FCN | Future Energy Consumer Needs and Behavior

E.ON Energy Research Center

RWTH AACHEN UNIVERSITY

FCN Working Paper No. 4/2017

Impacts of an Ice-Free Northeast Passage on LNG Markets and Geopolitics

Michael Schach and Reinhard Madlener

April 2017
Revised June 2018

Institute for Future Energy Consumer Needs and Behavior (FCN)

School of Business and Economics / E.ON ERC

FCN Working Paper No. 4/2017

Impacts of an Ice-Free Northeast Passage on LNG Markets and Geopolitics

April 2017
Revised June 2018

Authors´ addresses:

Michael Schach
RWTH Aachen University
Templergraben 55
52056 Aachen, Germany
E-Mail: Michael.Schach@rwth-aachen.de

Reinhard Madlener
Institute for Future Energy Consumer Needs and Behavior (FCN)
School of Business and Economics / E.ON Energy Research Center
RWTH Aachen University
Mathieustrasse 10
52074 Aachen, Germany
E-Mail: RMadlener@eonerc.rwth-aachen.de

Publisher: Prof. Dr. Reinhard Madlener
Chair of Energy Economics and Management
Director, Institute for Future Energy Consumer Needs and Behavior (FCN)
E.ON Energy Research Center (E.ON ERC)
RWTH Aachen University
Mathieustrasse 10, 52074 Aachen, Germany
Phone: +49 (0) 241-80 49820
Fax: +49 (0) 241-80 49829
Web: www.fcn.eonerc.rwth-aachen.de
E-mail: post_fcn@eonerc.rwth-aachen.de

Impacts of an Ice-Free Northeast Passage on LNG Markets and Geopolitics

Michael Schach[1] and Reinhard Madlener[2,*]

[1] *RWTH Aachen University, Templergraben 55, 52056 Aachen, Germany*

[2] *Institute for Future Energy Consumer Needs and Behavior (FCN), School of Business and Economics / E.ON Energy Research Center, RWTH Aachen University, Mathieustraße 10, 52074 Aachen, Germany*

April 2017, revised June 2018

Abstract

In this paper we examine the economic and geopolitical relevance of an ice-free Northeast Passage as a shipping route, with a particular view on the major LNG-supplying and LNG-consuming countries, and expected changes in LNG trade flows. Several key aspects are considered in -depth, such as the developments in natural gas production in the Russian Arctic, important trends and strategies of major Asian LNG-consuming countries, and the geographical and climatic particularities of the Arctic. The analysis reveals the competitiveness of Russian LNG exports along the Northeast Passage due to Yamal LNG, which could be a game-changer for global LNG supplies. We further find that an ice-free NEP is primarily relevant for maritime bulk, and particularly LNG, shipping, and thus of great geopolitical importance and strategic interest, especially for Russia and the US on the supply side, and China, Japan, and South Korea on the demand side. The political relevance of the Arctic is becoming more lucid, because the retreating ice creates possibilities for the development of hydrocarbons but also fosters strategic and military considerations of the littoral countries.

Keywords: LNG markets, Geopolitics, Northeast Passage, Arctic, Russia, Asia;

* Corresponding author. Tel. +49 241 80 49 820, e-mail: Rmadlener@eonerc.rwth-aachen.de (R. Madlener)

List of acronyms

AMSA	Arctic Marine Shipping Assessment
BP	British Petroleum
CNPC	China National Petroleum Corporation
EIA	U.S. Energy Information Administration
E&P	Exploration and Production
FID	Final Investment Decision
FSU	Former Soviet Union
GECF	Gas Exporting Countries Forum
IEA	International Energy Agency
IGU	International Gas Union
IMO	International Maritime Organization
JCC	Japan Crude Cocktail
JV	Joint Venture
LNG	Liquefied Natural Gas
LTC	Long-Term Contract
METI	Ministry of Economy, Trade and Industry
MOU	Memorandum of Understanding
NEP	Northeast Passage
NSR	Northern Sea Route
NWP	Northwest Passage
OIES	Oxford Institute for Energy Studies
OPEC	Organization of the Petroleum Exporting Countries
OTC	Over-the-counter
PAME	Protection of the Arctic Marine Environment
SAR	Search and Rescue
SCR	Suez Canal Route
SIPRI	Stockholm International Peace Research Institute
SOLAS	International Convention on Safety of Life at Sea
TOCOM	Tokyo Commodity Exchange
UNCLOS	United Nations Convention on the Law of the Sea
USGS	United States Geological Survey
VAT	Value-added Tax

List of units

bcm	billion cubic meters
bn	billion
CO_2	carbon dioxide
m	meter
m^3	cubic meter
MMBtu	million British thermal units
Mtoe	million tons of oil equivalent
MTPA	million tons per annum
t	ton
°C	degree Celsius
$	U.S. dollar

1 Introduction

The International Energy Agency (IEA) predicts a 45% increase in global natural gas consumption by 2040, driven by industrialization and urbanization in emerging economies (IEA, 2017: 2). Traditionally, natural gas has been traded and transported via pipeline, on the basis of bilateral, over-the-counter, long-term contracts (LTCs). Development of new conventional and unconventional supplies, technological advances, supply diversification, and domestic policy factors facilitated the spread of liquefied natural gas (LNG). In 2017, the global LNG trade reached an all-time high of 293 million t – accounting for roughly 10% of the globally consumed natural gas. The growth rate of LNG supplies averaged to 6% from 2000 to 2016; indigenous production and pipeline supplies have also shown substantial growth since 2010 (IGU, 2018: 5, 7). . British Petroleum (BP) forecast that LNG will substitute pipeline gas as the most frequent form of inter-regionally traded natural gas in the early 2020s (BP, 2018: 81, 82). The major LNG market is located in Asia: Japan, China, and South Korea were responsible for 55.5% of the global LNG imports in 2017 (IGU, 2018: 11). The rapidly increasing energy demand, particularly LNG demand, of Asian countries fosters the ambitions of suppliers like Qatar, Australia, USA, and Russia for extensive, new natural gas exports, especially via LNG supplies.

The Northeast Passage (NEP) has been a subject of researchers' curiosity for centuries. In 1878/79, the Swedish explorer and mineralogist Adolf Erik Nordenskiöld successfully traversed the passage for the first time in history (Avango et al., 2014: 22). The NEP is the shortest maritime connection between Europe and Asia. Over a century after Nordenskiöld's expedition, the progressive decline of the Arctic ice is uncovering the potential of the NEP as a seasonal supplement to or even a substitute for the Suez Canal Route (SCR) (Fig. 1).

Moreover, the retreating ice is exacerbating the disputes of such countries as the United States of America, the Russian Federation, Norway, and others, concerning their claims to Arc-

tic territories. Asian countries with massive maritime trade flows are monitoring these geographical and political developments closely. The transportation of Asian exports to Europe, as well as of commodity imports from the Russian Arctic to Asia is of great interest to countries such as Japan, China and South Korea. In early 2018, China's State Council Information Office formulated the country's national vision of the Arctic with regard to Arctic development of natural resources and shipping along the Northeast Passage in order to build a "Polar Silk Road" (SIPRI, 2018). Certainly, the Arctic sea route has the potential to convey the enormous Russian natural gas assets from the North of Western Siberia to European and Asian markets. Considering the challenging conditions of the present LNG market, the NEP might even become a crucial competitive advantage for Russian LNG exporters, such as Yamal LNG (Fig. 1), due to the considerable cost and time savings involved.

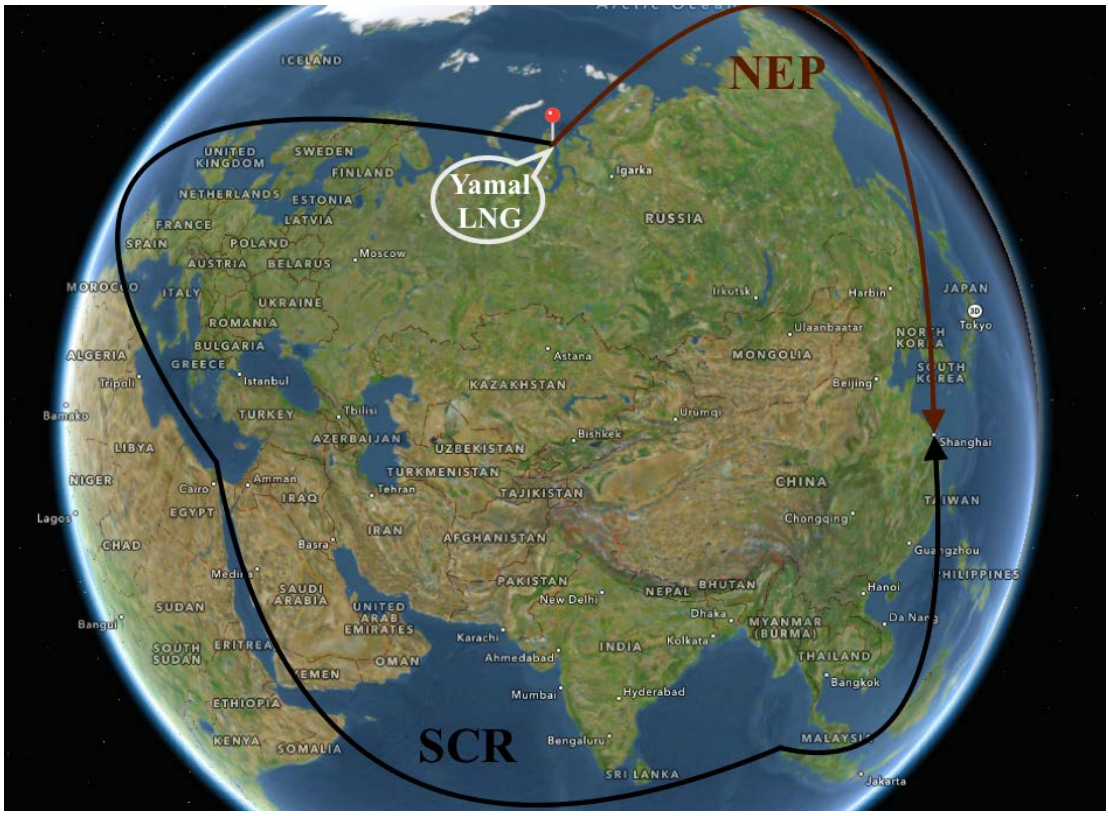


Fig. 1: Yamal LNG, the Northeast Passage (NEP) and the Suez Canal Route (SCR)

