The impact of demand uncertainties and China-US natural gas tariff on global gas trade

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The uncertainties in gas demand levels and geopolitical issues may lead to significant changes in global gas trade. This paper uses an agent-based model to simulate the alternative market futures under two demand trajectories: a baseline following current policy pledges until 2060 and another where demand shifts to a lower level in 2030. Endogenously generated capacity investments are driven by long-term bilateral contracts between importers and exporters, where investors are assumed to evaluate the potential risks of demand changes while making their decisions. The results suggest that, when the demand decreases in 2030, the Middle East takes the dominant position in Eastern Asia, whereas this role is occupied by North America in the current policy scenario. In addition, the impacts of a 25% tariff by China on U.S. natural gas are studied for both scenarios. The revenue of North American gas trade is only marginally affected by this tariff. Under the normal demand trajectory, the tariff influences the Chinese market more notably in the longer term when global supply is tightened by decommissioning. In the case of lower global gas demand, the market share of Russia in Western Europe could be threatened by increasing North American export there.

1. Introduction

The significance of natural gas in the global energy mix has been growing over the last several decades. In 2017, gas contributed to nearly a quarter of total primary energy consumption [1] and huge investment has been directed towards the development of new gas supplies [2]. However, this investment is subject to many risks, including risks in demand levels and geopolitics, both of which may have a substantial impact on global natural gas trade dynamics.

The risk in natural gas demand is partially attributed to the perception that is may be a transition fuel [3]. Since gas combustion emits less CO_2 compared to other fossil fuels when generating the same amount of energy [4], in the short term, its demand may escalate to replace coal in many countries to help reach their medium term climate mitigation targets [5]. However, in the long term, and in the absence of carbon capture and storage, fossil fuels may be replaced by renewable and nuclear generation to achieve climate targets. Gas demand can therefore vary significantly depending on the pathway of decarbonisation, renewable technology deployment, energy efficiency improvement, and climate legislation.

Regarding the risks in geopolitics, a wide range of studies have focused on the relationships between the European Union, Ukraine, and Russia. European countries imports around 150-200 Billion Cubic Meter (BCM) of natural gas annually from Russia and this accounts for 30-40% of their total natural gas demand [6]. A considerable amount of these gas supplies are transmitted via Ukraine, and price disputes between Russia and Ukraine has caused several disruptions [7]. Furthermore, more than half of transmission pipelines in the Ukraine are more than 30 years old, and the average efficiency of their compressor stations is less than 30% [8]. Due to a lack of financing, the maintenance and upgrade of the Ukraine transmission system has been postponed for a long time [9]. This threatens the energy security of Europe. As a result, European consumers have sought to diversify their supplies and import less Russian gas [10]. Besides the Europe-Russia-Ukraine issue, the trading relationship between China and the U.S. became strained in 2018. Alongside this, China may account for a third of global demand growth in the near term [5]. A significant amount of gas needs to be imported via both pipelines and Liquefied Natural Gas (LNG) to satisfy this rapidly growing demand. The U.S. is considered as an important LNG supplier to China. However, in August 2018, China stated a potential 25% tariff on the U.S. LNG [11]. This tariff may redirect the U.S. gas export to other markets and therefore may threaten the shares of other major suppliers in these markets.

Subject to the risks discussed above, the pattern for global gas trade may vary significantly under different scenarios. The objective of this paper is to analyse the impacts of different demand levels and tariff conditions on global gas import-export relationships. Regarding the demand uncertainties, this paper presents the scenario of a "disjoint shift" condition: demand levels are higher initially based on current policy pledges, whereas a sudden shift to lower levels is induced by new climate policies or other factors. Such a condition has not been studied in-depth by the available literature, but is important because the scenario can have unpleasant consequences for both investors and the industry. Another contribution of this study is that it provides insights on how the China-US LNG tariff would affect global gas trade dynamics. How the prices in different markets are affected and what influences such a tariff would have on other exporting countries is analysed. The discussion focuses on not only the short-term global gas flows but also the long-term investments in production and export infrastructure.

The simulation is based on the Gas-GAME-Risk model, which is built using an agent-based framework with exporting investors and importing markets represented explicitly. The initial model Gas-GAME [12] is extended by allowing investors to incorporate stochastic analysis during their decision making when facing uncertain demand conditions. This better mimics the behaviour of real-world investors, as their risk evaluation process is explicitly represented.

The paper proceeds as follows. Firstly, a literature review on the studies about natural gas trade scenarios under demand and geopolitical uncertainties is presented. This section also addresses the application of stochastic methodologies in gas market simulation and highlights the features of Gas-GAME-Risk. The details of this model are explained in section 3, followed by the datasets and scenario framework of this study. In section 5, the discussion firstly focuses on the results of alternative gas market futures under base and "disjoint shift" conditions. Then, how the China-US tariff would influence global gas trade under both conditions is examined separately.

2. Literature review

A wide range of literature is available for natural gas market analysis on a variety of topics. Here, the review focuses on those discussing future global trade dynamics subject to demand uncertainty and geopolitical issues.

To understand future gas markets, two types of approaches are generally applied. The first is based on economic principles and often examines the logic and causality of different uncertainties. Kumar et al. provide an overview of both demand and supplies of natural gas. The reasons for uncertainties in different regional gas demand and the corresponding influences on future trade patterns are discussed qualitatively [13]. Chen et al. study the potential structural risk in global gas trade by using a network analysis. Norway and Qatar are found to have the greatest impact on price fluctuations [14]. van Goor and Scholtens apply the market fundamental demand and supply relationships to examine the gas price volatility in the UK [15]. Rogers studies the possible American gas production and exportation scenarios subject to different Asian gas demand conditions via a system balance approach [16]. The study is based on a fixed global LNG supply system, and therefore the trading preference and hierarchy has been exogenously defined. Rogers also investigates the impacts of lower oil and gas prices on global natural gas trade [17]. The paper focuses on the profitability of LNG projects and the Asian market price structure. In general, the economic approaches are comprehensive and informative. However, these studies can hardly capture the complex interactions of multiple aspects and generate quantitative projections on global market developments.

The second approach, known as energy systems modelling, has the advantage by enabling quantitative evaluation with components in the energy system connected. The structural designs of different models vary depending on the questions that the model targets to address. For instance, The Integrated MARKAL-EFOM System (TIMES) and its versions with alternative functionality for climate response simulation, TIMES Integrated Assessment Model (TIAM), both take a bottom-up approach to minimize the system cost or maximise social welfare [18, 19]. The main application of these models is to examine the optimal pathways for achieving a climate target. For example, Selosse and Ricci applied TIAM-France to evaluate the viability of using Bioenergy with Carbon Capture and Storage (BECCS) to help decarbonize in the power sector [20]. Gambhir *et al.* used TIAM-UCL to study India's long-term mitigation options and how the economy is influenced by carbon trading permissions [21]. Another important family of models are based on simulation methods and they focus on the likely evolution of energy systems [22]. Two examples are the U.S. Energy Information Administration's National Energy Modelling System (NEMS) [23] and Price-Induced Market Equilibrium System (PRIMES) [24]. While NEMS is used to compute the equilibrium fuel prices and quantities for the U.S. Annual Energy Outlook, PRIMES is adapted by the European Commission to provide analysis for EU's Energy Roadmap 2050 [25].

