboptimal decisions and require a higher effort to achieve similar outcomes as a coordinated approach. However, the diverging supply and storage structures of European may result in conflicts between the interest of the national interests and the overall welfare, as providing own storage for neighbors or opening up long-term contracted supply can worsen one's own supply situation, despite an overall positive welfare impact. This could call for a clear regulation of the management of crisis situations to avoid conflicts of interests and delayed responses.

2.5.   Comprehensive Indicator Assessment

As indicated in the previous section, assessing the supply security of the European natural gas market is a complex endeavor. The notion of supply security includes different aspects and dimensions. While we rely on a set of different scenarios to address some of these dimensions in the previous sections, our assessment remains far from comprehensive. In this section, we aim to extend the previous model outlet to include a broader evaluation of the European supply security. In the following section, we provide a short review of the different supply security dimensions and approaches, explain the underlying model adjustments, and present the updated analysis.

2.5.1. Supply Security Indicators

While a notion of central importance, supply security is not easily defined. It emerged in the 1970s in the context of energy, notably in relation to the two oil shocks which led to soaring oil prices. Initially, import dependency was considered as the first and foremost driver of energy insecurity. The notion subsequently widened over time. Kruyt et al. (2009) highlight four main dimensions of supply security: the (physical) availability of supply, its accessibility (i.e. geopolitical considerations), its affordability and its environmental or social acceptability. Alternatively, supply security is often subdivided into short-term security (mainly concerned

with the resilience of the system to an outer shock) and the long-term one (linked with the diversification of the supply portfolio and the adequacy of the system).[17]

A parallel notion is the one of diversity. Stirling (2010) defines it as the "pursuit of an evenly balanced reliance on a variety of mutually disparate options"'. Its basic rationale ("do not put all your eggs in the same basket") finds application in numbers of domains in economics, among which the study of supply security. Analyses of the diversification of the supplier-mix are a classical basis for supply security evaluations

Numerous indicators attempting to describe and quantify supply security have been designed over the years. Sovacool and Mukherjee (2011) listing more than 350 different indicators of energy security is rather symptomatic of this fact.

As a first approximation, simple indicators of supply security are often used (i.e. reserves to productions ratios, energy intensity, the share of fossil fuels or the import dependency of various energy carriers). In a more general context, the market share of each supplier, the proportion of long-term contract or the share of high-risk history suppliers and routes might be considered. These metrics allow to grasp the dependence of a market on given commodities, suppliers or routes. Yet, their narrow coverage and simplistic approach limit their usage to crude assessments. Moreover, they cover a single dimension of supply security, and are limited to static assessments.

A further strand of indicators is characterized by the consideration of diversity as the key driver of energy security and consequently refines on the simple market, supply or contract shares considered before. As portfolio diversification in finance, diversity is regarded as a simple yet powerful method for mitigating risks. Stirling (1998) argues that diversity is best represented by the Shannon index which is extended by Neumann (2004) to assess supply security. Neumann's approach integrates a political risk index as well as the ratio of domestic production to the evaluation of supply sources diversification.[18] In parallel, other indicators of diversification have been used as basis for energy security evaluation. The Herfindhal-Hirschmann index (HHI), which is commonly known as a measure of the concentration of firms in a market, is notably used by Le Coq and Paltseva (2009). Stirling (2010) proposes a comprehensive framework to assess energy security using a heuristic approach with three dimensions: variety, balance and disparity.

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[17] For a thorough review of the various definitions of supply security and its various dimensions, one can notably refer to Winzer (2012).

[18] Building upon this idea, Jansen et al. (2004) propose four different long-term indicators derived from the Shannon index, notably considering the diversity of energy sources and of the imports thereof, the political risks and the level of resource depletion.

There are two main limitations to diversity-based indices. First, they evaluate the diversification of supplier portfolios on a static basis. The current diversification is measured, disregarding potential alternatives and substitutes. Moreover, a consumer benefiting from a well-balanced portfolio may nonetheless be exposed to shortages in the event of deliveries interruption from one of the supplier. Since the diversity-based indicators only consider the realized market shares, they neither recognize a substitution alternative nor technical limitations of the current portfolio, thus yielding an incomplete evaluation of the situation. Second, these indicators measure supply security along the sole dimension of the portfolio diversification. Yet, numerous other factors influence supply security; to name a few: the reaction of the demand and supply side, the possibility to stockpile the goods or the nature of the commercial relationships.

There are other indices that aggregate numerous factors related to supply security into a single index; among them the supply-demand (S/D) indicator of the European Commission (Scheepers et al., 2006), the IEA ESI_{price} index based on the HHI and the IEA ESI_{volume} index measuring the physical unavailability of gas (see Lefèvre, 2007). Additionally, the IEA has further developed the Model of Short-term Energy Suppy (MOSES) (Jewell, 2011), aggregating various risk and resilience factors related to the external and domestic dimensions of different energy carriers. These aggregated indicators suffer two main caveats. First, they represent an ex-post evaluation of the situation on a given market. Hence, they offer limited guidance for decision-makers when evaluating the impact of various policies or infrastructure projects on supply security. Second, they disregard dynamic aspects, such as demand adaptation to shocks or global market trends. Thereby, they might yield an unrealistic assessment of the situation.

A further strand of assessments, similar to the analysis of Section 2.4, is based on stress tests and simulation approaches. These typically rely on modeling techniques to simulate shock scenario or extreme conditions. The stress tests pursued by the European Union and inspired by the financial market stress tests are prominent examples of this methodology. For instance, European Commission (2014a) simulates the collapse of either the Russian-Ukrainian pipeline or of all Russian exports both during a period of one and of six months. Recently, the European Network of Transmission System Operators for Gas followed a similar approach to publish a union-wide study on the simulation of gas supply and infrastructure disruption scenarios (ENTSOG, 2017). Their study is based on a detailed technical model of the European gas system. They identify various risk scenarios for the European gas system and simulate them for three cases of peak demand. The collapse of

the Russian-Ukrainian route or the disruption of all exports from Algeria are, among others, tested in the study. The choice of scenario represents the one of the main limitation of these approaches. They often tend to solely consider scenarios that have occurred in the past or that might seem likely to one's mind. A scenario-based approach bears the inherent limitation of the selection of scenarios, and thus the risk of omitting relevant cases. Furthermore, these approaches lack a unified indicator for the quantification of supply security, as they generally rely on ad hoc assessments or are interpreted qualitatively. Finally, the studies tend to provide a detailed technical formulation of the supply, but neglect the responsiveness of the demand side, thereby disregarding its adaptation possibilities.

Lastly, an approach regularly used in the evaluation of energy security is the so-called N-1 rule developed by the European Commission. This rule is both a methodology to evaluate supply security and a "minimum standard" of security which all member states must comply with (European Commission, 2014b). The rule aims at determining whether a country is capable of satisfying its demand in spite of the disruption of its single largest infrastructure – be it an import, production, LNG or storage capacity. The disruption represents an extreme event with a statistical probability of once in 20 years (European Commission, 2010). Market-based demand-side measures are also considered in fulfilling the obligation. This methodology presents two majors caveats. First, the assessment is a purely static one. Therefore, it neglects market dynamics, for instance global shortages in supply which could result in energy insecurity even when complying with the N-1 rule. Second, the analysis is limited to a single scenario of disruption, whereas a network often consists of numerous nodes and lines that are crucial to its functioning. Owing to these flaws, the N-1 might yield unrealistic evaluations of supply security.[19]

Against this background, we aim to combine the different dimensions of the above described indicators into a holistic approach. Specifically, our indicator measures the ability of a market to cope with various interruptions of the network services and supply structures. We account for the technical structures of the market while at the same time including demand reactions and market dynamics.

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[19] It is to be noted that new security of gas regulation of the EU establishes a more dynamic approach of the supply side based on hydraulic modelling.

2.5.2. Indicator Design and Model Adjustment

To derive a comprehensive indicator, we draw on Section 2.4 and extend the disruption simple Russian-Ukrainian disruption to all the relevant types of interruption scenarios to include technical pipeline outages, complete supply interruptions of specific suppliers, as well as politically induced disruptions of import corridors. Further, to include the consumers' reaction, we replace the previously used model structure with a fixed demand during the crisis months derived from average market conditions (D_{nit} is a parameter during the crisis, see Section 2.4) to a fully elastic demand representation (D_{nit} remains a function during the crisis). This allows an easy incorporation of different time dimensions.

The specific individual interruptions are modeled as shock cases. For this, the transmission or transport capacity or the production capacity of the respective node are iteratively set to zero for a given time period. Once the shock realizes, the market attempts to cope with the disruption by finding alternative supply sources, which are constrained by the global market dynamics. In parallel, demand adapts to the disruption adjusting to increasing prices according to the demand elasticity.

To evaluate the impact of the crises on the market, we compute for each interruption the ratio of the consumer surplus in the crisis case over its counterpart in the undisturbed base case. In order to obtain a single indicator, the different individual shock scenarios are weighted with a corresponding risk factor. Formally the indicator is defined as follows:

$$\Phi_n = \sum_c \lambda_c \left(\frac{\sum_i \omega_i \frac{CS_{i,n}^{crisis}}{CS_{i,n}^{base}}}{\sum_i \omega_i} \right)$$

with *c* as the classes of considered shocks and λ_c as the respective weight of this class; *i* are individual disruption scenarios, and ω_i as their respective weight in the shock class *c*. CS is the consumer surplus at country *n* in scenario *i* under the disruption (*crisis*) and normal (*base*) market conditions.

We consider three classes of disruptions:

(1) Technical failures of pipelines: we consider the disruption of each pipeline due to, e.g., an explosion or to severe leaking.

(2) Collaps of gas producing countries: We simulate the disruption of production of each supply country due to geopolitical reasons like wars or major internal turmoil. In these scenarios, the country's complete gas infrastructure is disrupted and its demand set to zero.

(3) Pipeline disruptions due to political reasons: Several politically-driven pipeline disruptions are considered, representing for instance retaliatory outages linked to geopolitical tensions between two countries. For this class, we simulate the disruptions of all major European import canals (e.g. Algeria-Spain, Libya-Italy, Russia-Ukraine, etc.).