Source: Own illustration, based on Google Earth (2018)

The emergence of a new shipping route that could greatly impact the long-distance maritime trade flows is of global economic and political relevance. Especially for Russia, it could constitute a potential game-changer, enabling extensive LNG exports not just from the Sakhalin Peninsula, but increasingly also from the huge resource base in the Yamal region. Hence, aside from low production costs, Arctic shipping along the NEP could constitute a unique competitive advantage for LNG suppliers in Russia – not just to Asia but also to Europe, where it may become the least-cost shipping route: Schach and Madlener (2018) find, in a quantitative analysis using a world gas model, that when surplus volumes are diverted to Europe after Asian demand is satisfied, it will be predominantly LNG from Yamal, rather than for example from the US, going to Europe because of the relatively short distance. In their analysis, however, they abstract from destination clauses and strategic governmental purchases and assume abundant global LNG supplies.

The aim of the present study is to examine the relevance and eligibility of the NEP for LNG shipping, based on a detailed literature review. While there is an extensive body of geographical literature, and another one on LNG markets without much geographical coverage, our paper's original contribution is to combine the two, providing an economic and geopolitical analysis of the NEP on international LNG trade and markets. Three distinct *research questions* are raised: (1) How will the LNG market be impacted by the developments on the supply and demand side? (2) To what extent is the NEP economically and politically relevant for LNG-producing and LNG-consuming states? (3) What are the impacts of an ice-free NEP on LNG markets and geopolitics?

The remainder of the paper is organized as follows. Section 2 analyzes the developments and trends in LNG production outside of Russia, inside of Russia, and in particular in the Russian Arctic. Section 3 investigates key developments in major LNG-consuming countries, particularly in Japan, South Korea, and China. Section 4 assesses the geographical and climatic particularities of Arctic shipping along the NEP. Section 5 discusses the key results and insights

gained from the analysis, whereas Section 6 concludes on the economic and geopolitical significance of the NEP, reflects on both the limitations of the analysis undertaken and ideas for future research, and provides some policy implications derived from the analysis.

2 Developments in the global supply of LNG

Crude oil prices at around $100 and the rising demand for energy in Asia and LNG, particularly in Japan, resulted in extraordinarily high LNG prices in Asia in the years 2010 to 2014 (NASDAQ, 2018; IGU 2018: 17). Driven by this trend and the progress in the development of unconventional hydrocarbons, high investments in new LNG liquefaction sites were made, especially in Australia and the US (Henderson, 2016a: 4).

2.1 Non-Russian LNG production

2.1.1 Australia – the world's prospective leading LNG producer

Seven new Australian projects, with a total investment of over $200 billion (bn), which will supplement the three already existing ones, will come on stream in the period of 2015-2020. Australia may rival Qatar, the presently leading LNG exporter by 2019, when Australian liquefaction capacities will expectedly reach a volume of 87.6 million tons per annum (MTPA) (IGU, 2018: 71-74; Henderson, 2016a: 4). According to an Oxford Institute for Energy Studies (OIES) publication, the new LNG production facilities in Australia will not generate positive returns on a full-cost basis, unless the low LNG prices return to a level of $10-14 per million British thermal units (MMBtu) (0.36-0.5 $/m^3) (Henderson, 2016a: 4-5). Despite that, the producers will probably still sell off large portions of their annual output, as long as marginal revenues exceed marginal costs. A temporary export reduction would only result in a decrease of Australia's market share, due to a variety of other exporters with lower costs and greater production capacities, such as Qatar, who can easily meet the current and expected demand. As a result, it

is likely that the Australian export volumes will enhance the current global supply-side competition. However, concerning new Australian developments, even projects with brownfield economies are unrealistic under the present market conditions.

2.1.2 USA – LNG supplies after the shale gas revolution

The shale gas revolution in the US has made natural gas a top priority topic in both domestic and foreign policy due to the economic and geopolitical impacts. The US energy mix has changed drastically, for the first time in history replacing coal with natural gas as the largest source of domestic power generation (Cole et al., 2016: 486). In addition, the premium prices in Northeast Asia have been an excellent business opportunity for US companies to export the less expensive North American shale gas. The construction of six US liquefaction terminals with a total capacity of 72.25 MTPA was decided in the 2010s. Production already began at Sabine Pass, and Cove Point; Elba Island, Cameron and Freeport LNG are also expected to commence with exports in 2018. Due to the availability of gas at prices related to the Henry Hub ($2-2.5 per MMBtu x 1.15), tolling fees of $2.50-3.50 per MMBtu and the relatively low shipping costs, the effective costs for LNG from the US shipped to Asia and Europe amount to $7-8 per MMBtu and $6.5-7.00 per MMBtu, respectively (Henderson, 2016a: 5; Schach and Madlener, 2018). Based on Asian and European LNG prices in the period of 2010-2014 (IGU 2018: 17), the US producers calculated with an acceptable profit margin. An algorithm-based LNG transport capacity optimization as well as a quantitative comparison of shipping routes, e.g. transportation of LNG, originating at the US East Coast through the recently extended Panama Canal to the Asian Pacific economies such as Japan, China, and South Korea, can be found in a companion paper (Schach and Madlener, 2017).

2.1.3 Qatari LNG supplies

Today's leading LNG exporter, Qatar, began exporting LNG in 1997 (Esen and Oral, 2016: 104). Qatar has been limiting its exports artificially to a stable volume of approximately 77

MTPA and a market share of about 31% through the whole period between 2010-2015 (IGU, 2018: 10). In 2017, Qatar announced that it would lift its moratorium on LNG production and declared that it would expand its liquefaction capacities by 30% to 100 MTPA by 2024 (S&P Global Platts, 2017). While Australia might supersede Qatar as the leading LNG exporter for a brief period of time before the end of this century, Qatar will likely dominate the LNG trade in the long term. Due to the low production costs (estimated at below $2 per MMBtu), Qatar has been able to maintain a profitable margin in all the previous years and is expected to resume with this trend (Henderson, 2016a: 6). Nevertheless, there are various political risks that could endanger the supply security of Qatari LNG. "…Iran's incessant threat to close the Strait of Hormuz, piracy in the Gulf of Aden, political instability throughout the Middle East and North Africa, and other conflicts throughout the African continent" are major threats to a stable supply and energy security in Asia (Mroczkowski and Hsiao, 2012: 1). The recent discord between Doha and Riyadh, which led to a boycott of Qatar in the Arab world constituted a severe threat to the global supply security of LNG. As modelled quantitatively by Schach and Madlener (2017), a cut-off of the cost-efficient Qatari gas supplies would not endanger the global supply security, although it would considerably impact the LNG prices and trade flows.

2.2 Russian LNG production

2.2.1 Privately and publicly owned gas suppliers

During the same time period, i.e. 2010-2014, several new LNG projects were being discussed in Russia. Due to the location of the majority of the Russian gas fields in Arctic or Subarctic regions, shipping along the NEP is a fundamental premise for Russian LNG exports. The state-owned company Rosneft and the private company Novatek received the permits for LNG export in 2013. Before that, Gazprom enjoyed this privilege exclusively (Motomura, 2014: 72). Novatek's gigantic Yamal LNG project deserves closer attention, due to the crucial role of the NEP in its business strategy. From a politico-economic perspective, the export liberalization is

a notable development considering the conservative structure of the Russian market: Since Novatek is a publicly listed company, whereas Gazprom and Rosneft are state-owned enterprises, this decision changes Russia's gas strategy, traditionally based on state-controlled exports through pipelines. If this trend leads to further liberalizations, facilitating competition and a more efficient market, Gazprom's monopolistic position and the company's enormous political power might be challenged. Almost a decade after operations began in 2009 at Russia's first LNG project, the Gazprom-led joint venture (JV) Sakhalin II, LNG production has started on the Yamal Peninsula: In November 2017, the first cargo of LNG was exported from the first train of Yamal LNG, while the second, third and fourth trains are expected to be operational by 2018 and 2019, respectively. Novatek also seriously considers the construction of a follow-up project, Arctic LNG 2, on the nearby Gydan Peninsula (Fortescue, 2016: 52; IGU, 2018: 73-74; Reuters, 2017; Schach and Madlener, 2018) :

2.2.2 Profitability of hydrocarbon exploration and production in the Arctic

The retreat of the Arctic ice is enabling hydrocarbon exploration and production (E&P) activities in this remote region which has an enormous geological potential but at the same time provides an incredibly sensitive environment. Still, the economic attractiveness of drilling operations beyond the Arctic Circle is limited by the extreme geographical remoteness, missing infrastructure, and harsh climatic and weather conditions, with temperatures at -50°C and nearly total darkness for a significant part of the year (Henderson and Loe, 2014: 1).