The above-mentioned model families cover the entire energy system and simulate all primary energy sources. However, they commonly assume a globalized gas price and simplify most gas market features. As a result, detailed analysis on natural gas system is often based on gas sector models. For example, Shi et al. examines the impact of uncertain China's gas market on a global scale [26]. In that study, they apply the Nexant World Gas Model, which uses a linear programming approach to minimise global gas procurement costs [27]. However, the uncertain demand conditions in other regions, including both Europe and East Asian countries like Japan and Korea, are not considered. Hence, the simulation does not explore the general picture of future global gas trade. Medlock et al. simulate two alternative scenarios, one liberalisation case and one North American export push case, to examine options for U.S. LNG exportation [28]. The simulation is based on Rice World Gas Trade Model (RWGTM): a dynamic partial equilibrium model developed using Marketbuilder software platform. This study highlights the geopolitical priority of liberalising the European gas market so that the regional energy security can be better achieved with the increasing U.S. LNG export. The two models mentioned above are both based on commercial software, and the available literature only discloses limited details on methodology and data input. The major players in gas markets are assumed not to anticipate different potential outcomes when deciding on gas trade and capacity expansion. Both studies apply the approach of general scenario analysis to examine the alternative outcomes under uncertainties.

Besides the scenario analysis approach, there are other techniques to address the uncertainty issue in energy systems models. Monte Carlo Analysis (MCA) generates multiple outputs with their corresponding likelihoods by using the probability distribution of uncertain input parameters. This method has been applied to examine how cost assumptions for future vehicle propulsion technologies would affect the road transportation sector under carbon constraints [29]. A major challenge of MCA is to obtain reliable probability distribution for the uncertain inputs, and therefore the number of studies based on this approach is limited. In comparison, the technique of stochastic optimization has been applied widely in over 20 studies [30].

The method of stochastic optimization is commonly used for multi-stage problems, in which actors need to make decisions at earlier stages and the uncertainties are revealed at later stages. The value of these stochastic solutions is reflected in explicitly considering the distribution of uncertain aspects while making decisions, and as such the results hedge the approach taken and thus are often more robust against different market futures. For natural gas models, the stochastic approach is applied initially to regional markets. The Stochastic-Natural Gas Equilibrium Model (S-NGEM) examines North American gas market activities, and Zhuang et al. illustrate that the stochastic solution of the equilibrium model improves the profits of market players and the consumer surplus [31]. S-GaMMES represents the major gas chain players in the north-western European market. The model relates demand functions to oil prices, whose uncertainty is simulated [32]. These two models, by formulating gas market participants according to specific regional gas trading features, focus on the issues regarding the regional gas market structure and pricing mechanisms. For the global trade of natural gas, Egging and Holz extended the World Gas Model (WGM) [33] to the Stochastic Global Gas Model (S-GGM) [34]. In S-GGM, gas market players maximise their expected discounted profits over all periods subject to eight scenarios varying on whether Ukrainian transit is disrupted, different gas demand levels, and different unconventional gas production developments. With the stochastic setting, they illustrate how the inter-temporal hedging behaviour of market agents may affect the timing of gas infrastructure investment.

A common feature shared by the three stochastic models is that they simulate the Nash-Cournot equilibrium by applying the Mixed Complementarity Problem (MCP) approach. In this way, the market power, which is a crucial feature in gas trade, is represented. Besides market power, another important feature of global gas trade, which is commonly simplified in the modelling exercises, is that the large-scale production and international transmission (i.e. pipelines, liquefaction infrastructure, and regasification infrastructure) projects are often underpinned by long-term contracts. These projects are always highly capital-intensive and therefore the investment risks need to be mitigated by long-term buyers [35]. The contracts also benefit consumers as their supply can then be secured [36]. In order to represent both features, Gas-GAME is developed using an agent-based framework with global coverage [12]. The bilateral contracting process between gas importers and exporters is explicitly simulated. Moreover, the endogenously generated capacity investment decisions are driven by the long-term contracts. This study extends Gas-GAME by incorporating stochastic features into the investment decision process. The details on modelling methodology are explained in the following section.

3. Method

The model, Gas-GAME-Risk is built based on Gas-GAME, which is an agent-based global gas model with features including market power representation, contract-driven investment simulation, and investors' imperfect foresight. Gas exporting regions are simulated as supply agents (denoted by i) and importing regions as demand agents (denoted by j). Table 1 shows the region segregation.

The model has two modules, namely the Market Equilibrium Module (MEM) and the Infrastructure Expansion Module (IEM). The MEM simulates short-term Nash-Cournot equilibrium and determines global gas trade volumes and gas market prices in every single time period. The IEM focuses on capacity expansion and the investment decisions are influenced by both supply and demand agents in the contracting process. Fig. 1 illustrates structure of the model and the information flow between the two modules. They run sequentially in each time period, and the whole model runs period by period from the base year to the end of simulation time horizon. For further details, the reader is referred to [12].

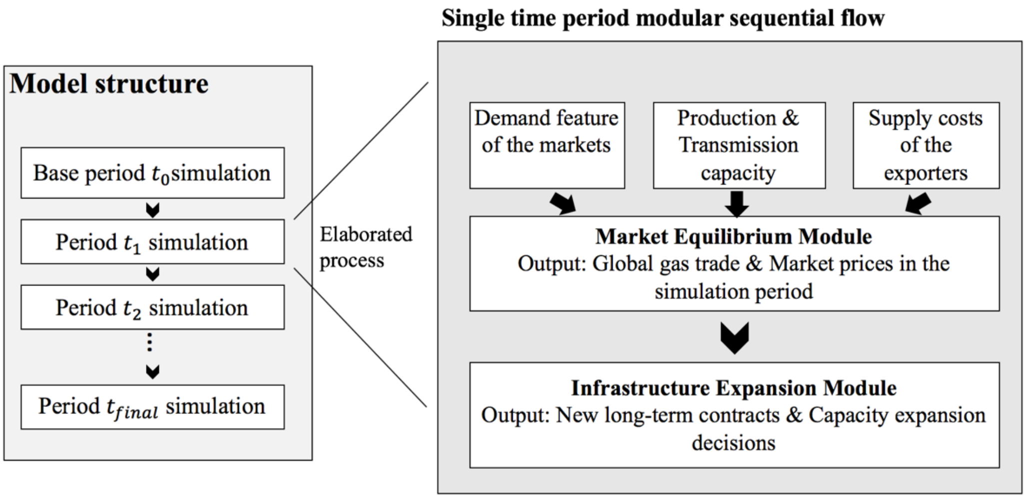


Fig. 1. Modular structure of Gas-GAME-Risk

Table 1

Region segregation

Region segregation	
Import markets (j)	East Asia; West Europe; East Europe; China; India
Export regions (i)	Russia; Norway; Middle East; ASEAN; Australia; North America; South America; Africa; Caspian

This section explains how Gas-GAME-Risk allows investors (supply agents) to evaluate their economic return on the contracts proposed by demand agents in a stochastic way. Since this study aims to analyse alternative global gas trade futures subject to demand uncertainties, the different demand projections used in this model are explained. The scenario tree representing the realization of alternative demand scenarios is then presented. After that, we discuss how the supply agents decides on investment and capacity expansion in this model and highlight the methodological difference compared to Gas-GAME. Finally, the scenario variation regarding the China-US tariff issue is described.

3.1 Global gas demand uncertainty

The base year price-demand relationships are computed using the consumption data from the BP Statistical Review of World Energy [37] and regional prices from International Gas Union (IGU) Whole Sale Gas Price Report [38]. The relationship is assumed to be linear, as shown in Equation (1), with the price in region j at time period t represented as $\pi_{j,t}$. The elasticity used to compute INT and SLP ranges from -0.25 to -0.75 [33] and the values for different markets are the same as presented in [12].

Price-Demand relationship $$\pi_{j,t} = INT_{j,t} - SLP_{j,t} IMP_{j,t}$$ Eq. (1)

The relationships for future gas markets are based on two demand trajectories: a base one referred as NPS and a low-demand variant referred as LOW. The base demand trajectory is calibrated based on the New Policies Scenario (NPS) in World Energy Outlook (WEO) 2018. The import levels in 2040 by different demand agents at their reference prices are presented in Table 2. This projection assumes that the gas consumption trend would follow current policy pledges and is the common baseline for natural gas market simulation. The SLP values remain constant throughout the simulation, whereas the INT values adapt towards the 2040 import levels in a linear manner between 2010 and 2040. From 2040 to 2060, the relationships are assumed to be the same as those in 2040.