The weights for each scenario (ω_i) depends on the underlying logic of the interruption case. In the technical failures scenarios, we use the length of each pipeline as weight since the failure rates of pipelines are often assumed to linearly depend on their length (see notably OGP, 2010). For both the collapse scenario class and the geopolitical interruption one, we make use of the World Governance Index compiled by the World Bank–more specifically the estimated index of "political stability and absence of violence" (World Bank, 2016). Since we use three different classes of disruptions, we have to choose additional weights (λ_c) to aggregate the intermediary results of each set to a single compound one. For the present analysis, we restrict ourselves to an equal weight for all three classes, thus putting equal importance to all types of disruptions. Table 10 summarizes the designed interruption scenarios and their weighting strategies.

Table 10: Summary of scenario assumptions and weights

c	Scenario	Type	ω_i	λ_c
1	Technical pipe failure	Line	Distance-based	1/3
2	Geopolitical country collapse	Node	Worldwide governance indic.	1/3
3	Geopolitical pipe failure	Line	Worldwide governance indic.	1/3

Possible shocks affecting the European gas market display a vast range of duration. A technical failure might be overcome within days, while larger breakdowns may take months to be solved. Given the stylized nature of our model and its monthly formulation, we design disruptions lasting four months and set them during winter (December to March), when gas consumption is peaking (similar to the scenarios of Section 2.4).

The demand elasticity of gas diverges strongly depending on the considered time horizon. In a short-term perspective, numerous consumers are captive, with limited substitution alternatives (e.g. households using gas as heating fuel). From a longer-term viewpoint, consumers may adapt and substitute more easily. Households may opt for new heating or cooking systems, while firms might invest in alternative technologies. To account for this discrepancy, we compute our indicator twice; once in a short-term and once in a long-term perspective. The main difference between a short and a long-term setting should be the possibility for agents to invest in substitutes. Since the model we use for our empirical

implementation does not allow to simulate investment behaviors, we approximate this difference with 50% higher demand elasticities in the long-term case (see the appendix for a detailed description of the elasticity adjustments). In order to maintain comparability between the short and the long-term cases, we simulate the exact same disruption scenarios in both cases. Thus, the sole difference between the two settings lies in the demand elasticities. More details on the formulation of the long-term case can be found in the appendix.

2.5.3. Assessment Results

To test the properties of the indicator and evaluate its suitability as a tool for policy support we first perform a general assessment and comparison with other indicators using the *Baseline 2013* case as example. Afterwards we perform a comparison of different supply security policies using the indicator.

2.5.3.1. Indicator Assessment and Comparison

Table 11 shows the results for the baseline 2013 setting with a short (ST) and long-term (LT) perspective. Numerous countries are graded with a high score, among others Belgium, France or Switzerland. Five states score 0.99 or higher, meaning than, on average, the crises lead to a consumer surplus reduction of less than 1%. On the other hand, some countries achieve poor results. Ukraine, Finland and Turkey achieve the three lowest scores, with welfare reduction of up to 5%. All three are heavily dependent on Russian gas – the entire Finish demand stems from Russia, while 69% of the Ukrainian and 33% of the Turkish ones are supplied by Russian gas. In general, Western Europe tends to score high in the indicator. This is notably explained by the important interconnections of the network in Western Europe which allows for numerous alternatives.

One further notices from Table 11 that countries which can rely on domestic extraction tend to do well in our indicator. Denmark or Great Britain score above the average, notably thanks to their self-sufficiency ratio. Nonetheless, one also finds evident counterexamples like Ukraine, Poland or, to a lesser extent, Romania. Additionally, Austria, Belgium or France prove that countries with high import dependency are not deemed to supply insecurity. Their geographical location allows them to rely on a variety of import canals – for instance Belgium has direct pipeline connections with Norway, the Netherlands, the UK and Germany, in addition to a LNG receiving terminal. In general, LNG has a positive impact on supply security as does the number of major cross-border connections. Countries with few connections, for instance Finland or Romania, have less substitution alternatives in case of a

supplier disruption. Some of these countries nonetheless achieve good levels of supply security. Sweden for instance has a single direct liaison with Denmark, whom is in turn linked solely with Germany. These two countries both score high in our indicator, most notably thanks to a high level of domestic extraction. When relying on a single connection, the nature of one's neighbor is of utmost interest. Finland scores lower than countries in similar situations, notably owing to its dependency on a somewhat unstable neighbor; Russia.

Table 11: Short and long-term SoS indicator and structural indicators, Baseline 2013

	Φ_n^{ST}	Φ_n^{LT}	Production / Demand	LNG / demand	cross-border connections
Austria	98.9	99.6	-	-	3
Belgium	99.4	99.7	-	46%	4
Czech Republic	98.5	99	7%	-	2
Croatia	98.8	99.2	-	-	2
Denmark	98.9	99	131%	-	1
Finland	95.4	95.2	-	-	1
France	99	99.5	-	58%	6
Germany	98.5	98.8	15%	-	8
Great Britain	98.2	98.6	50%	66%	4
Greece	97.1	97.8	-	88%	2
Hungary	98.5	98.9	22%	-	4
Ireland	97.9	98.4	-	-	1
Italy	97.5	98.7	12%	21%	5
Poland	96.6	97.3	34%	-	4
Portugal	98.9	99.3	-	316%	1
Romania	97.6	97.6	86%	-	2
Slovakia	99	99.5	-	-	4
Slovenia	99	99.6	-	-	2
Spain	98.8	99.4	-	213%	4
Sweden	98.9	99.1	-	65%	1
Switzerland	99.2	99.6	-	-	3
Turkey	96.5	97.2	-	24%	4
Ukraine	94.6	95.1	45%	-	3

The striking feature when comparing the long-term indicators to the short-term ones is the overall higher level of supply security, with the sole exception of Finland. On average, countries face a 0.4 percentage point smaller reduction of their consumer surplus; Italy even increases its score by 1.2 percentage points. Our long-term assessment of supply security uses 50% higher demand elasticities, allowing customers to substitute more towards alternative fuels or more efficient technologies. Consumers are thus less dependent on gas

and adopt a more flexible behavior. Therefore, one is not astonished that, for the vast majority of countries, the long-term framework yields smaller welfare impacts than the short-term one.[20] However, the different elasticities have no impact on the ranking of countries. The lowest scoring countries stay on the bottom of the scale (e.g. Turkey, Ukraine or Finland), the medium scoring countries are in the middle in both cases (e.g. Czech Republic, Germany or Great Britain), whereas the highest ranked one always achieve the best grades (e.g. Belgium, France or Portugal).

To assess whether the comprehensive indicator obtains different supply security assessments than existing ones, we compare it to the Herfindahl-Hirschman index (HHI) for market concentration, the Shannon-Wiener index (SWI) as well as its augmented version, the Shannon-Wiener-Neumann index (SWIN2) (Neumann, 2004), the S/D indicator by Jansen and Seebregts (2010), the REES from Le Coq and Paltseva (2009) and the EU's N-1 evaluation (European Commission, 2014b) (see Section 2.5.1 for a description of each indicator). Table 12 displays the values for the different indicators. Since all indicators use different scales and to ensure the readability of the table, we cluster all results from one, being the best achieved result, to five, the worst one, for each indicator respectively.

Overall, we note a strong heterogeneity of results among indicators. Unanimous evaluations represent an exception. Ukraine, which achieves the lowest scores in all metrics, and Switzerland, that is awarded the highest grades in all but one indicator, are the two best aligned countries – although it must be noted that not all indicators are available for these two countries. Rather well aligned results are for example: Finland, negatively judged by the large majority of indices, Poland, by most of them, or Romania, always scoring in the lower end of the scale. On the other hand, our indicator and the N-1 assessment evaluate Austria as secure, whereas the rest of the literature sets the country on the lower end of their scale. The opposite also happens, notably for Greece or Italy, which obtain good results in the diversity-based indicators, but poor ones in the rest.

The correlation between the current metrics and our indicator allows to grasp the overall alignment between the methodologies. The best fit is achieved with the N-1 approach. Notwithstanding its limitations, the N-1 possesses some similitudes with our methodology in the definition of supply security and the aspect covered, thus explaining the good alignment.

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[20] As the different elasticities are only rough approximations aiming at sketching customer response the results should not be taken for their absolute values, but rather interpreted as qualitative assessments of the impact of higher substitution alternatives for customers. Second, since our indicator is a ratio of consumer surplus under crisis and base conditions, we solely assess the change in welfare, not its absolute value. Different elasticity means different demand curve, hence different absolute welfare levels; therefore, a smaller percentage welfare change does not automatically imply a smaller impact in absolute terms.

Further, the correlation the SWIN2 is also important, notably explained by the indicator's broader stance on supply security than the simpler HHI or SWI. On the other hand, the IEA's S/D and the plain HHI both have a negative correlation, while the REES displays a correlation of zero. Given the important discrepancies in terms of methodology between these indices and ours, one is not particularly surprised by this result.

Table 12: Indicator comparison

	Φ_n^{ST}	HHI	SWI	SWI2	S/D	REES	N-1
Austria	2	4	4	4	4	5	2
Belgium	1	4	4	2	4	2	1
Czech Republic	3	2	1	3	2	4	1
Croatia	3	1	1	2	n/a	n/a	4
Denmark	2	5	5	5	1	1	2
Finland	5	5	5	5	4	3	4
France	1	3	3	1	2	2	3
Germany	3	2	3	1	3	3	1
Great Britain	4	3	4	2	1	1	3
Greece	4	1	2	3	n/a	4	5
Hungary	3	2	2	4	4	5	4
Ireland	4	1	2	1	n/a	1	2
Italy	4	1	2	2	5	4	4
Poland	5	5	5	5	3	2	4
Portugal	2	3	3	2	5	3	4
Romania	4	3	4	4	2	4	3
Slovakia	1	4	5	5	5	5	1
Slovenia	2	2	1	3	n/a	3	5
Spain	3	4	4	4	n/a	2	3
Sweden	2	3	2	3	2	1	5
Switzerland	1	1	1	1	n/a	n/a	2
Turkey	5	2	3	4	n/a	n/a	n/a
Ukraine	5	5	5	5	n/a	n/a	n/a

Clustered assessments of supply security by different indicators: our own methodology, the Herfindahl-Hirschman index (HHI), the Shannon-Wiener index (SWI), the Shannon-Wiener-Neumann index (SWI2), the S/D indicator, the REES from Le Coq and Paltseva (2009) and the EU's N-1 evaluation. Each indicator assessment is transferred into a 1 to 5 scale, with 1 representing the best achieved result, to 5, the worst ones.