On the one hand, the profitability of Arctic E&P operations is determined by the oil price and therefore, by the reactions of the hydrocarbon markets to other supplies, such as unconventional oil & gas and alternative energies. On the other hand, the rising demand for natural resources in emerging markets and the imminent end of easily accessible hydrocarbons increase the potential of the Arctic as the world's next offshore hotspot for oil and gas development (Henderson and Loe, 2014: 1) The United States Geological Survey's (USGS) estimates 22%

of the global, undiscovered, but technically recoverable oil and gas resources within the Arctic Circle (Ellis and Brigham, 2009: 97). Specifically, the Arctic Council estimates two-thirds of this undiscovered gas to be in the South Kara Sea, South Barents Basin, North Barents Basin, and the Alaska Platform (Gautier et al., 2009: 1178). While in the past, conflicts around natural resources and distribution routes frequently led to conflicts of interest in the Middle East and North Africa, the retreating ice may transform the Arctic into a new political battleground for hydrocarbons. The strategic importance of the Arctic Ocean as a future prospective artery for the global trade flows enhances the significance of this region not only for its littoral states, but also for the Asian and European trading nations. Hence, a joint and constructive approach for regulation and legislation as followed by the Arctic Council is indispensable for a peaceful, environmentally safe and prosperous future of the region.

2.2.3 Yamal – Russia's prospective leading LNG project

Of all discussed, planned and constructed Artic LNG projects the most notable is Yamal LNG. The plant, currently under construction on the Russian Yamal Peninsula, is located within the Arctic Circle (Fig. 1). The project is a JV between Novatek (50.1%), Total (20%), CNPC (20%) and the Silk Road Fund (9.9%) with a capital expenditure amounting to $27 bn. The significant financial support of Chinese investors was decided at a time when Russia was alienated from the West, due to the events in Ukraine. Moreover, the ongoing difficulties for the European-Russian pipeline project Nord Stream 2, and the general trend towards gas supply diversification in Europe, foster the prospects for a major Russian-Chinese energy alliance. The gas to be liquefied at Yamal LNG originates from the South Tambey Field, with estimated natural gas reserves amounting to 926 bcm (Yamal LNG, 2017a). The field development license that Yamal LNG holds is valid until the end of 2045 (Yamal LNG, 2017b). The first production train was scheduled to be operational by the end of 2017. Indeed, the first cargo amounting to 170,000 m^3 of LNG was loaded onto one of Novatek's icebreaking LNG tankers during a festive

ceremony on December 8, 2017 in the presence of Russian president Vladimir Putin – emphasizing the national importance of the project (Novatek, 2017e). The second, third and fourth train will be operational by 2018 and 2019, respectively producing a total amount of 17.4 MTPA of LNG and up to 1.2 MTPA of gas condensate for Asia-Pacific and European markets (Yamal LNG, 2017a). The fourth train is a mid-scale liquefaction train with a capacity of 0.9 MTPA, based on Novatek's proprietary Arctic Cascade technology. The company aims at the developing of full-scale liquefaction trains – "made in Russia" – for its consecutive projects. Yamal LNG will increase the total Russian LNG production capacity to 28.2 MTPA by 2019 (IGU, 2018: 32). According to the company's CFO, Mark Gyatvay "… total operating costs including feedstock, liquefaction and shipping come in a little under $3 per MMBtu" (S&P Global Platts, 2016: 6). Based on the Asian spot prices the project seems to be competitive (METI, 2016a; IGU 2018: 17). Moreover, most of the LNG to be produced is already sold, due to multiple, mostly oil-indexed LTCs already signed (Novatek, 2017a). Henderson estimates in calculations regarding the Yamal LNG project, prices of $7-8/MMBtu ($4 per MMBtu) to be necessary for a break even on a full-cost (cash) basis (Henderson, 2016b: 24).

Governmental support and political impact. The Russian government recognized Yamal LNG's special status and granted major tax incentives in 2015: 0% mineral extraction tax (applied to natural gas and gas condensate) for a duration of 12 years, a 15.5% tax rate on the company's profits for the duration of 12 years, a zero export duties rate and a value-added tax (VAT) exemption for imported equipment (Russian Government, 2017). Moreover, the Russian government supports the infrastructure development (Sabetta sea port and airport and proposed optimized tariffs for icebreaking support via the NEP) (Novatek, 2017d). Put differently, Yamal LNG is not regarded as a purely economic project by the Russian government, but as one of strategic significance for the state: Its success is crucial for Russia's future perspective as one of the globally leading LNG producers alongside Qatar, Australia and the US. In the same way

the NEP is perceived as a strategic maritime pathway and trading route. The construction of infrastructure along the Northeast Passage is a chance for the Russian authorities to develop the country's most remote regions.

In March 2017, Vladimir Putin declared that "... the country not only can – but will become the world's biggest LNG producer." (Paraskova, 2017). This objective sounds very ambitious, when comparing all production sites operational or under construction in Russia with the ones in the US, Australia and Qatar (IGU, 2018: 71-74). However, Putin's statement, in combination with the prospective expansion of LNG export capacities in Russia, can be interpreted as the opening of a new front in the LNG supply competition between the US and Russia – enabled through an ice-free NEP.

Purchasers of LNG. Yamal LNG signed multiple LTCs with various international companies for 95% of their LNG volumes (Novatek, 2017a); (Table 1). Moreover, in 2015 Fluxys LNG (the owner and operator of the Zeebrugge LNG terminal) and Yamal LNG signed a 20-year contract on the transshipment of up to 8 MTPA of LNG at the Zeebrugge LNG terminal in Belgium, in order to ensure year-round deliveries of the LNG. During the Arctic winters, the LNG will be reloaded at the terminal from icebreaking to conventional tankers to proceed its journey to the Asian-Pacific LNG consumers (Yamal LNG, 2017f). Novatek also declared the construction of a transshipment terminal on the Kamchatka peninsula in Russia's Far East (Schach and Madlener, 2018).

LNG shipping via the NEP. The remote location of the Yamal LNG plant is both a competitive advantage and a challenge. Presumably for five months per year the NEP offers a very competitive shipping route to the destinations in Asia. The estimated duration of the LNG's journey amounts to 14 days to Japan and 18 days to China (S&P Global Platts, 2016: 8). But even during the summer and fall, occasional ice makes icebreaker support necessary. To be independent from the ice's extent, Yamal LNG ordered up to 16 icebreaking LNG tankers. The 172,600 bcm

LNG tankers will be able to operate at temperatures as low as -50°C and to independently navigate in 2.1 m thick ice (Yamal LNG, 2017g; LNG World News, 2017).

Table 1: LTCs of the Yamal LNG project

Purchaser	Volume (MTPA)	Duration (a)	Pricing (if known)	Destination (if known)
CNPC	3	20	Indexed to JCC	China
Total Gas & Power	3	24	-	-
Gazprom M&T Singapore	2.9	20	Crude oil index.	Asian-Pacific region
Gas Natural Fenosa	2.5	Long-term	-	Spain
Engie	1	23	-	-
Total Gas & Power	1	15	-	-
Shell International Trading Middle East	0.9	20	-	-
Gunvor	0.48	Long-term	-	-
Sum:	**14.78**	-	-	-

Source: Own compilation, based on Yamal LNG (2017c-f); Novatek (2017b-c); S&P Global Platts (2016): 6

3 Developments regarding global LNG demand

The value of the annually traded LNG amounts to over $150 bn, making it the second-largest traded commodity after crude oil. In accordance with the IEA forecast (IEA, 2017: 2), the Japanese Ministry of Economy, Trade and Industry (METI) expects the global LNG demand, which is driven by the rapid growth of energy consumption and industrialization in Asia, to increase from the current 250 million t to 350 million t by 2020 (METI, 2017a: 2,3).

The world's five biggest consumers of LNG are: Japan, China, South Korea, India, and Taiwan (IGU, 2018: 11). South Korea, Japan, and China have made large investments in domestic LNG infrastructure and assets in North America (Mroczkowski and Hsiao, 2012: 2). Japan, the world's leading importer of LNG, has substantially increased its demand for LNG since the Fukushima fallout in March 2011 (METI, 2017a; METI, 2016c). In 2016, its government published an ambitious national LNG strategy, with significant implications for the whole industry.