The LOW demand trajectory is calibrated based on the lowest levels from multiple literature results [39-42]. Regional import volumes in 2040 are compiled with Table 2 presenting details. For Western Europe, Eastern Europe, and Eastern Asia, the values are taken from the Sustainable Development Scenario (SDS) in World Energy Outlook [5]. For China, the lower import volume in 2030 projected by China National Petroleum Corporation (CNPC) [40] is used with an extrapolation towards the volume in 2040. Indian natural gas import in NPS is at the lowest end of multiple projections [5, 42], and therefore a 20% reduction is assumed in the low demand trajectory.

Table 2

Different future demand scenarios

	Reference price ($/MMBtu)	Import level in 2040 (BCM/yr)	
		Base Scenario (NPS)	Low Demand Scenario (LOW)
West Europe	8.0	463	347
East Europe	4.5	58	44
East Asia	10.5	359	215
China	6.3	278	205
India	4.4	99	79

3.2 Scenario tree

The demand level in each market may evolve following either NPS or LOW trajectory after 2020. However, a disjoint shift from the base towards the low-demand may happen. Such a disjoint shift represents the demand trajectories in which efforts to tackle climate challenge are initially insufficient, but the perception of climate disruption triggers a precipitous transition towards lower emissions and hence induces the shift in import market price-demand relationships. One scenario framework in World Energy Outlook [5] assumes the shift happens between 2025 to 2030. However, it is unclear to the exporting countries whether and when the shift towards lower gas demand may happen. A fast transition may happen between as early as 2020 to 2025 if policymakers determine to drive the decarbonisation process mainly by renewable energy. In contrast, it is also possible that the transition does not happen until 2050-2060 due to the lock-in effect of gas power plants and other gas-related infrastructure. The intermittency issue of renewable supplies, which may require natural gas to back up for energy security, can also lead to a slow transition in the coming decades.

Therefore, a scenario tree reflecting the potential demand trajectories with disjoint shifts at different periods is constructed.

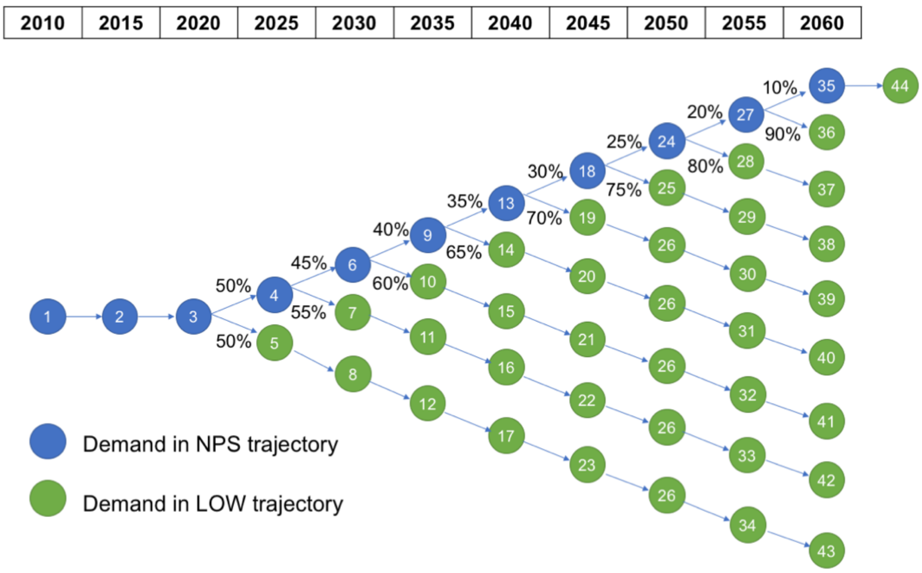


Fig. 2. Scenario tree

As shown in Fig. 2, the demand relationship shifts can happen in every time-period after 2020. Once the demand relationship has shifted to the LOW trajectory (represented by green nodes), it follows the LOW trajectory and does not shift back. If the demand relationship keeps following the NPS trajectory (represented by blue nodes), the possibility of shifting increases over time. Such a design assumes that if decarbonisation does not happen early, due to the urgency for climate change mitigation, gas demand is increasingly likely to shift lower in order to meet the climate target.

3.3 Investment decision based on stochastic analysis

The IEM module uses a heuristic algorithm to simulate the capacity investment driven by the contracting process. This is an abstraction of the real world gas market mechanism where expansion decisions are often underpinned by long-term contracts. As shown in Fig. 3, the simulation consists of two parts and runs sequentially; (a) demand-supply contracting, and (b) contract-based capacity expansion. In brief, part (a) demand-supply contracting section endogenously generates new long-term contracts. This process starts from the demand agents who calculate the required import and contracting volumes for a future period t'. They then distribute the to-be-contracted volumes as contract requests to partner supply agents. The supply agents, when receiving the requests, evaluate the profitability of these requests and accept those meeting the defined criteria. The new contracts are thereby confirmed. Then in part (b), investment happens to construct new capacities that can supply the amount of gas as required by the contracts.

The design of the IEM module in Gas-GAME-Risk is similar to the original Gas-GAME except for the economic analysis process. Instead of evaluating the potential return of the contract requests based on the volumes proposed by importers, the supply agents evaluate the expected revenue for all possible realizations of future demand trajectories in the scenario tree and therefore consider the risks of lower demand scenarios.