Summing up, we can draw two main conclusions from the comparison of our indicator to some of the currently used ones. First, the rather weak correlation between our indicator and the established measurements – or even its absence in some cases – cannot be interpreted

as a negative sign for our methodology. All indicators measure different dimensions of supply security, thereby necessarily leading to diverse results. Moreover, the broadest approaches and those which share common characteristics with ours (the N-1 and the SWIN2) display a strong correlation. This confirms our belief that the developed indicator covers more dimensions than the current ones. Second, the blurred definition of supply security mechanically leads to very diverse approaches for its measurement. Absence of a common and accepted definition, it seems impossible to achieve a common ground so that approaches can truly be compared to one another.

2.5.3.2. Policy Evaluation

To further test the suitability of the indicator and extend the supply security assessment we now use our indicator to evaluate three infrastructure projects and one policy, which are broadly considered as positive for the European gas security. Specifically, we introduce following projects:

- *SGC & Reverse Flow:* Combining the pipeline extensions of the Southern Gas Corridor (SGC) and the opening of a South-North route from Italy to Germany and Belgium thanks to the technical transformation of the existing pipelines.
- *LNG:* Additional LNG regasification terminals in Europe, notably Croatia, France, Spain, and Sweden[21]
- *Nord Stream 2:* Doubling the transport capacity of the Russian-German connector.
- *Strategic storage*: Implementation of a strategic storage policy at EU-level as in Section 2.4.2.1 with a 30% strategic reserve from November to December and 20% from January to February. The strategic reserve may only be used in case of crisis on the market or at the end of the period.

For each of the projects we assess the supply security situation using the above described indicator logic.

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[21] The list of LNG and storage projects can be retrieved from Gas Infrastructure Europe (2015)

Table 13 shows the indicator values for the different projects. One can observe that the three infrastructure scenarios have a rather modest impact on the indicators of European gas security. A majority of countries obtain approximately similar scores in *SGC & Reverse Flow*, *LNG*, or *Nord Stream 2* as in *Base* without any further infrastructure projects. This concerns notably states with already high levels of supply security, among others Austria, Denmark, Spain, France or Sweden. Low grade ones, for instance Finland or Poland, also tend to be relatively unaffected by the new infrastructures.

Overall the two projects *SGC & Reverse Flow* seems to have only a limited impact on the European natural gas security. Looking at the countries directly concerned by the pipeline projects, Greece and Turkey, both obtain large improvements of their score, up to two percentage points for the latter. On the other hand, neither Italy nor the rest of Europe seems to be significantly impacted by the additional pipelines. The *LNG* setting also displays an overall minor impact, yet some individual effects are to be noted. Sweden sees its security improved thanks to its enhanced import capacity. France and Spain, since they already benefited from high levels of supply security beforehand, do not, or only marginally, improve their score. Croatia and Poland do not display significant variations of their score despite the new LNG terminals. Indirectly, Portugal benefits from the enhanced import capacity of its neighbors. Finally, the extension of the Nord Stream pipeline yield slightly higher gains than the previously tested infrastructures. The positive effects are both apparent for countries situated close to Germany (e.g. Austria, Belgium, France or Switzerland), who benefit from its enhanced import capacity, and in regions more remote (e.g. Croatia, Great Britain, Ukraine or Turkey). The latter are indirectly impacted, as the Nord Stream 2 frees up capacity on other import canals, be it from Russia (e.g. towards Ukraine or Turkey) or from further sources (e.g. LNG import capacity).[22]

In contrast to the infrastructure projects the indicator shows rather large gains of supply security through the implementation of a strategic storage policy. Thanks to the policy, the vast majority of European countries obtain higher score than without the storage obligation; the average result increases by 0.7 percentage point.[23] The result is in line with the

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[22] As Nord Stream 2 increases the dependency on Russian gas, this result heavily relies on the political risk index assigned to Russia.

[23] The presence of values above 1.0 for some countries (Austria, Slovenia and France) indicates that a crisis situation actually improves the consumer surplus of those countries. This is a result of the underlying storage implementation. The lower storage bound is removed in all cases of crises, regardless of whether a country is actually affected by the interruption or not. If a country is not impacted by the event, neither in terms of quantity nor of price, but is still allowed to use its security buffer sooner than in the base case, a crisis might turn out to be welfare enhancing for him. Hence, provided a country is rarely impacted by the crises, its average result might lie above the 1.0 value.

assessment carried out in Section 2.4 and again highlights the benefits storage has for managing supply shortages.

Table 13: Indicator values for the different SoS measures/policies

	Base	SGC&RF	LNG	NS 2	StrStore
Austria	98.90	98.90	99.00	99.40	100.10
Belgium	99.40	99.40	99.40	99.60	100.00
Czech Republic	98.50	98.40	98.50	98.90	99.40
Croatia	98.80	98.70	98.80	99.10	99.40
Denmark	98.90	98.90	98.90	98.70	98.80
Finland	95.40	95.40	95.40	95.40	95.90
France	99.00	99.00	99.00	99.30	100.20
Germany	98.50	98.40	98.50	98.70	99.00
Great Britain	98.20	98.10	98.20	98.50	98.60
Greece	97.10	97.90	97.20	97.30	98.20
Hungary	98.50	98.50	98.50	98.80	98.90
Ireland	97.90	97.80	97.90	98.30	98.50
Italy	97.50	97.50	97.60	98.00	99.00
Poland	96.60	96.60	96.60	96.80	97.70
Portugal	98.90	98.90	99.00	98.90	99.20
Romania	97.60	97.90	97.60	97.70	97.10
Slovakia	99.00	98.90	99.00	99.40	100.00
Slovenia	99.00	98.90	99.00	99.40	100.10
Spain	98.80	98.80	98.80	99.00	99.60
Sweden	98.90	98.90	99.10	98.70	98.80
Switzerland	99.20	99.10	99.20	99.40	99.80
Turkey	96.50	98.50	96.60	96.80	97.20
Ukraine	94.60	94.80	94.60	94.70	96.60
Average	98.1	98.2	98.1	98.3	98.8
Std. Deviation	1.2	1.1	1.2	1.3	1.2

Comparing the results of the indicator analysis to the SOS assessment in Section 2.4 we can observe some differences in the assessment for specific countries. This is a natural result of the more extensive coverage of the indicator assessment compared to the singular case study forming the basis of the SOS analysis in Section 2.4. The latter only highlights the impact of the Russian-Ukrainian shortfall whereas the former captures all possible cases. As Russia is one of the main suppliers the limited case study assessment nevertheless identifies many countries as critical that also score low on the indicator assessment, namely Bulgaria, Greece, and the Ukraine. However, other countries that suffer from the lost load in some of the scenarios in Section 2.4. have a more positive overall evaluation with the comprehensive

indicator, like Croatia, Portugal and Slovenia. And some countries that are not impacted in the case study show a low overall indicator level, like Poland and Finland.

These comparisons highlight the main difference between a singular case study and an extensive multi-case assessment. As a case study may omit other important shortage situations the results can provide a too positive picture for critical countries. At the same time a comprehensive assessment may put weight on cases that some could consider as unimportant and therefore lead to a too negative assessment. The possibility to alter the weights of the different scenarios in the indicator assessment aims to address this concern.

2.5.4. Conclusion

By combining both demand and the supply dynamics of natural gas markets, our indicator provides an additional dimension to the supply security assessment. Especially in comparison to more one-dimensional indicators like the HHI, our evaluation provides a more comprehensive judgement of market conditions. One of the main advantages of the indicator is its suitability to compare different approaches concerning supply security. If those measures address different dimensions of a system, i.e. technical or infrastructure aspects and operational or market choices, the currently established methodologies usually fall short in providing insights for all cases.

Our indicator confirms the insights drawn from the Ukraine-Russian scenarios that countries having a high dependency on Russian supplies are subject to strong security concerns. As the methodology also includes disruptions on other potential import routes, the fact that the main source of concern remains Russia highlights the prominence of the relationship with Moscow for Europe's gas market. Neither the African supplies nor the Middle East have a similar impact.

The comparison of different infrastructure options with a strategic storage policy also confirms the finding of the previous sections. Albeit improving the overall supply situation for Europe, the overall impact of the additional investments is rather limited. Measures directly aimed at crisis management like storage obligations seem more efficient in this regard.

2.6. Conclusions

The recurring political tensions between Moscow and Kiev about gas – which culminated in delivery interruptions in 2006 and 2009 – and the liberalization process of the European gas

market raised vast concerns about energy security. Numerous research efforts have been devoted to tackle this issue, yielding heterogeneous insights. In this context, the present study draws on existing literature on the modeling of energy markets and on energy security. We formulate an optimization model of the European natural gas market, accounting for technical details on the supply side, as well as on the transport sector (both pipeline and LNG) and the storage one. Moreover, we ensure the linkage to the global market via aggregated consumption and production hubs. The model, which is designed with a monthly resolution to capture the market's seasonal dynamic, helps addressing specific questions, notably through scenario analyses.

The results indicate a general sufficient European gas infrastructure under normal market conditions. The existing pipeline and LNG infrastructure in Europe and the expected increase in global gas production are sufficient to compensate the reduction in indigenous European gas extraction. European price levels are reflecting transport costs differences with sufficient pipeline and storage capacity. However, the strong dependency on Russia leads to subsequent threats on supply security. Based on these general system characteristics the different supply security assessments allow three main conclusions.

First, the projected extension in terms of LNG terminals and the Southern Gas corridor might help to improve the security of supply, yet are not sufficient to completely eliminate the threat of demand curtailments in case of Russian-Ukrainian transit disruptions. North Stream 2, on the other hand, reduces the importance of the Ukrainian route, on the expense of increasing the reliance on Russian gas. Equally important to Europe's infrastructure is the capability of the global gas market to provide flexible gas that can be reallocated towards Europe. The expected increase in global production capacities is likely to improve this situation. However, if the market cannot react, additional import capacity may not provide any benefit for critical situation. In this context, the role of reverse flows is even more important, as they allow gas imports to be reallocated and to reach those regions with supply shortages.