Likewise, Japan's decisions are of great relevance for any follow-up projects in the Arctic, especially in light of the MOUs between Japanese investors and Novatek (Schach and Madlener, 2018) In the following, the LNG strategies of Japan, South Korea, and China are analyzed in some detail, and the possible economic and political impacts are evaluated.

3.1 Will Japan re-shape the LNG markets?

In 2014, Japan purchased approximately 89 million t of LNG. The country plans to maintain the amount of imported LNG at around 62 million t, with LNG contributing 27% to the Japanese Energy Mix by 2030 (METI, 2017a: 2; METI, 2016c). This limitation of LNG imports in the long-term derives from the ambition to partly revive the nuclear industry despite the Fukushima nuclear accident. According to the Gas Exporting Countries Forum (GECF), the Japanese nuclear industry is expected to reach around 70% of the pre-Fukushima capacities in the next five years (GECF, 2017: 32). Nevertheless, the Fukushima disaster and the shale gas revolution have resulted in substantial changes in the LNG market. "Securing flexibility and resiliency and better market utilization" are the newly declared priorities of Japan. The country is aiming for a leading and initiating role in the creation of a global LNG market. Supply security will be achieved through a diversification of suppliers and third-party access to regasification facilities (METI, 2016b: 2,4,6). Taking into account the mentioned MOU, this diversification policy may result in extensive LNG supplies from Russia – a quite bold ambition of the traditional US ally.

The national objectives that are determined in the strategy are the development of an LNG market, which will be liquid and flexible, and the formation of an LNG trading hub, "as a center of LNG transactions and the place where LNG price signals are formulated and published" (METI, 2016b: 5; Stern, 2016: 2). The required flexibility will be created by expanding spot trading and supply & demand-based pricing, thus substantially contributing to the creation of a trading hub in the early 2020s. There are three fundamental elements for the achievement of

these objectives: “the enhancement of tradability, the creation of a proper price discovery mechanism, open and sufficient infrastructure”. With regard to the pricing mechanism, the end of oil-linked pricing in favor of market-based pricing has been declared (METI, 2016b: 7,8). This form of pricing is fairly new for Russian gas producers, whose business models are premised upon oil-indexed LTCs. The increasing unpredictability of a more dynamic pricing may negatively affect capital-intensive investments, such as the Arctic LNG production sites and infrastructure developments along the NEP.

Furthermore, Japan is determined to abolish the destination clauses (regulations in LTCs which require the ordered cargo to be delivered to the market of the cargo’s buyer). Japan’s leading LNG purchaser JERA announced that it would not be signing any new contracts including these clauses and would renegotiate existing contracts (Stern, 2016: 2). Such a development would heavily impact the LNG distribution routes. One-way shipping routes that were leading to Northeast Asia may turn into dynamic, multi-directional routes in the future (METI, 2016b: 5). The full liberalization of the Japanese gas market and the trend towards low-carbon energy will increase the uncertainty of Japanese LNG demand and will drive LNG purchasers towards rather flexible and diverse options (in terms of destinations, contract duration, and pricing mechanism). In order to successfully compete in this changed market environment and to restrict the procurement costs, companies will have to progressively leverage the flexible market to optimize and hedge the quantities and prices of their LNG portfolio. This is likely to contribute to an excess of available LNG volumes, originating from LTCs and therefore to an enhancement of spot trading. These quite substantial volumes could generate a new procurement model, within which LTCs coexist with short-term or spot market purchases, by a number of diversified market players (METI, 2016b: 4). Considering the recent price trends for LNG and the described market developments, it can be assumed that the price gap between LTC prices and spot prices, and the arbitrage potential will narrow down. These developments could facilitate the creation of a global LNG market.

3.2 South Korea – coal, oil or LNG?

According to the GECF Global Gas Outlook 2040, South Korea was the world's eighth-largest energy consumer in the period of 2010-2015. The consumption in 2015 amounted to 286 million tons of oil equivalent (Mtoe) (GECF, 2017: 24). South Korea, like Japan, is highly dependent on the external supply of hydrocarbons. Roughly 95% of the country's total primary energy supply was imported from foreign countries in the 2010s (Kim and Kim, 2016: 202). In 2015, the LNG imports amounted to 45.3 bcm, originating from Qatar (37%), Oman (12%), Indonesia (11%), Malaysia (11%), Russia (8%), and Australia (6%), among others (EIA, 2017: 1,11,12). Hydrocarbons and oil are the main resources used for power generation. The domestic electricity demand is expected to rise by 64% in the next decade, with coal and LNG remaining the major contributors for power generation (Shim and Hong, 2016: 283). In 2016, the South Korean government announced a $36.6 bn investment into the renewable energy sector by 2020 (Yonhap News Agency, 2017). Although South Korea's fossil supplies are diverse, the total import dependency of the country on foreign suppliers constitutes a political risk factor. Hence, a wide expansion of renewables could mitigate this factor by enabling the use of domestic energy resources. In addition, South Korea seriously considers the NEP as a future pathway for the country's export trade. With Europe being the leading consumer market for South Korean exports, the Arctic maritime pathway constitutes a significant element in the country's future trade strategy (Ha and Seo, 2014: 82).

3.3 China – natural gas instead of coal?

Although the growth of the Chinese economy has substantially slowed down, China remains the world's leading consumer of energy. The annual demand has grown steadily over the last years, and amounted to 3098 Mtoe in 2015 (GECF, 2017: 15,24). Until 2007, China was able to fulfill the domestic demand for natural gas with its domestic production. In the following ten years, the country became one of the world's leading natural gas importers. Approximately half

of the imports are supplied by pipelines, primarily from Turkmenistan (Egging and Holz, 2016: 474). The Power of Siberia pipeline, which is currently under construction will bring additional natural gas capacities from Russia to China (Sidortsov et al., 2016: 54). The other half of the natural gas arrives in liquid form at the regasification terminals. The Chinese regasification capacities were expanded in recent years, and amount to 68.4 MTPA in 2018 (IGU, 2018: 79-83).

The rising demand for natural gas is not a coincidence. It derives from a strategic change in the country's energy policy – a necessary change, taking into account the serious domestic air pollution and other environmental challenges (GECF, 2017: 31). Likewise, China is the world's leading CO_2 emitter. The carbon emissions amounted to 9.5 bn t of CO_2 in 2013 (27.1% of the global emissions) (Jiang, 2016: 866). Therefore, China's energy mix will probably undergo substantial changes in the next decades: The contribution of coal to the Chinese energy mix is expected to decline from currently almost 75-45% by 2040, while the electricity demand is expected to rise by 85% over the next two decades (IEA, 2016: 2,3). Natural gas may substitute a large share of this future demand. China's new natural gas strategy supports the creation of a trading hub for LNG. The market liberalization, thus dissolving the monopolistic market, aims at creating transparent and equal market conditions for private and governmental companies. The gas trading platform in Shanghai was opened in 2015 (Shi and Padinjare Variam, 2016: 588). However, a substantial share of China's gas imports will arrive by pipeline from FSU markets, fully based on LTCs with an oil indexation (GECF, 2017: 56). Therefore, LTCs might coexist with short-term purchases and spot trading in the future, both from pipeline and LNG imports.

4 Arctic shipping and the (ice-free) Northeast Passage

The Arctic Ocean is becoming a center of interest for its coastal states as a sea with new maritime transport routes and a location of natural resources. The attractiveness is enhanced by receding ice, longer navigation seasons, and the rapidly growing demand for natural resources in emerging markets, especially in Asia. Although there are different constraints to anticipate for shipping in the Arctic waters: political factors, shallow waters, infrastructure, especially search and rescue (SAR) capabilities, and climatic conditions (weather, ice etc.). Still, there is huge potential for the Arctic, even if not for regular global shipping, but for the export of Arctic natural resources (Buixadé Farré et al., 2014: 299).

4.1 Geographical definition

There are two major routes in polar shipping, the Northwest Passage (NWP) and the Northeast Passage (NEP) / Northern Sea Route (NSR) (Fig. 2).[1] Thick, persistent, multi-layer ice (having survived one or more summers) disqualifies the NWP, even if daring climatic forecasts are considered (Østreng et al., 2013:23,24; Yoshikawa et al., 2016: 9). From the current point of view, only the NEP, which has remained ice-free for several months a year in the last decade, is suitable for navigation and has by far the biggest potential among the presented alternatives to become a popular Arctic shipping route (Buixadé Farré et al., 2014: 299, 300). Therefore, if generally assumed that Arctic shipping will evolve in the next decades, Russia finds itself with both a remarkable and exclusive opportunity: a strategic corridor for shipping and various other purposes right offshore their territories, connecting the Atlantic and the Pacific Ocean.

[1] "The Northern Sea Route (NSR) is defined in Russian law as the set of Arctic marine routes between Kara Gate in the west and the Bering Strait" (Ellis and Brigham, 2009: 23). "The Northeast Passage (NEP) is defined as the set of sea routes from northwest Europe around North Cape (Norway) and along the north coast of Eurasia and Siberia through the Bering Strait to the Pacific" (Ellis and Brigham, 2009: 34). The NSR is the main, Russian part of the NEP. While the term NSR is mainly used by the Russian authorities, the NEP is rather common internationally. Due to the analogously coherent meaning the terms are often used synonymously.