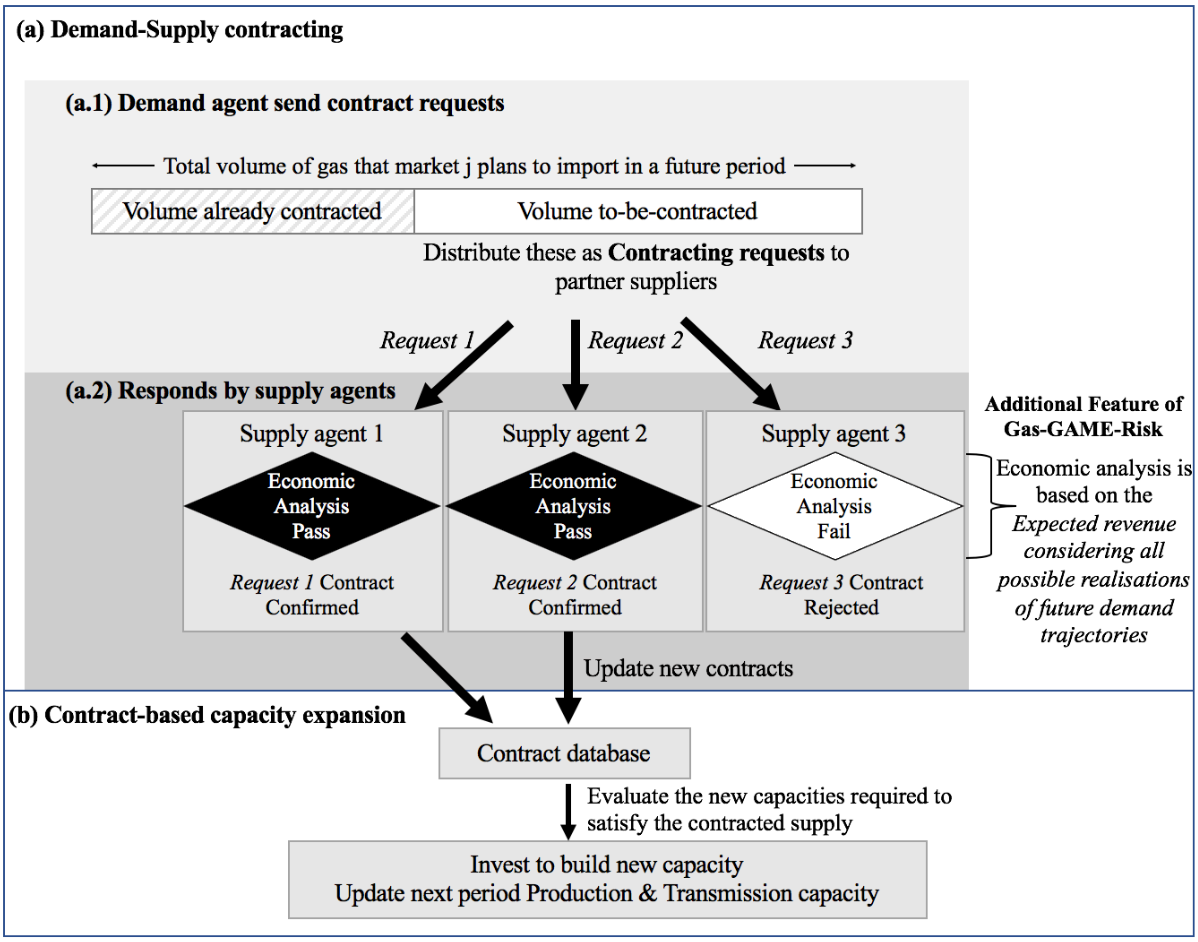


Fig. 3. IEM module method illustration

When the demand relationship at the time-period for decision making is in the NPS trajectory (i.e. the market has not yet shifted to the lower-demand scenarios), the supply agents evaluate all the possible routes linked to the current node within the term period of the proposed contracts. It is assumed that, for future nodes in NPS trajectory, all proposed volume ($CT_{i,j}^{LNG}$ or $CT_{i,j}^{PIPE}$) will be sold at the current period market equilibrium price. For future nodes in the LOW trajectory, the current equilibrium prices are still used but the volume those suppliers expect to sell is only a portion of the proposed volume ($\beta_j CT_{i,j}^{LNG}$ or $\beta_j CT_{i,j}^{PIPE}$). Table 3 presents the reduced levels for each import market, and the values are obtained by comparing the 2040 imports in LOW to those in NPS. The expected revenues for the following periods are therefore calculated based on the branching probabilities in the scenario tree, and these revenues are used for the computation of the Internal Rate of Return (IRR). When the IRR value of a contract request exceeds the economic criteria, the supply agent accepts the request and confirms the new long-term contract, which is then used to drive capacity expansion. Details of the calculation of the IRR value are explained in section 4.

Table 3

Values of parameter β_j

West Europe	East Europe	East Asia	China	India
75%	76%	60%	74%	80%

3.4 Simulation of China-US tariff

Since the model aims to analyse the potential impacts of China-U.S. LNG tariff, two aspects in Gas-GAME-Risk are modified to cater for the tariff. Firstly, in the MEM for single period market equilibrium, the Chinese market price $\pi_{China,t}$ in the profit maximization function of supply agent *i*=North America is reduced to $0.75\pi_{China,t}$. This is based on the 25% tariff China may charge on U.S. LNG [11]. Secondly, in the IEM, when North America evaluates the contract requests proposed by China, the revenue expectation is reduced by 25% as well.

4. Data sets and scenario framework

The data used for this simulation is presented in this section. Moreover, we describe four cases representing different realizations of future demand conditions and Chinese tariff on U.S. LNG.

4.1 Data sets

The model uses 2010 as the base year and the simulation runs with a 5-year time-period until 2060. Base year production, consumption, and global trade data is obtained from Natural Gas Information [6] by the International Energy Agency (IEA) and is used for initial MEM calibration. Existing production capacity is obtained from the BP Statistical Review of World Energy [37], and short-run production cost is from the Wood Mackenzie Upstream Database [43]. Pipeline transmission annual operational cost ranges from \$10M/BCM to \$30M/BCM, with high and low values depending on transmission distance and onshore/offshore infrastructure. LNG transmission annual operational costs cover liquefaction (\$40M/BCM per year), regasification (\$6M/BCM per year), and shipping processes (\$2M/BCM/day and speed at 19 knots) [44-46]. Calibration on cost extra terms (reflecting all other drivers or barriers for inter-regional gas trade) is undertaken to ensure the modified short-run delivery cost induces the MEM to generate gas flows very similar to the historical record in the base year. These values are also used for future periods. Existing international pipeline transport capacities are compiled from the European Natural Gas Network map [47], Energy Supply Security report [48], Natural Gas Information [49], and data from Gazprom Project announcement [50]. The liquefaction and regasification capacities are summed up from country-wise data in the World LNG report [51].

Feasible contracting pairs in IEM are based on real-world conditions. Demand agents plan 15 years ahead. They use the current-period equilibrium price and next-period demand curve to estimate future import requests. How the total requests are allocated to different suppliers is the same as in [12]. The economic criteria for contracts to be agreed is an Internal Rate of Return (IRR) over 12% [52]. Both production and transmission expenditures are included in the estimation of the contracts. The CAPEX values used for production projects are based on the supply curves for each region built using the Wood Mackenzie Upstream Database [43]. The values are updated after new production capacities are built. Pipeline initial capital investment is calculated based on transmission distance [53] and unit construction cost [54]. Liquefaction capital costs are averaged from the World LNG report [45]. The project capital investments are spread evenly across every year in the initial 5-year period and 30-year operational lifetime is assumed [55].

Initially, the infrastructure database is based on the capacities in 2010 with a decommissioning rate of 20% in each future time-period. The newly constructed infrastructure has a lifetime of 30 years [55-57]. In this study, it is assumed that regasification capacities are enough for LNG import in all markets, for example based on the development and cost reduction of floating storage and regasification units (FSRU) [58]. The contract database is built from the Literature survey of long-term contracts compiled by DIW Berlin [59] and the latest annual reports by the International Group of Liquefied Natural Gas Importers (GIIGNL) [41].

The model is programmed in Python for future open-source release. In order to solve the problem in MEM, the Pyomo (Python Optimization Modelling Objects) package [60] is used to interface to the PATH solver [61].

4.2 Scenario framework

The demand trajectories in the scenario tree reflect a variety of possible developments of gas import markets. The demand relationship in each market may shift at a different time-period and therefore has 7 potential routes. This can depend on not only international climate policy implementation, but also the regional efforts and strategies to achieve the decarbonisation goal. Hence, these markets may follow different pathways, and in total 7^5 outcomes may happen. In this work, we examine two major realizations of these pathways, namely Shift2030 and NPS2060 as described above. It is assumed that all markets follow the same development trend and the pathways of these two realizations are shown in Table 4. The Shift2030 takes the same scenario framework as WEO 2017 for its analysis on stranded natural gas assets [5], while NPS2060 assumes that the development would follow current policy pledges and is the common baseline of many gas market studies. Though only two realizations are examined, the supply agents, prior to the realization of future periods, still consider other possibilities when evaluating the potential return of their contracts.

Table 4

Realizations of the changing import market demand relationships

Scenario	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**	**2060**
	Node number										
Shift2030	1	2	3	4	7	11	16	22	26	33	42
NPS2060	1	2	3	4	6	9	13	18	24	27	35

In addition, this work also studies how the LNG tariff between China and the U.S. would affect the natural gas market future globally, and therefore, for both Shift2030 and NPS2060, the scenarios with (Shift2030T and NPS2060T) and without (Shift2030B and NPS2060B) the tariff are simulated.

5. Results and discussion

In this section, how gas markets evolve following different demand trajectories is discussed first. Among the five importing regions, East Asia and China show considerable changes when their demands shift to lower levels. After that, how the China-US gas tariff would influence the markets as well as supply agents, including both North America and its competitors, is presented.

5.1 Alternative gas market futures

As the gas demand by major importers shifts to lower levels after 2030, the supplies towards these markets show significant changes.