Second, policies tackling the management of storage seem a cost-efficient method to meliorate supply security. A relatively modest amount of strategic storage of 20% to 30% already allows to cover the majority of demand curtailment for a four-month Russian supply shortage. Assuming further short-term flexibility options that cannot be represented with the model approach, like demand management and bi-fuel consumers, this is likely to suffice for most of the crisis situations. At the same time the costs of this policy is rather modest as the reduced capability for seasonal arbitrage is not yet significantly reduced at this obligation

level. Furthermore, gradually freeing up the strategic storage over the winter months will further reduce the negative market impacts.

Third, to achieve an efficient crisis management, coordination across European countries is essential. The model assumes a perfectly linked market and reallocates gas between countries. Real market conditions are likely to deviate from this ideal. If introducing security storage obligations, one must set clear rules on their operation during a crisis situation. As the storage capacity in relation to the demand varies greatly across European countries, it seems crucial to ensure collaboration among neighbors and coordination in crisis management. The assessment of the role of long-term contracts points in a similar direction. While they provide higher supply security for the signing party, they can negatively impact other European countries. An optimal European policy approach therefore is likely to trigger trade-offs and may potentially require compensations to incentivize all countries to participate.

Generally speaking, the overall assessment for Europe's supply situation is relatively positive, as the region already possesses most of the needed structures to address longer shortages. As the country is directly dependent on Europe, this also translates into a general positive picture for Switzerland. Being linked to Germany, which is an important gas hub in case of supply shortages, provides Switzerland with a good position from an infrastructure perspective. Given that most of the critical situations concern Russian supplies, its central European position provides a natural buffer. For Switzerland, the extension of Nord Stream also presents an additional security improvement, as the vast import capacities towards Germany further increase the probability that sufficient gas will be available in Central Europe, on the expense of an increased dependency on Russia.

However, as Switzerland is not part of the European Union and does not possess own storage facilities, it needs to ensure a close linkage to secure access to those capacities in critical situations. It must be noted, that the present study does not account for the flexibility provided by the dual-fuel consumers. In the diverse simulations, Switzerland was never subject to critical demand curtailments. As the model assumes a perfect coordination and threats all European countries equally, this is a natural translation of the above described favorable location of Switzerland. In case of exclusive EU storage policies or other regulations of flow allocation, this may not hold. However, given the scarce supply situation in Italy, the linkage between North and South Europe via Switzerland is likely to provide a natural safeguard against too exclusive policies. Summarizing, the supply security for Switzerland is likely to remain high.

3. The Swiss Natural Gas Market: Redesign as Entry-Exit?[24]

In the second part of our study, we turn from the European market dynamics to the Swiss market and its envisioned restructuring. Given the natural monopoly character of natural gas, networks are the central element of restructuring and liberalization efforts. To promote competition, energy regulators seek to ensure non-discriminatory third-party access to the transport network as well as to appropriately compensate the network owner for its costs. To that aim, the regulator must decide on various market design characteristics, notably the ownership structure (e.g. strict unbundling between energy providers and network owners or simpler legal unbundling) and the calculation of access fees.

Defining the respective access fees for the natural gas network is a twofold problem. First, the regulator must define the adequate remuneration for the network owner (i.e. setting the level of cost to be recovered). Second, he must decide on how to allocate these costs between the network users. The first question is part of a classical regulatory problem which can be tackled in various ways; rate-of-return, cost-plus, price cap or yardstick to name a few (see e.g. Joskow (2007) or Armstrong and Sappington (2007) for a thorough discussion). In turn, the second problem is specific to network-based industries such as electricity, natural gas, railway or telecommunication markets. The question to be addressed is how to charge users in relation – or not – with their spatial usage of the network.

Within gas markets, the "entry-exit"' (EE) system has established itself as a popular approach. EE systems introduce two separate fees, one for the injection into the network (entry) and one for the withdrawal from the network (exit). Both the entry and exit charges are set independently for each entry and exit point; the physical path actually followed by the gas between these two points is not taken into account.

In its current organization, the Swiss gas market partially allows for third-party access with a path-dependent allocation of costs, yet solely for industrial customers meeting certain criteria. The allocation is partly path-dependent as the country is divided into six main balancing zones, and the sole cross-regional transport is billed path-dependently. Further downstream, the network users are charged with a uniform price per region and city. In the context of discussions around a liberalization of the gas market, the Swiss Federal Office of

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[24] This Chapter is based on the research paper Abrell, J., Chavaz, L., Weigt H. (2018) 'Entry-Exit market design - Implications for the Swiss natural gas' available on the project webpage, see https://fonew.unibas.ch/de/projects/

Energy, while working on a Gas Supply Act, currently weighs up the introduction of an EE system.

In this chapter, we aim to evaluate the possible implications of a redesign of the Swiss network access towards an entry-exit system. To that aim, we rely on a model-based analysis and simulate various case study. Owing to the nature of the Swiss market and limited availability of data, we restrict ourselves to a stylized model. Nonetheless, we are able to depict the main interactions on the market and to capture the dynamics of an entry-exit system. In the following sections, we will provide a short review on the aspects of network access and entry-exit systems as well as the specifics of the Swiss natural gas market. In section 3.3, we present our model and the underlying dataset. Section 3.4 then presents the study results, while section 3.5 concludes.

3.1. Literature Review

As network access plays a central role in transforming regulated monopoly systems into competitive markets, several approaches on how to allocate network costs among users have been developed. The aim of these approaches is to establish a system along which network owners will be allowed to bill their users, with the overarching goal to ensure an efficient and non-discriminatory access for third parties, while adequately compensating the network owner for its costs. Alonso et al. (2010) highlight the three main possibilities: First a "postal stamp system"' where network users are billed uniformly, regardless of their spatial usage. Hence, neither the injection and withdrawal points nor the actual path followed by the energy are considered. Second, in a "point-to-point" or "distant-based" system, users pay a fee which depends on the path actually used in the network. Longer paths will be charged more than shorter paths. Third, the "entry-exit" (EE) system with two separate fees for injection (entry) and withdrawal (exit). The EE system allows market participants to inject gas into the network at any entry point and to withdraw it from any exit point. Hence, EE separates the physical network (the actual pipelines) from a conceptual or commercial one, where each exit point is linked with each entry point via a central virtual hub.

European authorities and regulators have had a long-standing preference for the entry-exit as method for natural gas market organization (see e.g. CEER, 2002). The EU's Third Package for gas recommends the introduction of an EE organization with a separate booking of entry and exit capacity as the standard market design with the overarching objective of

creating a single European gas market (Yafimava, 2013). This spurred growing research interest on topics related to the EE system.

Vazquez et al. (2012) highlight the benefits of an entry-exit organization around a virtual hub, notably as it reduces the trade specificity of the network, and it enlarges the spatial and time scopes of the market. On the downside, they underline the negative impact of EE on cross-border trade (i.e. between EE zones), the non-reflective usage fees which create cross-subsidies among users and the vanishing investment signals for network owners. Hallack and Vazquez (2013) further deepen these viewpoints, in addition to proposing short-term market-based mechanisms of network service allocation that allow to reveal the users' preferences. Finally, in Hallack and Vazquez (2014), the authors analyze the European and the American network organization with a game-theoretical approach characterizing the network as a common good.

In addition to providing technical details on EE and its pricing, Hunt (2008) addresses in depth the impact of the system on the European gas markets liberalization. The author is dubious about the EE system promoting a competitive European gas market, and proposes remedies to the regulators, notably on the definitions of the system's elements.

Research efforts have also been put in quantitative assessments of entry-exit. Alonso et al. (2010) develop a methodology for the calculation of EE tariffs and apply it for Spain. The authors conclude that the EE fees reflect more accurately the network costs than the, at the time used, postal stamp system. Pickl (2016) simulates the network fees of the Southern gas corridor and of the Nabucco pipeline project, both with a distance-based methodology and with an entry-exit system. The resulting prices are higher for the distance-based pricing; hence, the author concludes to higher margins for the gas producer in an entry-exit regime, assuming constant sales price.

Summarizing, an entry-exit market design presents various advantages and disadvantages. Since gas can be traded independently of location, EE enhances the liquidity of the market, thus promoting trade and competition. Specifically, by introducing a virtual hub, entry-exit reduces entry barriers in the market for new players (see e.g. Hallack and Vazquez, 2013). Further, transparent tariffs ensure a non-discriminatory access to the network. Finally, the two-part tariff structure allows for flexible network use. On the other hand, EE systems require balancing mechanisms to reconcile the conceptual network with the physical one, putting additional burden on the regulator and the market participants. Moreover, as the fees paid do not reflect the costs induced by their usage, EE creates a cross-subsidy between users. For instance, nodes which are located farther away from entry

points tend to pay less with an EE system than with a point-to-point one. The opposite holds for exit points located close to entry points. Finally, on an international scale, "pancaking" effects may arise when transactions cross multiple borders (see e.g. Harris and Wilson, 2012).

3.2. Market Review

As Switzerland does not possess any source of natural gas on its ground, it relies entirely on imports. Switzerland possesses four[25] main import and export canals; two pipelines stemming from Germany, one from France and one going towards Italy (Figure 6). A peculiarity of the Swiss market is the *Transitgas* pipeline which crosses Switzerland bringing gas from Germany to Italy. Roughly two third of the Swiss import capacity stems from *Transitgas*, nonetheless leaving 75% of the pipe's capacity for transit. No storage infrastructure has been built in Switzerland, yet Swiss firms hold shares of a French storage facility.