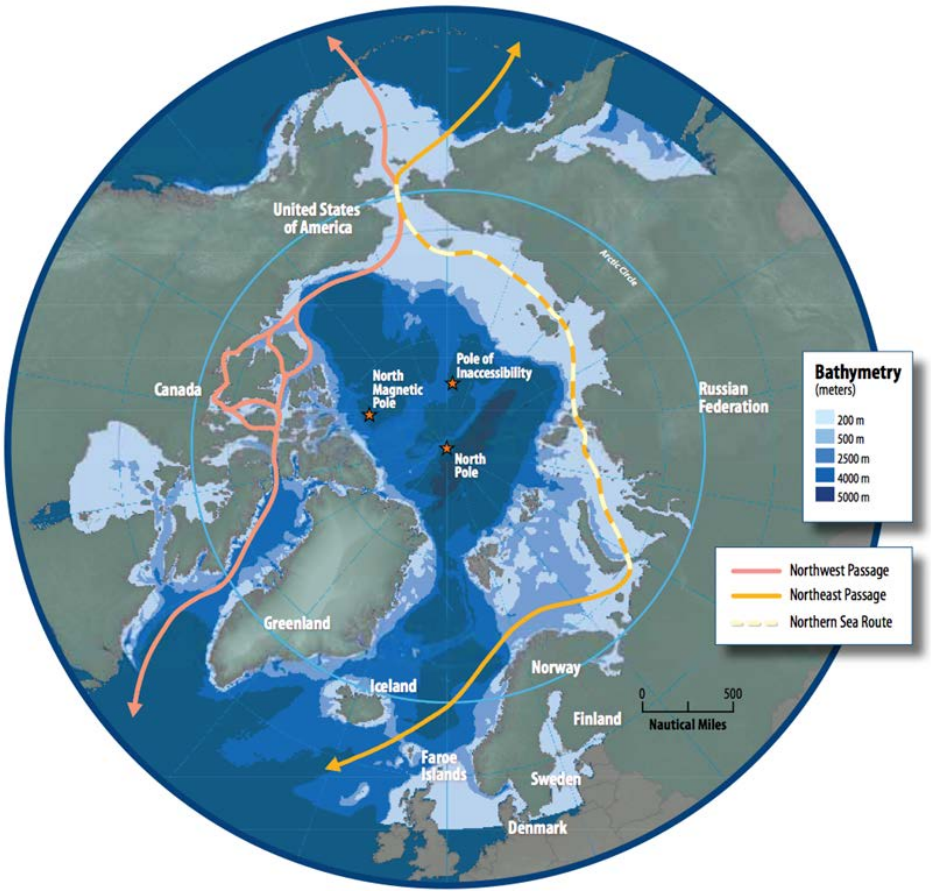


Fig. 2: Polar navigation routes (NWP, NEP/NSR)

Source: Ellis and Brigham (2009: 17)

4.2 Feasibility of commercial shipping

4.2.1 History of commercial shipping

The transport capacities through the NSR reached their climax in 1987: 1306 voyages and 331 ships, carrying 6.58 million t of cargo. Almost all voyages were made by Soviet ships, escorted by icebreakers, for supply purposes of remote Soviet communities and the shipping of natural resources. In other words, the international relevance of the NSR or NEP was negligible during this time. International shipping only gained momentum in the beginning of the 21st Century (Buixadé Farré et al., 2014: 302; Ragner, 2008: 114; Stephenson et al., 2013: 112).

In 2009, two German cargo ships traversed the NEP, originating from the South Korean port

city of Ulsan and reaching Rotterdam in record time. The next year, four ships braved the journey along the Siberian coast. In 2012, the number increased to 46 ships, sailing the NEP in the ice-fee period from July until late October (Evers, 2013). The first shipment of LNG trough the NEP was made by Gazprom in 2012. The LNG carrier, which was escorted by a Russian ice-breaker along the passage, left the port of Hammerfest in Norway in order to deliver the LNG cargo to the Port of Tobata in Japan. The NSR was traversed in just 10 days (Gazprom, 2017a).

4.2.2 Freight specification

The exact specification of freight is an important factor to consider. Cargo shipped by container ships using a just-in-time system has to be delivered with precise accordance to the schedule; in contrast, bulk cargo – hydrocarbons (oil, gas etc.) and minerals (phosphates, nickel, copper) – is not dependent on just-in-time delivery (Buixadé Farré et al., 2014: 302; Humpert and Raspotnik. 2012). Therefore, the advantages of the SCR, especially the predictability that is crucial for the just-in-time schedules of container shipping, will guarantee a central role of the SCR in the future. Moreover, the majority of container ships deliver their cargo to various destinations, most of which are not located at the northern shore of Russia. For the majority of scenarios, the SCR is more suitable for container shipping than the NEP (Lu et al., 2014: 62). On the contrary, the transportation of bulk freight, consisting of e.g. natural resources, which may have even been mined in the Eurasian Arctic, bears great potential for the NEP (Ragner, 2008: 116; Stephenson et al., 2013: 114).

4.3 Shipping of hydrocarbons

In case the Russian Federation proceeds with the developments of their natural resources in the Arctic region, the NEP will gain importance as an international, maritime shipping route, being a crucial element for the competitiveness of companies operating in the Arctic (Bai and Jin, 2016: 233). Therefore, it can be concluded that the development of the NEP and its infrastruc-

ture is directly and strongly correlated with the development of Arctic natural resources. Considering the planned hydrocarbon developments, more than 700 annual voyages are expected between the Pechora Basin and Murmansk in the period from 2020 to 2030 (Reeves et al., 2014: 382). This trend provides additional political motivation to develop the country's most remote communities. Another consideration is the development of military and strategic infrastructure in the Russian Arctic – being the closest region by linear distance to North America.

There is a positive correlation between the development of Arctic natural gas resources and the exponential growth of the Northeast-Asian demand for energy. LNG shipments to Asian markets would not necessarily have to face as many chokepoints (e.g. Strait of Hormuz, Gulf of Aden, Suez Canal, Panama Canal, Strait of Malacca) as today (Schach and Madlener, 2017).

Shipping through the NEP shortens the total distance between Europe and Northeast Asia by approximately 4000 nautical miles (Mroczkowski and Hsiao, 2012: 2). With regard to the LNG supply of the Asian markets the NEP is only relevant for Russian LNG producers, as well as for other exporters of natural resources, originating in the Arctic region. In addition, the economic and strategic importance of the NEP for shipping between Europe and Asia in general is considered by many of the leading Asian economies. Especially the Northeast Asian countries are already investing in this future scenario: To encourage the development of Arctic shipping, the South Korean government has recently issued a subsidy policy for shipping companies that engage in Arctic shipping to or from South Korea (Moon et al., 2015: 18). China has started the construction of its first domestically built icebreaker, which is expected to be ready for service in 2019 (Staalesen, 2016). As described in the previous section, the Asian partners have made a significant contribution to the financing of hydrocarbon development in the Russian Arctic: China National Petroleum and the country's Silk Road Fund provided the financial foundation for Yamal LNG. Japanese investors are currently involved in prospective, consecutive projects.

4.4 Climatic constraints

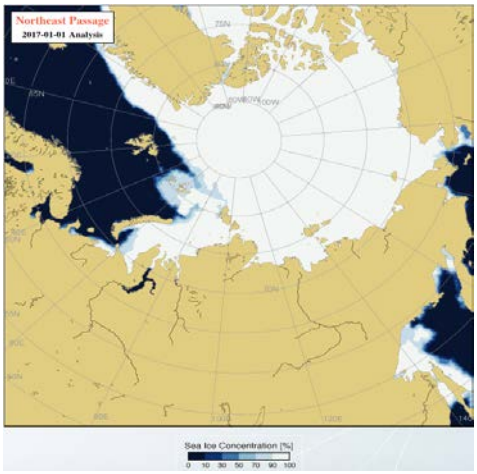
The determining factor for navigation and shipping in the Arctic is the extent and the thickness of the ice. Due to various factors a retreat of the ice has been in progress for decades, but has accelerated since 2000. The summer extent of Arctic ice in comparison to the winter maximum amounted to 90% before 1997. Over the ten years that followed, this percentage decreased to 55% (Buixadé Farré et al., 2014: 311; Kwok and Rothrock, 2009). Although the forecasts differ, there is consensus about the ongoing recession of Arctic ice, enabling commercial shipping along the NEP in the long term. The central climatic constraints remain the predictability of the spread of ice in spring and fall, free-floating ice in summer, low visibility due to almost total darkness in winter, and intermittent fog in all seasons (Buixadé Farré et al., 2014: 312).

The NSR Information Office specifies the navigation season for NSR transits from the Atlantic to the Pacific Ocean, currently starting by the beginning of July and lasting until the end of November (Fig. 3). In early July, the ice is broken and can easily be passed (Fig. 3(b)-(c)). In September and October, the route is usually completely ice-free (Fig. 3(d)-(f)). In these months, voyages can be conducted with a regular speed of 14 knots (NSR Information Office, 2018). In winter, the main route is covered by one-year-old ice, reaching an average thickness of 1.6 m (Fig. 3(a)).