Gas import by East Asia, as shown in Fig. 4, increases from 150 BCM/yr in 2010 to 280 BCM/yr in 2030. In scenario NPS2060B, the level rises further to 340 BCM/yr in 2040 and then stabilises there. In contrast, the Shift2030B scenario shows a declined East Asian demand to 210 BCM/yr after 2030. Notable changes are observed not only in the total import amount, but also in the market shares of different exporters. When the demand trend follows current policy pledges (NPS2060B), North America penetrates the East Asia market gradually. The share is around 14% in 2020, and it increases to a considerable 42% in 2040. Eventually in 2060, North America becomes a dominant supplier in East Asia, taking over 65% market share. The reasoning behind this is the low capital requirement in the U.S. for the production of natural gas reserves since the shale boom, which is supported by the supply curve from Wood Mackenzie upstream data [43]. East Asia stays as the most profitable market for North American LNG, and as more North American gas is exported to East Asia, more contracts are signed between these two trade partners. Consequently, more North American LNG projects targeting East Asian clients are invested in. This gradually leads to the dominance of North America in this market. Such dominance is not observed in the Shift2030B scenario. After the markets change their price-demand relationships in 2030, North America stops exporting to East Asia. The price in this market, as shown in Fig. 9, is \$2-4/MMBtu lower relative to the NPS2060B result. Considering the high LNG shipping cost between the two regions, North American exporters find the deal no longer favourable. The Middle East, instead, becomes the major supplier, increasing its supply from 50 BCM/yr in 2020 to 80 BCM/yr in 2040 and 100 BCM/yr in 2060. Its market share in East Asia also increases from the initial 30% to 50% in 2060.

Fig. 4. Major market import sources and volumes in NPS2060B (left) and Shift2030B (right)

China is a fast-growing gas market and its import amounts to 240 BCM/yr in 2040 in the NPS2060B scenario. Whereas in Shift2030B, the import reaches a plateau of 180 BCM/yr in 2040 and then drops slightly to around 160 BCM/yr afterwards. One of the major differences between these two scenarios is the supply from Russia. In NPS2060B, Russia takes up the Chinese gas demand gradually and its market share increases to as high as 40% in 2060, leaving the other exporters (ASEAN, Africa, Caspian, Middle East, and North America) splitting the remaining amount. The broad diversification of gas supplies grants China the bargaining power for its gas import deals, though the dominance by Russia can be an issue worthy of concern. However, China imports considerably less from Russia in Shift2030B, with market share taken at around 20% in 2040, and it decreasing to 5% in 2060. In contrast, North America and Middle East exports increase. By 2060, they occupy a majority of the Chinese market (North America 30% and the Middle East 35%). Notably, North America plays a more important role in China when the demand decreases in the Shift2030B scenario. Between 2030 and 2060, the LNG trade between North America and China increases by an average of 30% relative to NPS2060B. The total additional volume amounts to nearly 400 BCM.

The impact of the demand shift in Western Europe is relatively less significant compared to China and Eastern Asia. With the demand reduction, Russian supply decreases by 10-20% since 2030. The gas imports from Africa shrink by a large extent between 2030 to 2040, mainly because LNG supplies from North America start flowing into this market.

Fig. 5 shows the total revenue of natural gas trade by different exporters between 2010 to 2060. Among the major exporters, North America faces a substantial revenue reduction by 60% (from US$3.9 trillion in NPS2060B to US$1.6 trillion in Shift2030B). The loss of revenue by Russia is also considerable, which amounts to US$1.0 trillion throughout the simulation horizon. For the medium-sized exporters, Africa has its revenue reduced by nearly 40% when facing the global gas demand shift. In contrast, the impacts on ASEAN countries are relatively slight because their supplies remain to be cost-competitive in China and Eastern Asia.

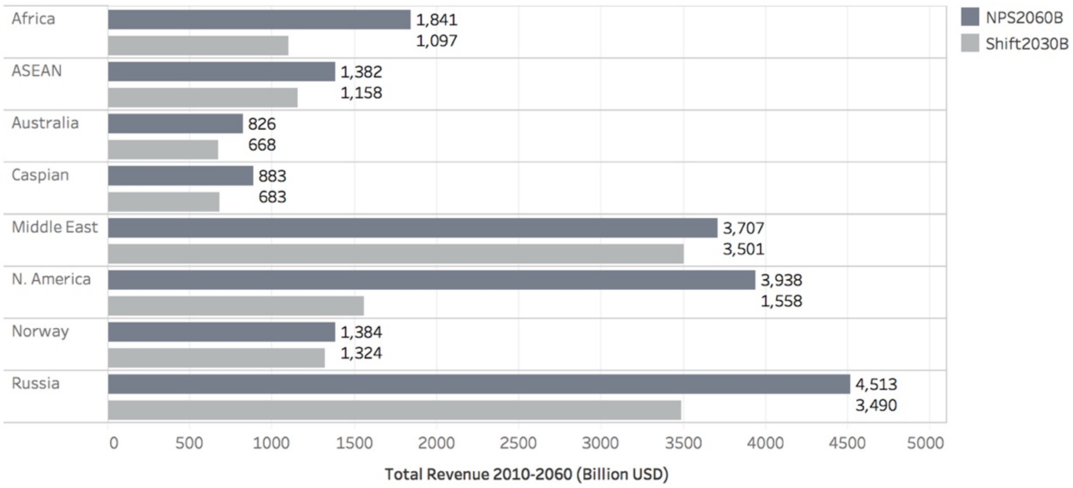


Fig. 5. Supply agents total revenue comparison

5.2 The impact of China-US natural gas tariff

The above results illustrate how different global import-export relationships could evolve under the two demand trajectories. In this section, how the global gas trade may be affected by the Chinese tariff on U.S. LNG export is discussed for the two demand scenarios separately.

5.2.1 Under the current policies gas demand trajectory

The market prices in the two scenarios, namely NPS2060B and NPS2060T, are presented in Fig. 6. With the tariff imposed, China needs to import natural gas at slightly higher prices (by around US$0.3/MMBtu) in the near future (2020 to 2030). Such influence becomes more noticeable in the longer term, as the Chinese gas price increases by US$0.5 to US$1.0/MMBtu after 2045. This change in price is caused by the change in import volume. As shown in Table 5, China imports much less from North America because of the tariff. The annual amount drops significantly from 20-30 BCM/yr to less than 10 BCM/yr, which can increase the Chinese gas price by $2/MMBtu. The reason why Chinese gas price is only influenced mildly between 2020 and 2030 is that the reduced North American LNG supplies are replaced by the additional gas from Middle East, Russia, Caspian, Australia, and ASEAN countries._These exporters each contributes to part of the demand (around 3 BCM/yr) and these additional supplies together allow the Chinese market to remain in equilibrium without much LNG import from North America. However, after 2045, a considerable amount of existing and upcoming gas production and export infrastructure will reach the end of its life. These infrastructures include the major pipelines between China and Russia and the liquefaction plants in ASEAN countries. The LNG supply capacity in Australia also drops to nearly zero due to the lack of further investment.

Though Middle East and Caspian can compensate the reduced North American supply by each increasing by around 5 BCM/yr export to China, other gas exporters lack the spare capacity to sell additional volumes to China. As a result, total Chinese import after 2045 is 4 - 10 BCM/yr less in the tariff scenario relative to the base one. As such, with the tariff imposed, China would see its price increases in 2045-2060 by a relatively higher amount than in 2020-2030.