Figure 6: Swiss natural gas network (Source: Swissgas)

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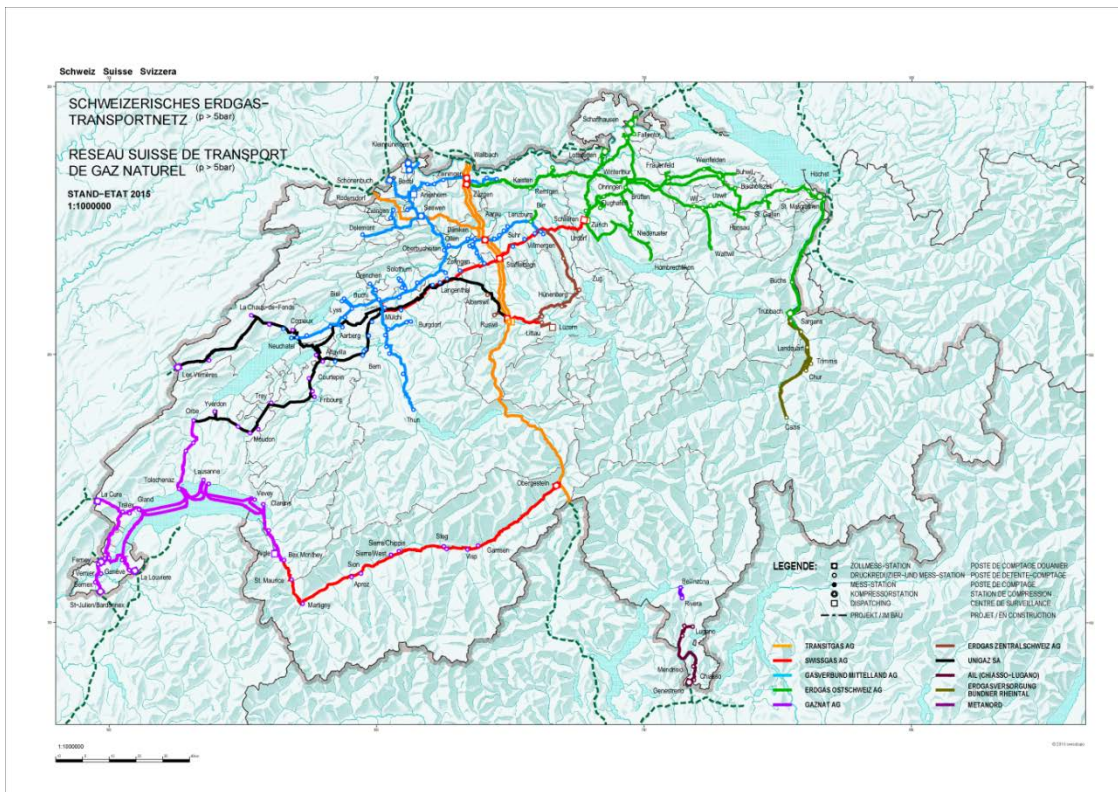
[25] As a side note, there are currently only three large entry pipes, because TENP 1 in Germany is temporarily closed.

In its current state, Switzerland tends to be a strongly fragmented market. Each city is supplied by a sole local monopolist, which is usually a state-owned firm. More than 100 of these local firms exist in Switzerland. The five largest firms represent more than 40% of the total Swiss consumption (VSG, 2016).

The gas providing firms are then regrouped into four regional firms (*Gaznat*, *Gasverbund Mittelland*, *Erdgas Ostschweiz* and *Erdgas Zentralschweiz*), which are owned by the city firms. Finally, the four regional player jointly own *Swissgas*, a national firm mainly responsible for procurement and transport of gas in Switzerland. In addition, two additional "island" regions (*Kreuzlingen* and *Tessin*) are connected with neighboring countries, but not with the rest of the Swiss network.

Albeit local monopolies still prevail for domestic gas consumers, industrial customers act in a partially liberalized market. Bearing the respect of certain criteria (notably: capacity booking above the 150 Nm^3/h threshold, final usage of gas must not be heating), the Swiss law (*Rohrleitungsgesetz*) as well as a private agreement between firms and the gas industry (*Verbändevereinbarung I*) ensure third-party access to the network.

Usage fees of the network are determined partially on a path-dependent basis. Transport across the four main region leads to a path-dependent tariff depending on the injection point. Regional transport is, however, charged with a unique fee for each region; the same applies for local distribution. For all levels of transport and distribution, fees are settled based on the cost to be recovered; the methodology for the calculation thereof is jointly defined by the industry and the authorities.[26]

In the context of current discussions around a *Verbändevereinbarung I* (*"Marktmodell Schweiz 2 Gas" - MACH 2*) and a new law (*Gasversorgungsgesetz*), the Swiss government weighs up numerous changes around the Swiss gas market. Among others, the five current balancing zones may be united into a single one, the network ownership might be legally unbundeld, and a virtual trading hub created.

The most relevant point with respect to the objective of our study is the introduction of an entry-exit (EE) system for the cross-regional and regional transport network. Different options of EE design are up for debate; notably the number of zones, or the integration of the *Transitgas* pipeline into the balancing zone. A still open discussion is the one of whether the EE system would not encompass the local distribution network. Contracts would thus still

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[26] See the Preisüberwacher's study: *Schweizer Gasmarkt und Kosten des Netzzugangs – Ermittlung der risikogerechten Kapitalverzinsung für schweizerische Gasnetze*. Available at: https://www.preisueberwacher.admin.ch/dam/pue/de/dokumente/studien/schweizer_gasmarktundkostendesnetzz ugangs.pdf.download.pdf/schweizer_gasmarktundkostendesnetzzugangs.pdf

have to be made with the corresponding local network operator. Exit would have to be booked at the so-called city gates. The number of entry points has not been settled yet.

Furthermore, initiated by the Swiss Federal Office of Energy, a series of studies tackle related questions around the new organization of the Swiss gas market. Frontier Economics (2015a) addresses the different level of market opening as well as the timing thereof, concluding to positive effects of a liberalization for Switzerland. Closely related to the topic of the present paper, Frontier Economics (2015b) pursues a qualitative study of an entry-exit system for Switzerland, advocating for a deep and broad design of the EE. They identify the main trade-off posed by an EE system as the one between market efficiency (in form of a more liquid trade) and higher burden on network operations (to reconcile commercial and physical network). Given a full liberalization, the authors propose an EE system integrating the local distribution level, while in case of a partial market opening (i.e. only to industrial customers), the city-gates solution is suggested.

A further study (Frontier Economics, 2016) deepens the question of the entry-exit design for Switzerland, notably discussing the city-gate solution and the integration of the *Transitgas* pipeline. Frontier Economics (2015c) addresses the question of tariff setting, both on how to define the regulatory cost basis for network owners and on how to allocate the cost for users. Regarding EE fees, the authors recommend a 50/50 split between entry and exit.

3.3.   Model and Data

To assess the impact of the introduction of an entry-exit system for Switzerland, we formulate a stylized model of the Swiss natural gas market. Our methodology is based on state of the art modeling efforts of gas market, notably Egging et al. (2010). Yet, since we focus on the sole Swiss context, we can make numerous simplifying assumptions.

3.3.1. Model Design

Given the aforementioned characteristics of the Swiss gas market, we formulate our model as follows:

- On the **supply side**, profit maximizing providers import gas from the neighboring countries and sell it to customers. They pay the wholesale price in the import country as well as the corresponding entry and exit fees to transport the gas to its consumption location, while their revenue is the price paid by customers net of the

CO_2 and value added tax. Contrarily to numerous models from the literature, we do not need to consider gas extractors as Switzerland is fully import-dependent. Further, no LNG or storage is required for the representation of the Swiss market.

- The **network** is operated by a perfectly regulated firm; third-party access is thereby guaranteed. The entry-exit fees are ex-ante defined by the regulator so that the sum collected with last year's consumption covers the cost-base.

- On the **demand** side, we model a single type of customer, owing to insufficient data to disaggregate into final consumer categories. Further, we assume a linear demand based on the price and quantities observed in each region.

As a first approach, we make the simplifying assumption that all importers behave like perfect competitors. We can thus formulate a single representative agent who takes the consumer price PD_n as given.

$$\max \Pi = \sum_{nt} \left(\frac{PD_{nt}}{1 + vat} - co_2 tax \right) S_{nt} - \sum_{nt} pi_{nt}\, I_{nt} - \sum_{n\tilde{n}t} (pen_n + pex_{\tilde{n}})\, FP_{n\tilde{n}t}$$

with S_{nt} as the respective supplied gas in period t at market area n, I as the respective imported gas with pi as the import price, and $FP_{n\tilde{n}}$ as the gas transit between market areas and pen and pex as the respective entry and exit prices of the market areas.

The profit maximization is subject to the following constraints, ensuring that the injection at a node (in from of cross-border imports and transported gas) is equal to the withdrawals (the supply to consumers and gas transported to further market areas), the flow between regions respects capacity limitations, and supply to consumers is sufficient to cover demand:

$$I_{nt} + \sum_{n\tilde{n}} FP_{n\tilde{n}t} = S_{nt} + \sum_{n\tilde{n}} FP_{\tilde{n}nt}$$

$$cap_{n\tilde{n}} \geq FP_{n\tilde{n}t}$$

$$S_{nt} \geq D_{nt}$$

The demand-price relation is given by the following linear function:

$$D_{nt} = a_{nt} + b_{nt}\, PD_{nt}$$

3.3.2. Data and Calibration

Our model is calibrated with real market data. For the consumption, we aggregate the daily data provided by *Swissgas* to monthly values. From the same source, we use the regulated cost-basis for each region as well as the import capacity at all entry points to the Swiss

network. Due to lacking data, we assume that congestion within Switzerland does not represent a binding constraint.[27]

We use spot prices at the neighboring wholesale markets gather from Eikon (2017) as import prices. As reference prices for Switzerland, we rely on historical prices database provided by the *Preisüberwacher[28]*, the Swiss governmental body responsible for price surveillance and comparison. We average their local data[29] to our regional dimension. For the entry and exit prices, we divide the regulated base rate of the network infrastructure by the half of the annual consumption in the relevant zone (i.e. either the whole country or each of the four region's one). We use a half-half split, so that the entry and the exit prices are equal. Details on EE fees methodology will be provided in the next section. Table 14 sums up the main data parameters for each region.

Table 14: Main data assumptions

	Annual consumption	**Infrastructure base-rate**
Mittelland	5.28	5.20
Ostschweiz	5.43	5.53
Westschweiz	5.33	7.62
Zentralschweiz	1.0	1.0

Average annual consumption (2014-2016) and infrastructure base-rate. Due to non-disclosure agreements the annual consumption values are normed to Zentralschweiz's one, same for the infrastructure base-rate

The CO_2 tax is set at 84 CHF per emitted ton of CO_2, which translates to 17 cents per cubic meter, while the VAT is of 8%. The elasticity of demand is set at -0.11. As we only have one representative consumer, we opt for a value which is close to one used in our former analysis for the domestic consumer (see Section 2.2.2) but on the lower side to obtain an upper estimate of price effects resulting from changes in demand levels.