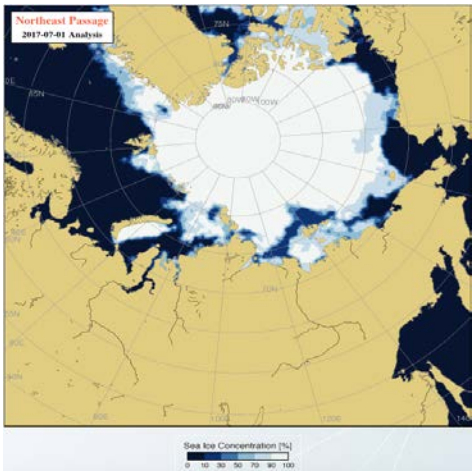
4.5 Institutional and legal framework

The United Nations Convention on the Law of the Sea (UNCLOS) 1982, the International Convention on Safety of Life at Sea (SOLAS) 1974, and the International Maritime Organization (IMO) Guidelines for Ships Operating in Arctic Ice-covered Waters, are considered to be the fundamental framework upon which the governance of Arctic marine navigation is currently based. The transport of LNG is regulated through the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (International Gas Carrier Code) in Ch. VII of SOLAS. In addition, the American Bureau of Shipping and the Russian Maritime

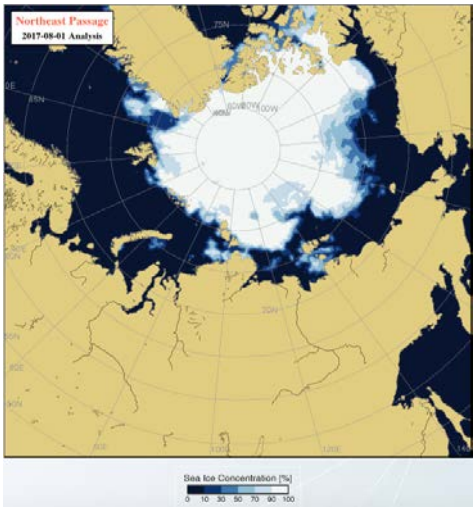
Register of Shipping are developing common classification rules for Arctic LNG carriers. The ice-strengthening measures and classifications for LNG tankers are concerned with hull, containment systems, propulsion, and propeller requirements (Ellis and Brigham, 2009: 5, 55).



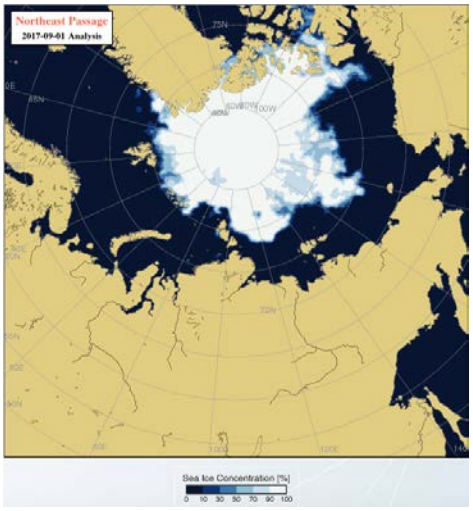
(a) January 1



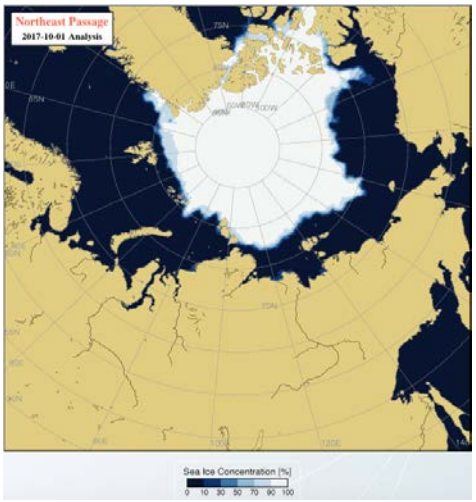
(b) July 1



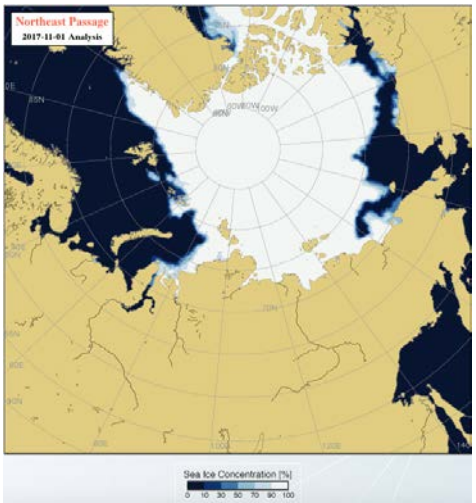
(c) August 1



(d) September 1



(e) October 1



(f) November 1

Fig. 3: Ice cover NEP, selected dates in 2017

Source: NSR Information Office (2018)

4.6 Institutional and legal framework

The United Nations Convention on the Law of the Sea (UNCLOS) 1982, the International Convention on Safety of Life at Sea (SOLAS) 1974, and the International Maritime Organization (IMO) Guidelines for Ships Operating in Arctic Ice-covered Waters, are considered to be the fundamental framework upon which the governance of Arctic marine navigation is currently based. The transport of LNG is regulated through the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (International Gas Carrier Code) in Ch. VII of SOLAS. In addition, the American Bureau of Shipping and the Russian Maritime Register of Shipping are currently developing common classification rules for Arctic LNG carriers. The ice-strengthening measures and classifications for LNG tankers are primarily concerned with hull, containment systems, propulsion, and propeller requirements (Ellis and Brigham, 2009: 5, 55).

The Arctic Council formed a working group in 2004, which focuses on the developments in the Arctic, influencing its current and future marine use, such as natural resource development, governance challenges, climate change, and marine infrastructure. The Arctic Marine Shipping Assessment (AMSA) is the product of the studies and research which the Protection of the Arctic Marine Environment (PAME) working group has conducted (Ellis and Brigham, 2009: 2). Within the AMSA, the Arctic Council appeals to the Arctic states to increase their cooperation, to unify and to uniform the work of governments and international organizations for the purpose of the enhancement of Arctic marine safety in the field of, e.g., governance, regulations, guidelines, and SAR instruments. Furthermore, the report calls for a broad collaboration in research activities, measures to ensure the protection of the ecological and cultural heritage of both Arctic environment and indigenous population, and to prevent oil spills (Ellis and Brigham, 2009: 6). Overall, it has considerable potential to affect the further development of the LNG business in the Arctic, but it seems too early to assess its actual effectiveness.

5 Discussion of results

5.1 Insights LNG supply side

The developments on the supply side of the market, the build-up of capacities in the US, Australia and Russia, as well as anticipated expansions, will impact the satiation of the market, as well as pricing: Until the mid-2020s an excess of LNG supplies can be expected in light of the massive expansion of production capacities. The abundant capacities will enhance the trend towards globally adjusting, comparably low prices. For new un-contracted capacities, a price agreement between LNG producers may be an option. But the extremely low production costs of today's leading LNG exporter Qatar, which make Qatargas' projects profitable even in very challenging market conditions, and the diverse political agenda of the very heterogeneous LNG-producing countries will probably avert such an initiative.

Particularly in Russia the liberalization of the LNG market – more specifically the issuance of LNG export licenses to Novatek and Rosneft in addition to Gazprom – paved the way for the country's prospects as a significant LNG exporter. Furthermore, this decision constitutes a politico-economical shift in Russia's national gas strategy, changing the role of the monopolist Gazprom. The completion of Yamal LNG will boost Russia's LNG export capacities from currently approximately 10 MTPA to 28.2 MTPA. Although this number may not be high in comparison to Australia's or Qatar's output, the Russian LNG projects have a good chance to operate profitably even under challenging market conditions, due to the comparably low production costs and the previously secured LTCs with mainly oil-indexed pricing for almost all of the output. The advantageous location of the Yamal LNG and Sakhalin II projects for LNG deliveries to Asia are another crucial factor for their competitiveness. The mentioned statement by Vladimir Putin on Russia's LNG future and Novatek's ambition for a follow-up project may open a new dimension in the global gas competition. Russia's foray to the Asian LNG market, enabled through a temporally ice-free NEP is a direct challenge to the US ambitions in this

region. The geopolitical impacts of the natural gas competition between the US and the Russian Federation, which have been limited to the European continent and market until now, could be shifted to the Far East in light of such developments.

Extensive Russian LNG exports are only enabled through shipping along the NEP. The shipping possibilities to Asia along the passage are a unique competitive advantage for Russian LNG producers, compared to their US competitors. In this regard, the NEP is relevant not only for Russia, but also for its competitors. Yamal LNG's icebreaking tankers will be the first ships to operate in the NEP on a regular basis. In fact, the ice-free NEP is one of the crucial elements for the whole operation. The project's competitiveness and strategy are based upon the shipping to the Asian consumers through the NEP. The Yamal LNG project is of enormous economic, strategic and political significance for further hydrocarbon developments in the Arctic, for Arctic shipping, and for the Russian Federation. It will indicate whether the NEP can be a seasonal supplement to or even a substitute for the SCR for bulk shipping and whether Russia will be able to become a significant exporter of LNG. All in all, the NEP is of great economic and political significance for Russia, heavily impacting the supply side of the LNG market and opening up a new dimension in the energy supply competition between Russia and other competitors such as the US.