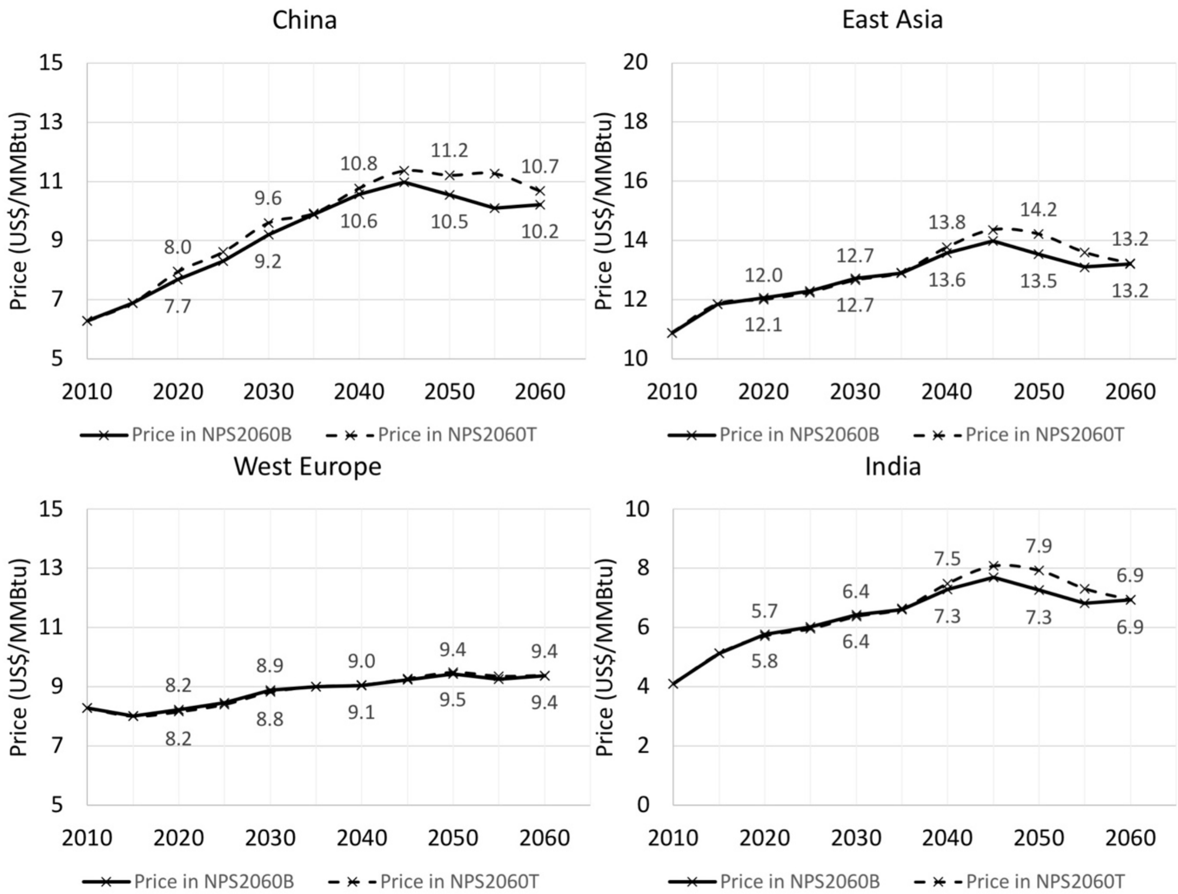


Fig. 6. Price in major markets for NPS2060 scenarios

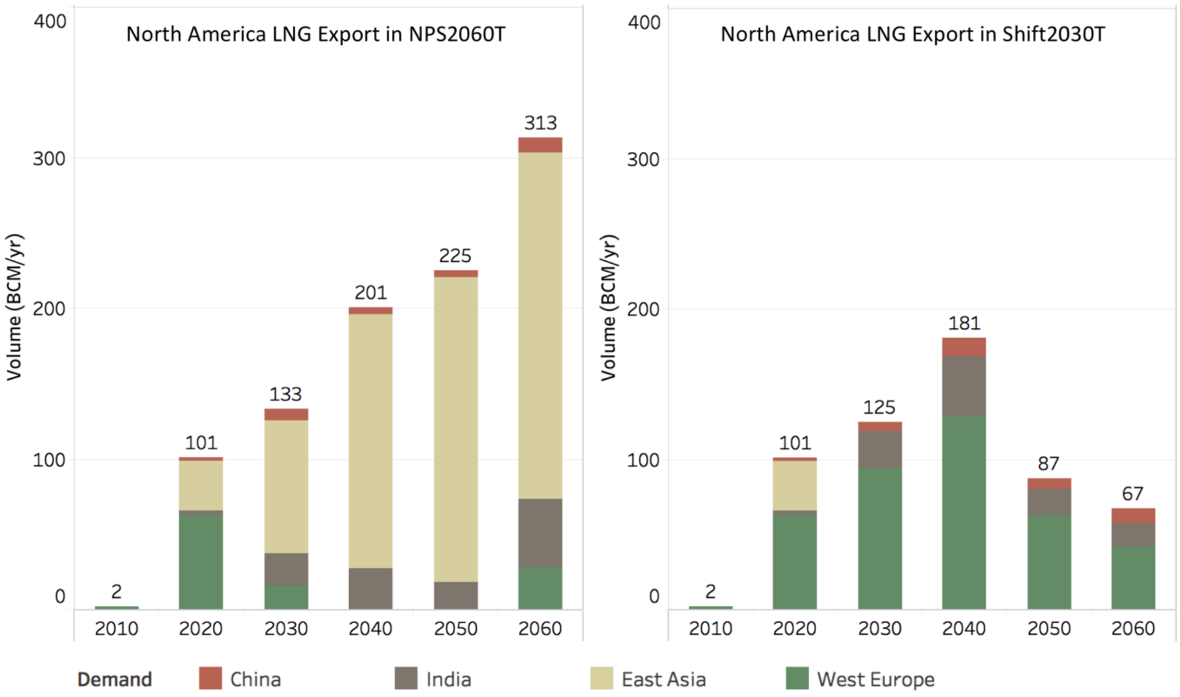
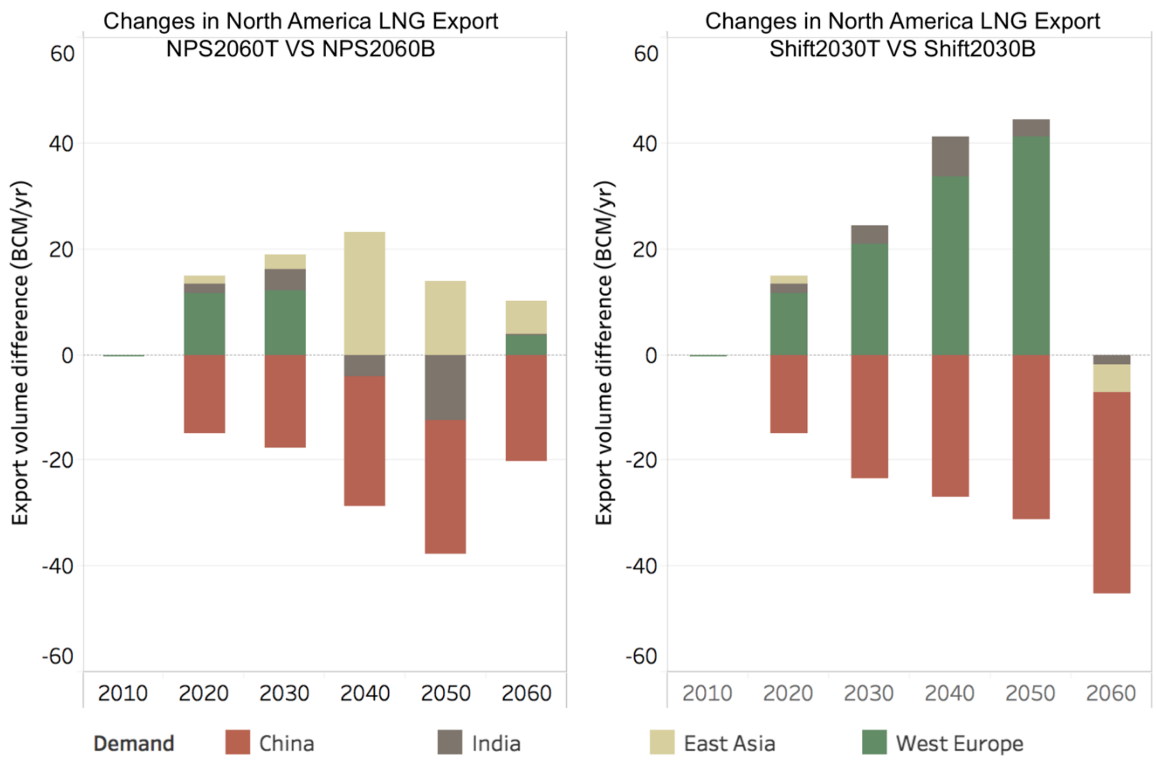


Fig. 7. Gas export by North America under two tariff scenarios



Note: The bar chart illustrate how North American LNG export in the two tariff scenarios differs from their corresponding base scenarios. The value on the negative axis means that North America decreases the export to the market when the China-US tariff is imposed. The positive values indicate an increasing export from North America to the market.