Our model has a monthly time dimension so that it captures the seasonality, relevant for the gas consumption. We calibrate the model for the reference prices and quantities of the years 2014 to 2016. Due to limited data, we restrict ourselves to simple spatial dimension, with only four nodes (*Mittelland*, *Ostschweiz*, *Westschweiz* and *Zentralschweiz*)

Table 15 compares the main variables of our simulation with the observed market values. Obviously, the rough and stylized nature of our model prevents us from expecting neatly calibrated results. We choose to focus on consumption calibration rather than on price. As is often the case in natural gas modeling, the obtained prices are rather far away

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[27] This assumption was further confirmed by representatives of *Swissgas*.
[28] http://gaspreise.preisueberwacher.ch/web/index.asp
[29] We use following category: Typ II, which corresponds to the use of a one-family house: 20'000 kWh

from the market ones. This can be explained by a multitude of factors, notably the perfect competition assumption, the assumptions on parameters, and the omission of uncertainty.

Table 15: Model calibration

	Annual consumption		Prices	
	Market	**Model**	**Market**	**Model**
Mittelland	1.0	1.05	97.0	39.3
Ostschweiz	1.0	1.03	96.9	42.3
Westschweiz	1.0	1.06	85.0	42.0
Zentralschweiz	1.0	1.04	102.1	43.4

Model values compared to the observed market data; market value of consumption is normed to 1.0. Prices in CHF/MWh. Values of consumption and prices are averaged for the period 2014 – 2016.

3.4.   Entry-Exit for Switzerland

The objective of the present study is to simulate the implementation of an entry-exit system in Switzerland. When designing such a system, the regulator must decide on various parameters. First, he must define the external and the internal boundaries of the EE system, i.e., at which network points entry and exit will be levied. This is both a conceptual question – e.g. at which layer of network (city gates, local distribution network, etc.) the exit is located – and a geographical one. Second, the pricing mechanism is to be defined – uniform pricing vs. independent price for each entry or exit zone – as well as the split between entry and exit fees. Last, the regulator must decide and enforce a pricing calculation methodology.

As stated previously, the currently discussed scenarios of EE in Switzerland includes a city-gate solution. We will mimic such an implementation, thus solely considering the Swiss transport network. With this functioning, the gas trader must still contract separately with each local distribution network owner. For our model, we consider the import points as entries, while each city represents an exit. Given the stylized nature of our model, we aggregate the entry and exit points to the region where there are located (i.e., *Mittelland*, *Ostschweiz*, *Westschweiz* and *Zentralschweiz*).[30]

Regarding pricing schemes, we test two different designs. The first one with a separate EE price for each of the four regions[31], while the second one represents uniform pricing. For the split between entry and exit prices, as it among others the case in Germany or Italy, we

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[30] A more detailed assessment would require exact pipeline data for Switzerland. Given the data availability on regional level we are restricted to a four node representation.

[31] In a city-gate implementation, there can be different price for each city.

restrict ourselves to symmetric entry and exit prices, so that network operation costs split equally to entry and to exit prices; we thus use two identical prices.

Calculation of EE fees is a complex process. The overarching goal is to ensure that the sum of fees collected by the network operator amount to the costs of providing the network services. One can refer to Hunt (2008) for a thorough description of the various methodologies of EE pricing. The chosen methodology leads to differences in the magnitude of prices and in how network owners are refinanced. Yet, as pricing is *in fine* an exogenous question of policy design, we focus on the relative differences induced by the chosen EE system implementation, rather than tend to a detailed rendering of the price settling. Pricing methodologies can scale up or down the magnitude of the effect of an EE system implementation in Switzerland; yet, the core message is equivalent. Owing to this, we rely on simplified fees calculation.

For the *regional case*, we derive a differentiated entry and an exit price for each region. To calculate this price, we divide the regulated rate base – the amount of assets and capital owned by the network operator – of each region by the consumption in this region. As we use symmetric prices, we then halve the result to obtain both the entry and the exit fees.

$$pen_n = \frac{RateBase\_n}{2 * YearlyConsumption_n} = pex_n$$

Given this definition, gas users are billed for each injection into and withdrawal from a zone, regardless of the actual geographical locations of these actions. Injection in Wallbach or in Hüningen, for example, will cost the exact same price.

Opposed to the previous case, we here use the assumption that the EE system is implemented with a unique entry and exit price in the *uniform case*. All network users are charged the same fee, regardless of the actual path followed by the gas in the network. The EE fees are defined based on following definition.

$$pen_n = pen = \frac{\sum_n^N RateBase\_n}{2 * \sum_n^N YearlyConsumption_n} = pex = pex_n$$

Table 16 represents the different EE fees for both cases. As the prices are calculated based on proprietary data, we normalized the *Uniform pricing's* ones to the unity.

Table 16: Normalized Entry-Exit prices

	Regional pricing	Uniform pricing
Mittelland	0.86	1
Ostschweiz	0.89	1
Westschweiz	1.27	1
Zentralschweiz	0.89	1

Values are averaged for the period 2014 – 2016. Due to non-disclosure agreements the values for uniform pricing are normalized to one.

We introduce an additional difference between the *Regional pricing* case and the *Uniform* one. In the first one, we consider the four zones as separate EE systems. This means that when importing gas into a zone that has no direct access to foreign imports, as is the case for the *Zentralschweiz* zone, one is required to pay a double entry-exit fee. First, the importer is charged for entry into and exit from the zone where the import enters Switzerland. Second, additional fees are levied for entry into the consuming zone and exit at the city gate.

This represents an extreme formulation. The actual implementation of differentiated EE prices in Switzerland is likely to be based on a single billing zone for the whole country, as is usually the case on the national level in Europe. One would pay different prices depending on where the injection and the withdrawal take place, but one would only pay for entry into Switzerland and exit at the city-gate. We nonetheless opt for our formulation, as it allows us to identify the two extreme formulation of an EE implementation in Switzerland – *Uniform pricing* being the other end of the spectrum. Furthermore, such a system is rather close to the current status and the partially path-based pricing system currently used in the country. Given the limitations of our model, we cannot formulate a precise simulation of the current situation; hence, we choose to consider the *Regional pricing* as our best attempt at mimicking the as-is situation to allow for some comparisons.

3.4.1. Simulation Results

The first and obvious change between the two cases is the change in the price paid by the final consumer for its gas. In the *Regional* case, consumers in different regions will pay different EE fees and thus final prices, while in the *Uniform* case all consumers in Switzerland will pay the same fees and the same final price.[32] In the former, consumers in regions which are either located farther away from the import points or which possess a costly network will end up paying higher network charges than other regions, hence higher

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[32] Excluding price difference related to distributional grid charges.

final prices. On the contrary, the latter will equalize all prices and charges, thereby leading to a cross-subsidization between consumers. Those situated in regions with low network fees in *Regional pricing* are charged more under *Uniform pricing* and finance part of their neighbors' infrastructures. The opposite happens for consumers in regions with either distant import sources or expensive network infrastructures.

Table 17 displays the impact of each case on gas prices in the four regions. For the three zones *Ostschweiz*, *Westscheiz* and *Zentralschweiz*, a uniformly price EE system result in a price reduction for the final consumer. The *Mittelland's* consumers pay in turn a higher bill, compensating for the other regions. The most important variation – *Zentralschweiz* – represents a price decrease of roughly 10%. Yet, as our model yields a price level that is significantly below the one currently observed in Switzerland, a decrease of 4 CHF/MWh corresponds to a roughly 5% drop in prices when compared to real market values.

Table 17: Regional prices [CHF/MWh]

|	Regional pricing	Uniform pricing
Mittelland	38.6	38.7
Ostschweiz	41.3	38.7
Westschweiz	42.1	38.7
Zentralschweiz	42.7	38.7

Values are averaged for the period 2014 – 2016.

Comparing the price levels in the regional and uniform cases over time shows that the differences remain within +10% and -15% with a high correlation between the different regions (Figure 7). Compared to the real market price levels this would again reduce to less than 5%.

Changes in prices also have an impact on the consumption in the different regions. One can expect that regions which are farther away from import sources and possess expensive network infrastructure are likely to display an increased demand in the *Uniform pricing* case compared to the *Regional* one. The opposite should hold for the region which are close to import or have inexpensive infrastructures.

Figure 7: Price development over time
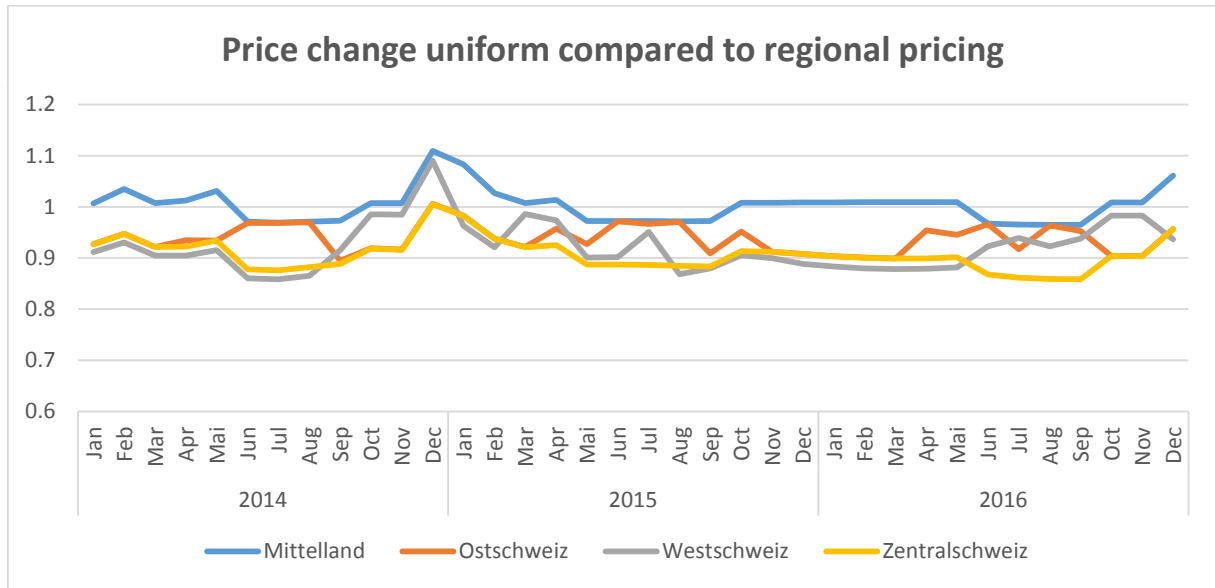
The results displayed in Table 18 correspond to these expectations. *Ostschweiz*, *Westschweiz* and *Zentralschweiz* all have a slight increased demand with uniform EE fees compared to the case of regional ones (ca. +0.3%). The strongest augmentation is seen in *Zentralschweiz*, the region which also had the strongest price differences between the two cases. Opposed to this, the *Mittelland* region sees its demand reduced by 0.06%. Overall, the reaction of consumers to the change in prices remains limited. This behavior is mainly driven by the elasticity assumption (see Section 3.3.2).[33] Most domestic consumers are, in the short-term, bound with gas and must use regardless of its prices. Industrial consumers are in turn more likely to react to price changes as they may have other alternatives. However, whether the price changes induced by a switch from the current system to an EE system is sufficient to initiate significant demand reaction is questionable, as other choice parameters (i.e. substitute fuel prices, investment costs) are likely to be more decisive.