5.2 Insights LNG demand side

The three major factors on the demand side of the market that might challenge the dissemination of natural gas and significantly impact the future of the LNG business are: (1) the extent of the revival of Japan's nuclear industry, (2) the development of renewable energy sources for power generation in South Korea, and (3) the sustainability of China's attempted policy to reduce pollution and CO_2 emissions.

However, based on the South Korean government's demand expectations it is rather likely that the emerging share of regenerative energies will replace coal-fired power plants, not limiting the prospective LNG imports. In addition, private and governmental investors from South Korea, Japan and China, have made various investments in the LNG infrastructure, the countries' LNG tanker fleets, and international production assets. The Asian economies anticipate the Northeast Passage becoming an important shipping route for both exports and imports. A large share of the contracted gas volumes from e.g. the Yamal LNG project are destined for the Asian markets. The current and planned Chinese and Japanese investments in Arctic LNG production affirm the economic and geopolitical significance of Arctic natural resources. Moreover, the involvement affirms the strategic significance of the NEP as an essential element of the LNG supply security in Asia and as a new pathway where governmental interests collide.

The liberalization of the gas markets is a trend that can be observed in several of the conservative Asian economies. Japan's revolutionary LNG strategy has the potential to change the procurement model of natural gas, to significantly contribute to the global integration of gas markets and prices, and to facilitate the creation of an internationally significant trading hub in Japan. With regard to the historical and present rivalry between Japan and China, the reaction and the measures that will be taken by China are of great interest, especially since China and other states in the region have very similar ambitions concerning an LNG trading hub.

The abolishment of destination clauses and LTCs might challenge the established financing models. In the long term, gas producers and their financiers will have to find a way to adapt to the changed market environments. Once the current oversupply has been overcome due to a stagnation in new upstream investments and the rising demand outruns the supply, diversified and dynamic market participants who can adapt to the changed environment will secure the globally emerging LNG market shares. Competitive transport routes, not facing any chokepoints or bottlenecks, will be crucial elements of a business strategy for those emerging suppliers.

5.3 Insights NEP's potential

Based on the discussed constraints and disadvantages, from today's point of view it is naive to speak about the general substitutability of the SCR. Nevertheless, the NEP has vast potential to become a seasonal complement to the SCR. The realization of this vision is directly correlated with the development of oil and gas in the Arctic. The production of hydrocarbons is the only economic force that could trigger and propel the large-scale infrastructure development necessary for the emergence of extensive, international shipping activities in the Arctic. From a business perspective and today's point of view, the NEP is only relevant to Arctic oil and gas producers, as the NEP will not be suitable for container shipping, due to comparably lesser capacities (than the SCR), insufficient schedule predictability, and simply the absence of major container ports along the route. However, the route is highly eligible for destination-specific bulk shipping, connecting Asian with European or even North American ports.

The progress of E&P activities in the Russian Arctic is quite promising, taking into account the ongoing successful construction of the Yamal LNG project and the extensive motivation of international, mainly Asian partners to proceed with consecutive projects. In the end, expectedly, the determining forces will be primarily rational and economic. The demand and prices for the hydrocarbons will be decisive for the feasibility of further developments.

The major constraint which limits any shipping activity today, is the extent of permanent ice for more than half a year and the abundant probability for the reemergence of the ice even in the summer months. This constraint makes the deployment of ice-reinforced vessels necessary. Only few shipping companies possess such unconventional, costly vessels, or are willing to invest in these. Therefore, in the short- and medium-term, only small-scale shipping activities of highly-specialized shipping companies can be expected along the NEP. Nevertheless, all forecasts indicate an ice-free Arctic in the long term. Thus, from a purely economic point of view, Arctic shipping seems inevitable in the long-term future. Until then, the use of the NEP

will remain a crucial competitive advantage for the producers of Arctic natural resources. Especially the transport of LNG to Asia can be executed with enormous time and cost savings (cf. Schach and Madlener, 2017).

6 Conclusions and policy implications

The dynamics in the global LNG market are likely to evolve in the next decade, due to significant developments both on the supply and the demand side: The wave of new upstream investments in the beginning of the 2010s will generate an abundance of LNG volumes on the market upon completion of the projects. In contrast, the demand of the mostly Asian LNG consumers is subject to many uncertainties. Even in the case of an optimistic demand development, the market is likely to remain well-supplied in the first half of the 2020s. As a result, the Japanese and Chinese consumers will find themselves in an advantageous position to enforce their requirements concerning short-term contracts or the abolishment of destination clauses. The greater availability of LNG volumes and the liberalization of regulations on gas infrastructure can facilitate an integrated, possibly virtual trading hub in Asia and progressively integrated prices in the region. Considerations about energy supply security and the diversification of supply sources strengthen the position of LNG in the energy mix of most Asian countries. In order to pursue these considerations, numerous investments in hydrocarbon production, amongst others in assets in the Russian Arctic, have been made. Therefore, it can be concluded that the LNG-consuming states have economic, political and strategic interests in the Arctic as a prospective hydrocarbon province and the NEP as a crucial future shipping route.

It is difficult to determine whether the NEP will impact the LNG market, or vice versa. Undoubtedly, the ice-free NEP will impact the Asian markets to some extent by facilitating Russian LNG exports from the vast gas fields in North-Western Siberia within the Arctic Circle. The completion of the Yamal LNG project will more than double the Russian LNG export

capacities. On the one hand, any further large-scale LNG export aspirations in Russia are ultimately correlated with the usage of the NEP as a uniquely competitive shipping route to the Asian markets. On the other hand, all further aspirations will primarily be driven by the market conditions and the prices. In the end, aside from strategic political interventions, the demand and corresponding investments will determine the prospects for any Arctic hydrocarbon developments, and therefore for any extensive Arctic shipping activities.

The geographical location of the leading LNG producers and consumers makes the NEP mainly relevant for Russian LNG suppliers, if all other global chokepoints remain intact. However, for Russia's ambitions as a major LNG supplier, the NEP is of ultimate significance, enabling exports both to Asian and European markets. The scale of the exports of Russian hydrocarbons from Arctic regions will determine the scale of any Arctic shipping activity along the NEP in the near future. However, the prospects for destinational bulk shipping will remain significant in the long term. Until then, the use of the NEP will remain a crucial competitive advantage for the producers and exporters of Arctic natural resources. Naturally, the future of shipping along the NEP is of national significance for the Russian Federation. Firstly, the development of infrastructure along the NEP can be a substantial factor of growth for the country's most remote regions, and will thus also be relevant from a regional development policy perspective. Secondly, an ice-free Arctic Ocean creates multiple perspectives not only for E&P activities and trade, but also for politico-military applications. Again, a joint policy approach by the Arctic Council, involving both the United States, Russia, and the other members, is necessary in order to limit the conflict potential and to create a statutory foundation for future commercial and governmental activities.

Nevertheless, Russia's entry into the LNG supply competition will probably exacerbate the political tensions between that country and the US. Since the shale gas revolution, the US has permanently tried to challenge the dominant Russian market position in Europe. Now, it will find itself competing against considerable volumes of highly competitive Russian LNG in the

mid-term future. A comparative economic analysis of Russian and US LNG supplies and a systematic analysis of the political risks and opportunities that examines these considerations in a broader manner, would provide useful but has to be left for future research.

The developments in the Asian LNG market and the facilitation of a trading hub are of great interest from both a scientific and a corporate perspective. Especially the interdependencies between the currently advantaged LNG consumers and the producers with regard to, e.g., contract conditions and market power could be examined in more detail. Another truly absorbing thought is a joint global reduction of LNG exports. The GECF was established as an imitation of the OPEC for natural gas producers. But unlike OPEC, which mainly consists of Arab states, the members of the gas cartel are very heterogeneous and pursue different political agendas. In this respect, a study that examines possible reduction measures and the corresponding effects appears very useful.

Acknowledgments

The first author would like to gratefully acknowledge financial research support of the Verbundnetz Gas AG.

References

Avango, D., Hacquebord, L. and Wrakberg, U. (2014), Industrial extraction of Arctic natural resources since the sixteenth century: technoscience and geo-economics in the history of northern whaling and mining, *Journal of Historical Geography*, 44, 15-30.

Bai, Y. and Jin, W. (2016), Development of Arctic Offshore Technology, *Marine Structural-Design*, 2, 229-243.

BP, British Petroleum (2018), BP Energy Outlook, [Online] URL: https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/energy-outlook/bp-energy-outlook-2018.pdf [retrieved July 13, 2018].