Fig. 8. Changes in gas export by North America

Table 5

Changes in the import volumes in NPS2060T as compared to NPS2060B

Origin	Changes in the Chinese market import (BCM/yr) 2020	2030	2040	2050	2060	Changes in the East Asia market import (BCM/yr) 2020	2030	2040	2050	2060
N. America	-15	-18	-24	-25	-20	2	3	23	14	6
Russia	0	-1	17	3	1	0	0	-26	-23	-5
Caspian	3	4	2	6	4	0	0	0	0	0
Middle East	3	4	2	6	4	0	0	1	4	0
Australia	3	2	0	0	0	0	-1	0	0	0
ASEAN	3	2	1	0	2	0	-1	0	0	-1
Africa	3	4	1	4	4	0	0	1	2	0
Norway	0	0	0	0	0	0	0	0	0	0
Total Change	-3	-4	-2	-6	-4	0	0	-1	-4	0

Due to the 25% tariff, no long-term LNG contract between North America and China is confirmed endogenously after 2020. This leads to a lower LNG export capacity in North America relative to the base case. In the base case, around 50 BCM/yr North American LNG capacities are underpinned by the contracts with China. However, this amount is zero in NPS2060T. Although the contracts with Eastern Asia and Western Europe have relatively higher volumes, they are not sufficient to compensate the impact of the Chinese tariff. As a result, North America develops less LNG capacities and this exacerbates the tightness in global gas supply between 2040 and 2050. Such supply tightness not only influences the Chinese market, but also leads to an increase in East Asian and Indian gas prices. Both markets see their prices $0.5/MMBtu higher than the base scenario. This shows how reduced investment in North American LNG capacities can affect gas markets globally.

Table 6

Total revenue of North America and Russia

	Total revenue between 2010 and 2060 in NPS2060 scenarios (Billion USD) North America	Russia	Total revenue between 2010 and 2060 in Shift2030 scenarios (Billion USD) North America	Russia
Base scenario	3,940	4,510	1,560	3,490
Tariff scenario	3,960	4,340	1,600	3,350
Difference in revenue	26	-180	46	-140

Fig. 7. describes the destination and volume of North American LNG export, and how it differs from the base cases is illustrated in Fig. 8. In addition, the comparison on the total revenue of

North American gas export is illustrated in Table 6. Between 2020 to 2030, the reduced export to China is redirected to Western Europe. Since Western Europe is a relatively large market, the additional amount of LNG import from North America (10-15 BCM/yr) does not significantly influence the market shares of other major suppliers. These suppliers, including Russia, Africa, and Middle East, only have their export reduced by 2-5 BCM/yr. After 2035, East Asia becomes the destination that North American LNG focuses on. The gas which is sold to China in the NPS2060B scenario is redirected to East Asia in NPS2060T. This strengthens the dominance of North American supplies in East Asia, and its market share increases from 42% (NPS2060B) to 50% (NPS2060T) in 2040 and from 55% to 60% in 2050. The total revenue of North America in the tariff case (US$3.9 billion) is approximately the same as that in the base one (US$ 4.0 billion). This indicates that if the demand trajectory follows current policy pledges, North America would only be influenced marginally by the tariff proposed by China.

In contrast, the Russian LNG export faces a serious challenge in this tariff scenario. Around two-thirds of the Russian supply to Eastern Asia in NPS2060B (20-30 BCM/yr) can no longer be sold because of the increasing North American supply to the market. Though Russia has the spare capacity to export more LNG to East Asia, the trade would be less profitable as the increasing volume would weaken the market price. Hence, during the short period between 2030 and 2040, Russia redirects its LNG to China. Afterwards, no more LNG projects are developed in Russia, and a revenue reduction of US$180 billion is observed. The result suggests that, if China imposes the tariff to North American LNG, Russia should consider investing more conservatively in their LNG projects targeting the East Asian market. Instead, the pipeline projects targeting China may play a more important role in the Russian gas export portfolio.

5.2.2 Facing gas demand change

Here, the discussion focuses on the scenarios when global gas demand shifts to a lower level in 2030 (Shfit2030B and Shift2030T). Notably, as shown in Table 6, no reduction in the total revenue of North America is observed when the Chinese tariff is imposed. In fact, revenue increases slightly from the US$1.56 billion (in Shift2030B) to US$1.60 billion (in Shift2030T). Between 2030 and 2050, North America exports more LNG in the scenario with the tariff than the one without. The LNG which would have been shipped to China is redirected to Western Europe. As shown in Fig. 8, gas export from North America to Western Europe increases by

30 BCM/yr in 2040 and 40 BCM/yr in 2050. Consequently, the long-term contracts signed between this pair have higher request volumes and these contracts then underpin more LNG capacities in North America. On average, North America has 15 BCM/yr additional export capacity between 2030 and 2050. Because of the increased capacity, the total export volume from North America sees an increase relative to the base case, though the trade between North America and China shrinks considerably. Similar to the NPS2060 cases, the results under the Shift2030 assumptions also indicate that the impact of the Chinese tariff on North American LNG business is limited. The cost advantage allows North America to increase its export to other markets to compensate for the loss in the Chinese market.

The result also suggests that the tariff only imposes a mild impact on the Chinese market. Details on the Chinese import in the Shift2030T scenario are presented in Table 7. The gas import price in China, as shown in Fig. 9, differs by maximally $0.4/MMBtu in Shift2030T as compared to Shift2030B. Though the Chinese import from North America decreases from over 100 BCM/yr (in Shift2030B) to less than 10 BCM/yr (in Shift2030T), additional gas can be sourced from other major suppliers. These suppliers, including the Caspian region, the Middle East, Australia, ASEAN countries, Africa, and Russia all have spare capacities to deliver additional gas because all markets shift to the low-demand scenario after 2030. Because of this, China can still import a similar level of gas (95%-98% relative to the amount in the base case) to retain the market equilibrium even if it loses the North American supply. In addition, the market demand becomes more elastic, and therefore a minor change in the import volume only has a low impact on the price.

The other market which is influenced by the tariff is Western Europe. Since North America increases its export there, other suppliers including Russia, Africa, and the Middle East have their export reduced to keep the market price at a profitable level. Among these suppliers, Russia is the dominant one in the base case, and its export is influenced to a great extent. For example, in 2040, over 15 BCM/yr Russian pipeline supply to Western Europe is replaced by North American LNG. As a result, the dominance of Russian gas in this market is alleviated. In the Shift2030B scenario, Russia supplies over 50% of Western Europe gas import in 2045. This percentage declines to 45% in Shift2030T, and the market share taken by Russia is below 40% for most of the periods. This suggests that Western Europe can benefit to further diversify its gas supply under the Chinese tariff scenario. On the other hand, Russia has a revenue reduction of US$140 billion. Though the amount is marginal relative to its total revenue of

US$3.5 trillion, the result indicates a threat to the Russian gas business from North America when the tariff is imposed.