Table 18: Regional demand

	Regional pricing	**Uniform pricing**
Mittelland	1.0	1.0
Ostschweiz	0.997	1.0
Westschweiz	0.997	1.0
Zentralschweiz	0.996	1.0

Values are averaged for the period 2014 – 2016. The values for uniform pricing are normalized to one.

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[33] A high elasticity assumption will generally lead to more pronounced quantity reactions but lower price reactions, and vice versa, see also the sensitivity analysis in Section 3.4.2.

As noted above, the introduction of uniform EE fees in our model induces relatively larger variations in prices than in "reality", since the calibration prices are significantly lower than market values. Translating our results to expectations on market behavior, one might still expect the qualitative result to hold.

3.4.2. Sensitivity Analysis

Since the small reaction of consumers to changes in price is mainly driven by our assumption on the (in)elastic demand of Swiss consumers, we further perform a sensitivity analysis by varying the assumed value of elasticity. Instead of the -0.11 value used previously, we now use -0.4. Thereby, we simulate consumers which are more easily able to react to changes in prices. This can also be understood as a more "long-term" model, since in the longer-run, gas consumers can more easily adapt to prices changes (e.g. by investing in new heating system)

Looking at Table 15 one notices that the sign of changes in both price and demand in all regions stay constant. While the demand reaction is more pronounced, the price change is smaller, which follows the implemented logic of a more elastic linear demand function: the new demand curve is flatter than in the base case which leads to a higher reaction to a shift in supply on the quantity side and a smaller on the price one.

Overall, one does not notice significant differences between both cases. The consumers react differently to a change in prices induced by the new regulation; yet, the impact remains rather limited both on the quantity consumed and on the price paid for it.

Table 19: Model calibration

	Change in av. demand		Change in av. prices	
	$\varepsilon = 0.11$	$\varepsilon = 0.4$	$\varepsilon = 0.11$	$\varepsilon = 0.4$
Mittelland	-0.10%	-0.10%	0.30%	0.80%
Ostschweiz	0.30%	1.30%	-6.20%	-6.10%
Westschweiz	0.30%	1.20%	-7.90%	-7.30%
Zentralschweiz	0.40%	1.20%	-9.20%	-8.60%

Values are averaged for the period 2014 – 2016.

3.5. Conclusion

The SFOE, while working on a Swiss gas supply act, currently weighs up the introduction of an entry-exit system for its natural gas market. While such a mode of organization is a

standard for European markets, it does nonetheless bring some changes compared to the existing system. As Switzerland's present regulation is based on a path-dependent billing, an EE system would abolish the path relation and require the definition of more aggregated network zones (i.e. market areas) in which transport fees are handled path independent.

The present study identifies changes associated with this system shift using a model-based analysis. Owing to the nature of the Swiss market and limited availability of data, the analysis is restricted to a highly stylized representation of the Swiss gas market. Keeping this in mind, we cannot provide an entire assessment of the changes induced by the EE system, notably on possible network implications. As our results show rather small changes on price levels and quantity allocations, one may guess that the accompanying network feedback is likely to be rather small, too. Assuming that the existing Swiss network structure is sufficient to cover the current demand level including an uncertainty margin, our model results could be interpreted that the network is likely to be capable of satisfying average market conditions even with the introduction of an EE system. However, whether there are potential local constraints or problems during high demand conditions cannot be identified.

With regard to the actual design of the EE system – whether regional differentiated (i.e. up to city-gate resolution) or more aggregated with uniform prices across regions – the results indicate only small differences. Nonetheless, the question of whether a specific design would lead to increased network congestion, increase overall network costs or lead to other regional distortions cannot be assessed with our model

Given the fact that network charges are small compared to wholesale prices, it is also likely that the overall European market development will have a bigger impact on the Swiss natural gas market dynamics. To that extent, the connection with Europe and a well-regulated network access (regardless of the exact specification of the entry and exit zone definitions) are likely to be more important determinants of the success or not of the restructuring of the Swiss gas market. Moreover, broader aspects surrounding the liberalization process, like incentives for consumers to switch supplier and competition between the different Swiss suppliers, may further prove to be more important drivers of success than the chosen EE design.

As network costs are the crucial element for defining the level of entry and exit fees, the determination of this cost basis is also an important element of the new market design. In this context, the role of the transit gas from Northern Europe to Italy is an important element. Given that 75% of the *Transitgas* capacity are for international transit the question remains

whether the respective cost share should be included in the transit fees with respective feedbacks from changed European trading patterns or be part of a general Swiss EE system.

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4. General conclusions and policy recommendations

In the course of the transition towards an energy system dominated by renewables, natural gas will play an important role in Europe's and Switzerland's energy supply. This opens the question of whether the European market structure can ensure a sufficient and secure supply during potential shortage situations. Owing to the fact that Switzerland is entirely dependent on gas imports, the question of supply security is a crucial one for the Swiss energy system too. In addition, the Swiss natural gas market is currently considering a restructuring of its natural gas market, notably discussing the conditions for third-party access to its gas network.

Against this background, we develop two simulation models to assess the situation on the European and Swiss natural gas markets under different system conditions. The first model focuses on the European gas transmission system and its interlinkage with the global gas market. Of particular interest is the resilience of the European gas supply during short-term outages of import and potential countermeasures. The second model addresses the specific situation of the Swiss market, and analyses the possible implications of introducing an Entry-Exit system in Switzerland, notably studying the difference between regional and uniform network charges.

In terms of supply security, our results are in line with other studies (e.g. Richter and Holz, 2015): the supply structure and cross-border capacities are sufficient to ensure stable supply under normal market conditions even with decreasing local production. Russian imports are the most important supply to be concerned about for European countries, especially for the Eastern and the Southern part of Europe. The vulnerability of these regions can be reduced by either additional import infrastructure (e.g. the Southern Gas Corridor) or by a coordinated strategic storage management. Turning to the study on Entry-Exit for Switzerland, our results show minor impacts of the different design options. It must be noted that the limited spatial scope of our model limits the possibility to identify local system bottlenecks.

The results from the different scenario assessments have three major implications for the Swiss natural gas policy. First, as the supply security assessments do not show a particular problem for Central and Western Europe, with respect to a Russian supply shock, there is no need for immediate action beyond the already projected reverse-flow extension of the

Transitgas pipeline. Switzerland also scored among the highest in a more extensive and broader supply security assessment, which includes the study of various disruption scenarios. Most infrastructure measures planned by the EU will further benefit Europe's supply security and thereby also have a positive externality for Switzerland.

Nevertheless, Switzerland should maintain close contact with the EU. Our results clearly indicate that the best approach to counter short-term supply disruption is a coordinated management of storage volumes and reverse flows from Western towards Eastern Europe. Given that Switzerland does not have own gas storage facilities, it should ensure to be part of coordination approaches on the European level to secure its gas access in the case of supply disruptions. One must bear in mind that our results represent an optimal benchmark based on perfect coordination between all European countries. Hence, the implemented policies will determine whether the technical and market potential that we identify in the study will actually be used or not.

Second, the supply security assessment also indicates that a simple static evaluation method is insufficient to capture all the underlying dynamics of the supply security notion. The stress tests conducted within the European Energy Security Strategy and the risk scenario assessment by the ENTSO-G are already solid approaches to this regard. However, they usually fall short in obtaining the full market interactions and, thereby, can overestimate actual supply potential; e.g. if LNG capacities are assumed to be available, but the global market does not provide additional gas in crisis situations. Europe and Switzerland should therefore combine the more technical security assessments with global market assessments to obtain the needed linkage between both aspects. Given the expected increase in global extraction capacities, the coming years are likely to remain uncritical, especially if the US should enter the market as additional LNG exporter. However, global shifts in demand in Asia could also cause limit the potential of suppliers to shift gas towards Europe if they are bound in long-term contracts.

Third, the opening of the Swiss natural gas market towards more competition will require a consistent market design. An Entry-Exit approach is a well-fitting approach for network access and also in line with ongoing European developments. Yet, the question of its design (i.e. whether there is a uniform Entry-Exit fee or more zones) is likely not the main aspect for a successful market restructuring. The price impact of different network charges compared to the wholesale price level and the overall market dynamic is relatively minor. To transform the current market into a competitive framework, open for new entry and adaptable to new

market developments, it will be crucial to have a solid network regulation that prevents cross-subsidies and ensures discrimination-free access to the network.

Given that all utilities in Switzerland are import-dependent, they all will face similar supply cost conditions. Thus, from a pure theoretical perspective, there is no direct threat that specific companies will dominate the restructured market. Nevertheless, experiences form electricity markets show that households and small consumers are reluctant to switch suppliers, even if it would pay off. This stickiness of consumers might prove an important source of concern in the course of a liberalization, as it guarantees market power for the incumbent. Such market challenges will not be altered via Entry-Exit designs.

Naturally, our results are subject to the underlying assumptions and to implications of the model design. For these reason, the results are not to be seen as predictions, but rather as a means to describe the underlying technical and economic mechanisms. Especially, with respect to the Swiss assessment we are not able to derive feedback effects of an Entry-Exit scheme on local network congestion as data limitations prevent a detailed spatial model approach. The obtained insights therefore focus on the general question of the role of Entry-Exit designs within a restructuring process. The conclusion that this design is important but that its exact formulation is not central for a successful market reform should remain valid, even with a more detailed model.

Based on the European market results presented in this report the next steps in research would be on a more in-depth evaluation of the suitability of the proposed security of supply indicator for policy and investment decisions. As the first results indicate, there are potential differences compared to other commonly used assessment approaches for specific countries which could merit a re-evaluation of Europe's security policy. Regarding the Swiss market evaluation the focus for further research should shift towards the demand side and whether and how consumer choice could be fostered in a redesigned market. Given the import dependence of all Swiss suppliers and thereby a rather homogenous cost structure on the supply side one could expect that the actual potential for price differences is rather low. However, as experience from the electricity market shows consumers can be slow to switch to new (and cheaper) suppliers even in a fully liberalized market.

Publications within this Project

This project report is based on three research working papers:

- Abrell, J., Chavaz, L., Weigt H. (2018) *'Infrastructure and policy – Dealing with supply disruptions on the European natural gas market'*
  A preliminary version of this paper has been presented at the '13th International Conference on the European Energy Market (EEM)' and has been published in the conference proceedings as: J. Abrell, L. Chavaz and H. Weigt, "Pathways for the European natural gas market," 2016 13th International Conference on the European Energy Market (EEM), Porto, 2016, pp. 1-6.

- Abrell, J., Chavaz, L., Weigt H. (2018) *'Assessing the supply security - A compound indicator'*
  Preliminary versions of the paper have been presented at the 'International Conference on the Economics of Natural Gas' in Paris (27.06.2017) and at the 'AURÖ Nachwuchsworkshop Umwelt- und Ressourcenökonomik' in Basle (14.02.2016).

- Abrell, J., Chavaz, L., Weigt H. (2018) 'Entry-Exit market design - Implications for the Swiss natural gas'

All papers are available on the project webpage, see https://fonew.unibas.ch/de/projects/

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A Appendix

Sensitivity Analyses

Cost of storage

For this sensitivity analysis, we run the model with a modified formulation of the storage cost function, where the holding of one unit of gas in storage induces a cost at each time period. For this, we multiply the storage level with a cost factor. In order to keep the results comparable, we assume that injection and withdrawal do not create additional costs and divide the so far assumed cost factor by five (thus assuming that average number of storage cycle per year is slightly greater than one). Looking at Table 20 one notices that both the lost load ratio and the increase in consumer expenses are rather close to their respective value with the former cost formulation. The missing supply resulting from the crisis is slightly larger than the former one, explained notably by the light drop in storage fullness that derives from the new cost structure. On the other hand, the growth in consumer expenses stay slightly below the former values. Overall, one does not notices significant differences in the main results with the alternative cost formulation.

Table 20: Results for cost sensitivity

Sto. oblig.	Av. fullness	LL / demand.	Cons. exp.
0%	65%	13.7%	-
10%	70%	9.7%	0.8%
20%	76%	5.5%	2.4%
30%	80%	3.7%	4.9%
40%	82%	2.4%	8.1%
50%	86%	1.5%	11.1%
60%	91%	0.5%	13.8%
70%	96%	-	16.7%
80%	97%	-	19.9%
90%	100%	-	24.8%

Average fullness of storage in relation to maximal storage capacity, ratio of lost load over demand during the crisis months, Increase in consumer expense under normal market conditions induced by the storage obligation.

Storage holding obligation

We further test two different formulations of the policy. In the first one, the storage obligation is formulated on the aggregated level. Instead of each country having to hold a certain percentage of their storage capacity, we assume that a certain percentage of the

yearly total European consumption must be held in storage somewhere in Europe, regardless in which country.

One can gather from Table 21 how the first few iterations of this alternative formulation only have a modest impact on the average storage fullness. The policy's impact only kicks in at approximately 15%, while it induces full storage at roughly 20% already. The level of storage required for the policy to be effective in terms of security of supply, e.g. 20%, induces larger rise in consumer expenses than with the former formulation. Hence, an aggregated approach seems less efficient than the previous one.

Table 21: Results for aggregated storage obligation

Sto. oblig.	Av. fullness	LL / demand.	Cons. exp.
0%	72%	11.2%	-
2.5%	73%	9.3%	0.8%
5%	73%	7.9%	3.5%
7.5%	73%	5.6%	6.6%
10%	70%	4.9%	9.8%
12.5%	73%	4.1%	12.7%
15%	78%	3.2%	15.6%
17.5%	86%	1.6%	19.8%
20%	97%	0.2%	24.2%
22.5%	99%	-	29.2%

Average fullness of storage at the beginning of the winter period in relation to maximal storage capacity, ratio of lost load over demand during the crisis months, Increase in consumer expenses under normal market conditions induced by the storage obligation.

As a second step, we test an alternative formulation which relaxes the year-round obligation of storage holding and introduces additional flexibility for the countries with large storage capacity over consumption ratio. The policy is formulated as follow: each country possessing gas storage must hold at the beginning of the winter (November) a certain percentage of its domestic winter demand or, if this exceeds its capacity, the same percentage of its storage capacity. Contrarily to the normal formulation, countries are hereby allowed to use their strategic reserves during the winter, bearing in mind they must have their storage refilled by the beginning of the next winter.

Looking at the benefits of the policy, although the first few iterations deliver insignificant changes, one notices that roughly starting from a 40% limit, the welfare destruction amounts to similar values as with the regular formulation. On the other hand, the induced increase in consumer expenses is significantly smaller. For example, a level of 50% results in a 5% increase in consumer expenses, whereas the same level induces a 12% rise for the previous

formulation, while both lost load ratios are at comparable level. Hence, for a similar benefit, this alternative formulation seem to create smaller negative welfare impacts. This is to be explained by the flexibility provided to the countries which must not hold the strategic reserve unused, but might actually withdraw it during the winter season and feed it back to the market.

Table 22: Results for demand related storage obligation

Sto. oblig.	Av. fullness	LL / demand.	Cons. exp.
0%	71.5%	10.9%	-
10%	73.3%	10.9%	-
20%	74.0%	10.9%	-
30%	75.5%	8.5%	0.8%
40%	80.1%	4.0%	3.3%
50%	83.1%	2.2%	4.2%
60%	85.7%	0.6%	4.9%
70%	87.3%	-	5.5%
80%	88.5%	-	5.9%
90%	89.0%	-	6.0%

Average fullness of storage at the beginning of the winter period in relation to maximal storage capacity, ratio of lost load over demand during the crisis months, Increase in consumer expense under normal market conditions induced by the storage obligation.

Technical note on the long-term indicator

The nature of our indicator model forces us to employ a counter-intuitive method to compute the long-term indicator. The naive approach would have been to simply use different assumptions on elasticity, and redo the calculations. Yet, this method prevents comparability between the short and the long-term perspectives. Indeed, our model uses a reference point of observed price and quantities on a given market, and assumes an elasticity to compute a linear demand. Changing the elasticity thus means using a different demand curve. In a perfect world, this would not pose a particular problem as both curves would cross each others in the reference point. Yet, since a model is the simplified description of a complex reality, notably in terms of demand curve, our model does not achieve perfect calibration; hence, the model's equilibrium point does not coincide with the observed market one. Owing to this fact, with the aforementioned approach, the two demand curves would cross at the observed market equilibrium, not at the model one. Thereby, we would loose the possibility to compare the results with each others.

To ensure comparability, we force the short and long-term demand curves to cross at the model's equilibrium. To do so, we compute the "achieved" point-elasticity at the equilibrium

point of the model. As we use linear demand, this elasticity will be different from the one used for the model's calibration. Once the achieved point elasticity retrieved, we assume an increase of the elasticity by 50% to obtain a long-term one. This process is repeated for each country, consumption sector and time period.

The left part of Figure 8 displays a "perfect world" situation, where the reference point used for the calibration and the model's equilibrium coincide. Here, the long-term demand (D_{LT}) can be derived simply with a different elasticity. On the right part though, since we can only use an approximation of the real supply curve ($\overline{S}$), the model's equilibrium is different than the reference point. Thus, we have to rely on an approximated long-term demand ($\overline{D}_{LT}$) which crosses the short-term one (D_{ST}) and the approximated supply curve at the model's equilibrium.
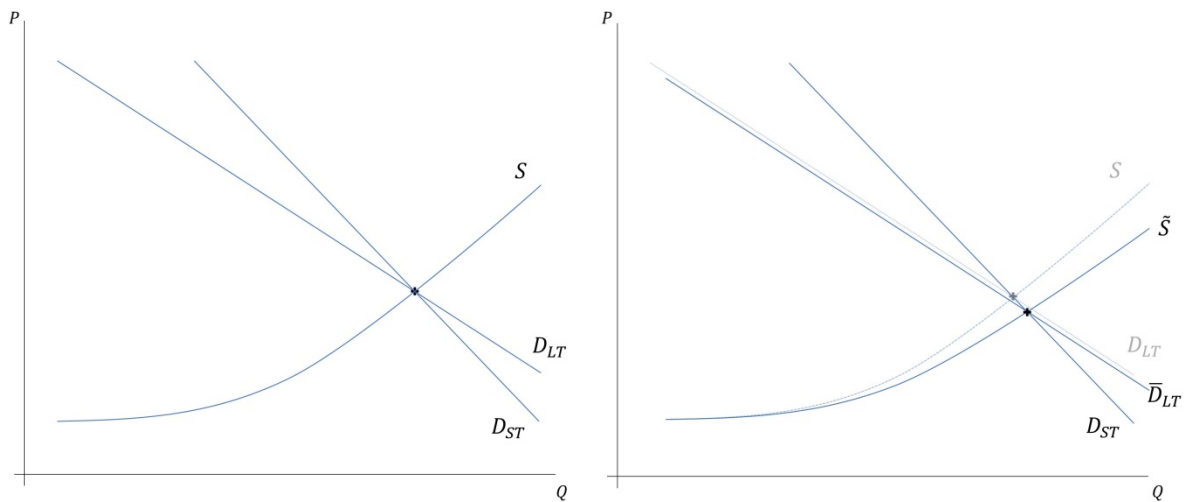

Figure 8: Schematic representation of demand dynamics for indicator assessment