Table 7

Changes in the import volumes in Shift2030T as compared to Shift2030B

	Changes in the Chinese market (BCM/yr)					Changes in the West Europe market (BCM/yr)				
Origin	2020	2030	2040	2050	2060	2020	2030	2040	2050	2060
N. America	-15	-23	-27	-31	-38	12	21	34	41	0
Russia	0	-1	7	-3	-2	-3	-5	-16	-2	-2
Caspian	3	5	3	5	7	0	0	-1	-3	-32
Middle East	3	5	3	5	7	-3	-4	-1	-18	-1
Australia	3	2	0	0	0	0	0	0	0	0
ASEAN	3	5	5	7	-4	0	0	0	0	0
Africa	3	4	5	14	22	-3	-5	0	-12	-13
Norway	0	0	0	0	0	0	-3	0	0	0
Total Change	-3	-5	-3	-5	-7	3	5	16	6	-48

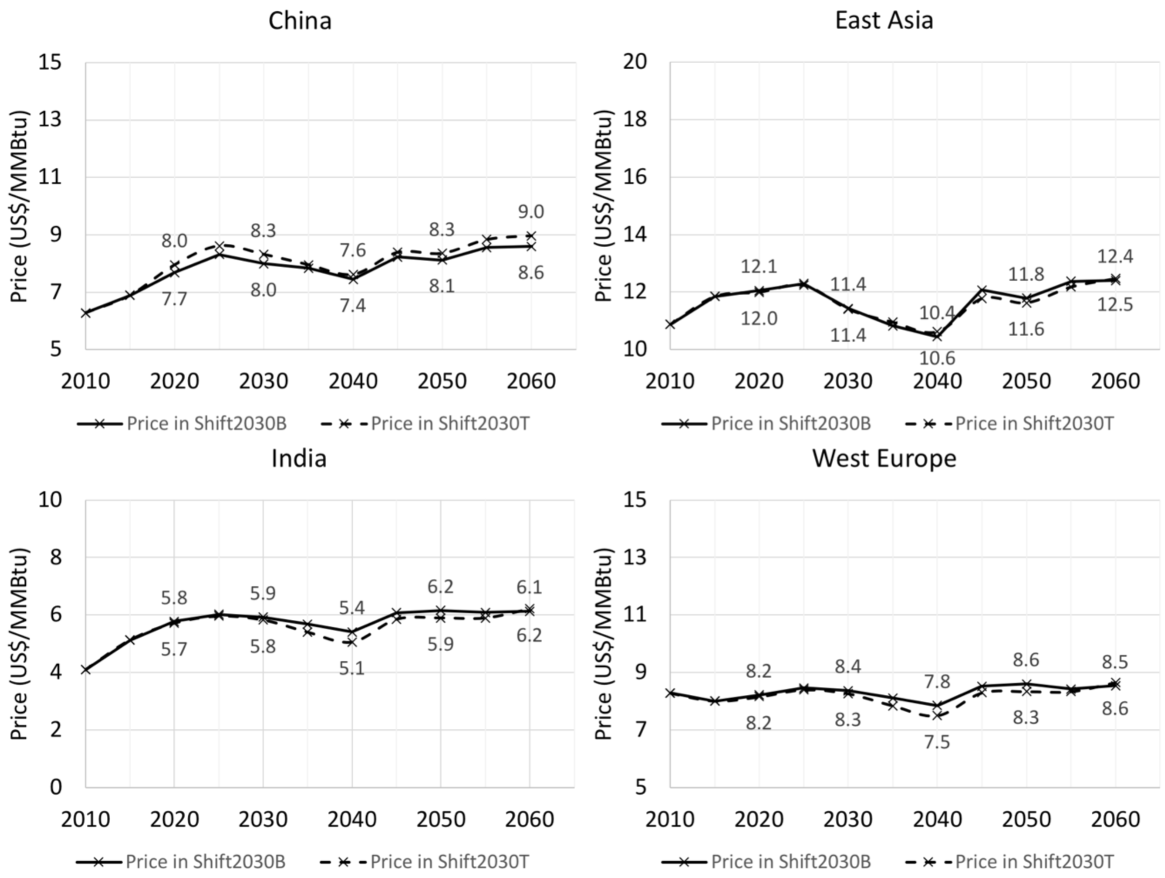


Fig. 9. Price in major markets for Shift2030 scenarios

6. Conclusion

This study analyses how a "disjoint shift" in demand levels of different regional markets would affect future global gas trade. The model, Gas-GAME-Risk, takes an agent-based approach and allows investors to evaluate the potential demand risks in a stochastic manner before making their decisions on long-term contracts.

The simulation results indicate that under the New Policies Scenario demand trajectories (NPS2060B), North American LNG supply would gradually dominate the Eastern Asia gas market and take more than 65% of the market share by 2060. However, with the disjoint shift condition (Shift2030B), export to East Asia becomes less profitable for North America and Middle East becomes the major supplier there with its export volume doubling from 2020 to 2060. The Russian pipeline supplies to the Chinese market are affected considerably by the demand change as China shifts to more flexible LNG supplies. Both North America and Russia, subject to the disjoint demand shift, may suffer significant revenue loss on global gas trade, of US$2.3 trillion and US$1.0 trillion respectively.

When the potential 25% China-US LNG tariff is imposed, under the New Policies demand trajectory assumption, the Chinese market is affected only mildly in the near future thanks to the additional supplies from other exporters. After 2045, China sees a notable price increase compared to the scenario without tariff because of the decommissioning of gas supply infrastructure and lower North American capacity development. The global LNG supply condition becomes tight and this also leads to higher prices in Eastern Asia and India. With its export to China reduced significantly, North America further dominates the Eastern Asia market, and as a result, Russian LNG faces serious challenges with a 66% supply reduction. The results suggest that Russia should invest more in the Chinese pipeline projects rather than LNG projects if such a tariff is imposed.

When the tariff is imposed under the Shift2030 assumptions, the Chinese market is only mildly affected. Additionally, no reduction in the total revenue is observed in North American LNG business. North America shifts its emphasis to the Western Europe market, and this leads to a further expansion of North American LNG capacities. Russia has its market share in West Europe reduced and the competition in the Chinese market allows Russia little space to increase its export there. As a result, Russia is negatively affected by such a tariff and has its total revenue reduced by US$140 Billion between 2020 to 2060.

Appendix

Table A.1

Base-period market elasticity

Import market	Elasticity [33]
East Asia	-0.25
West Europe	-0.7
East Europe	-0.6
India	-0.5
China	-0.5

Table A.2

Demand market relationships in under NPS trajectory

		West Europe	East Europe	East Asia	China	India
2010	***INT (Million US$/BCM)***	558	424	1412	281	217
	SLP (Million US$/BCM^2)	1	3	7	4	5
2015	***INT***	573	411	1640	455	290
	SLP	1	3	7	4	5
2020	***INT***	587	397	1868	628	364
	SLP	1	3	7	4	5
2025	***INT***	601	384	2096	801	438
	SLP	1	3	7	4	5
2030	***INT***	615	371	2324	974	512
	SLP	1	3	7	4	5
2035	***INT***	629	358	2552	1147	585
	SLP	1	3	7	4	5
2040-2060	***INT***	643	345	2780	1320	659
	SLP	1	3	7	4	5

Table A.2

Demand market relationships in under LOW trajectory

		West Europe	East Europe	East Asia	China	India
2025	***INT (Million US$/BCM)***	623	379	1493	687	450
	SLP (Million US$/BCM^2)	1	3	5	3	4
2030	***INT***	573	411	1640	455	290
	SLP	1	3	7	4	5
2035	***INT***	587	397	1868	628	364
	SLP	1	3	7	4	5
2040-2060	***INT***	601	384	2096	801	438
	SLP	1	3	7	4	5

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