Buixadé Farre, A., Stephenson, S., Chen, L., Czub, M., Dai, Y., Demchev, D., Efimov, Y., Graczyk, P., Grythe, H., Keil, K., Kivekäs, N., Kumar, N., Liu, N., Matelenok, I., Myksvoll, M., O'Leary, D., Olsen, J., Pavithran, S., Petersen, E., Raspotnik, A., Ryzhov, I., Solski, J., Suo, K., Troein, C., Valeeva, V., van Rijckevorsel, J. and Wighting, J. (2014), Commercial Arctic shipping through the Northeast Passage: routes, resources, governance, technology, and infrastructure, *Polar Geography*, 37, 4, 298-324.

Cole, W., Medlock, K. and Jani, A. (2016), A view to the future of natural gas and electricity: An integrated modeling approach, *Energy Economics*, 60, 486-496.

Egging, R. and Holz, F. (2016), Risks in global natural gas markets: Investment, hedging and trade, *Energy Policy*, 94, 468-479.

EIA, U.S. Energy Information Administration (2017), Country Analysis: South Korea, [Online] URL: https://www.eia.gov/beta/international/analysis_includes/countries_long/Korea_South/south_korea.pdf [retrieved May 15, 2017].

Ellis, B. and Brigham, L. (2009), Arctic Marine Shipping Assessment 2009 Report, Arctic Council, [Online] URL: https://oaarchive.arctic-council.org/handle/11374/54 [retrieved May 15, 2018].

Esen, V. and Oral, B. (2016), Natural gas reserve/production ratio in Russia, Iran, Qatar and Turkmenistan: A political and economic perspective, *Energy Policy*, 93, 101-109.

Evers, M. (2013), Russia moves to boost Arctic shipping. *Spiegel Online*, [Online] URL: http://www.spiegel.de/international/world/russia-moves-to-promote-northeast-passage-through-arctic-ocean-a-917824.html [retrieved May 15, 2017].

Fortescue, S. (2016), Russia's economic prospects in the Asia Pacific Region, *Journal of Eurasian Studies*, 7, 49-59.

Gautier, D., Bird, K., Charpentier, R., Grantz, A., Houseknecht, D., Klett, T., Moore, T., Pitman, J., Schenk, C., Schuenemeyer, J., Sorensen, K., Tennyson, M., Valin, Z. and Wandrey, C. (2009), Assessment of Undiscovered Oil and Gas in the Arctic, *Science*, 324, 1175-1179.

Gazprom (2012a), Main Page > Media > Gazprom News > December 2012 [Online] URL: http://www.gazprom.com/press/news/2012/december/article150603/ [retrieved May 15, 2018].

GECF, Gas Exporting Countries Forum (2017), GECF Global Gas Outlook 2040, [Online] URL: https://www.gecf.org/_resources/files/events/gecf-global-gas-outlook-2040--- synopsis/gecf-global-gas-outlook-2040---synopsis.pdf [retrieved May 15, 2018].

Google Earth (2018), [Online] URL: https://earth.google.com/web [retrieved May 3, 2018].

IGU, International Gas Union (2018), 2018 World LNG Report, [Online] URL: https://www.igu.org/sites/default/files/node-document-field_file/IGU_LNG_2018_0.pdf [retrieved May 15, 2018].

IEA, International Energy Agency (2016), World Energy Outlook 2016 Executive Summary, [Online] URL: https://webstore.iea.org/download/summary/202?fileName=English-WEO-2016-ES.pdf [retrieved May 15, 2018].

IEA, International Energy Agency (2017), World Energy Outlook 2017 Executive Summary, [Online] URL: https://webstore.iea.org/download/summary/196?fileName=English-WEO-2017-ES.pdf [retrieved May 15, 2018].

Ha, Y. and Seo, J. (2014), The Northern Sea Routes and Korea's Trade with Europe: Implication for Korea's Shipping Industry, *International Journal of e-Navigation and Maritime Economy*, 1 (2014), 73-84.

Henderson, J. (2016a), The supply outlook: Australia and the USA, *Oxford Energy Forum*, August 2016: Issue 106, 4-5, Oxford Institute for Energy Studies, Oxford, UK.

Henderson, J. (2016b), Novatek leads the advance of Russian LNG, *Oxford Energy Forum*,November 2016: Issue 107, 22-24, Oxford Institute for Energy Studies, Oxford, UK.

Henderson, J. and Loe, J. (2014), The Prospects and Challenges for Arctic Oil Development, *WPM 54*, Oxford Institute for Energy Studies, Oxford, UK.

Humpert, M. and Raspotnik, A. (2012), The future of Arctic shipping, *Port Technology International*, [Online] URL: https://www.porttechnology.org/technical_papers/the_future_of_arctic_shipping [retrieved May 15, 2018].

Jiang, J. (2016), China's urban residential carbon emission and energy efficiency policy, *Energy*, 109, 866-875.

Kim, J. and Kim, J. (2016), Korean public's preference for supply security of oil and gas and the impact of protest bidders, *Energy Policy*, 89, 202-213.

Kwok, R. and Rothrock, D. (2009), Decline in Arctic sea ice thickness from submarine and Ice Sat records: 1958–2008. *Geophysical Research Letters*, Vol. 36, Issue 15.

Lu, D., Park, G., Choi, K. and Oh, S. (2014), An Economic Analysis of Container Shipping through Canadian Northwest Passage. *International Journal of e-Navigation and Maritime Economy*, 1 (2014), 60-72.

METI, Ministry of Economy, Trade and Industry (2016a), Main Page > Statistics > Spot LNG-Price Statistics (November 2016) > Overview of Statistics [Online] URL: http://www.meti.go.jp/english/statistics/sho/slng/index.html [retrieved May 15, 2018].

METI, Ministry of Economy, Trade and Industry (2016b), Strategy for LNG Market Development: creating flexible LNG market and developing an LNG trading hub in Japan, [Online] URL: http://www.meti.go.jp/english/press/2016/pdf/0502_01b.pdf [retrieved May 15, 2018].

METI, Ministry of Economy, Trade and Industry (2016c), Annual Report on Energy (Energy White Paper), [Online] URL: http://www.meti.go.jp/english/press/2016/pdf/0517_01.pdf [retrieved May 15, 2018].

METI, Ministry of Economy, Trade and Industry (2017a), Japan's Energy Plan, [Online] URL: http://www.meti.go.jp/english/publications/pdf/EnergyPlan_160614.pdf [retrieved May 15, 2018].

Moon, D., Kim, D. and Lee, E. (2015). A Study on Competitiveness of Sea Transport by Comparing International Transport Routes between Korea and EU, *The Asian Journal of Shipping and Logistics*, 31, 1, 1-20.

Motomura, M. (2014), Japan's need for Russian oil and gas: A shift in energy flows to the Far East, *Energy Policy*, 74, 68-79.

Mroczkowski, I. and Hsiao, R. (2012), The Arctic and Natural Gas in Northeast Asia's Energy Future, Project 2049 Institute, [Online] URL: http://project2049.net/documents/arctic_naturalgas_mroczkowski_hsiao_1205.pdf [retrieved May 15, 2018].

NASDAQ (2018), Main Page > Markets > Commodities > Crude Oil > WTI (NYMEX) price [Online] URL: http://www.nasdaq.com/markets/crude-oil.aspx [retrieved May 15, 2018].

Novatek (2017a), Main Page > Business > Yamal LNG > Project implementation [Online] URL: http://www.novatek.ru/en/business/yamal-lng/yamal_current/ [retrieved May 15, 2018].

Novatek (2017b), Main Page > Investor Relations > Events > Archive > Novatek signs long-term LNG contract with Shell [Online] URL: http://novatek.ru/en/press/releases/index.php?id_4=972 [retrieved May 15, 2018].

Novatek (2017c), Main Page > Investor Relations > Events > Archive > Novatek concludes long-term LNG contract with Engie [Online] URL: http://www.novatek.ru/en/press/releases/index.php?id_4=970 [retrieved May 15, 2018].

Novatek (2017d), Main Page > Investor Relations > Strategy Presentation [Online] URL: http://www.novatek.ru/en/investors/strategy/ [retrieved May 15, 2018].

Novatek (2017e), Main Page > Press Center > Press Releases and Events [Online] URL: http://www.novatek.ru/en/press/releases/index.php?id_4=2066 [retrieved May 15, 2018].

NSR, Northern Sea Route Information Office (2018), Main Page > NSR > Ice concentration [Online] URL: http://www.arctic-lio.com/nsr_ice [retrieved May 15, 2018].

Østreng, W., Eger, K., Floistad, B., Jorgensen-Dahl, A., Lothe, L., Meilaender-Larsen, M. and Wergeland, T. (2013), *Shipping in Arctic Waters: A Comparison of the Northeast, Northwest and Trans Polar Passages*. Berlin, Germany: Springer.

Paraskova, T. (2017), Putin says Russia will become world's top LNG producer. *The Oil Price.* 2 April, 2017. [Online] URL: https://oilprice.com/Energy/Natural-Gas/Putin-Says-Russia-Will-Become-Worlds-Top-LNG-Producer.html [retrieved May 15, 2018].

Ragner, C. (2008), *The Northern Sea Route. The Barents – A Nordic Borderland*, Stockholm, Sweden: Arena Norden.

Reeves, R., Ewins, P., Agbayani, S., Heide-Jorgsensen, M., Kovacs, K., Lydersen, C., Suydam, R., Elliott, W., Polet, G., van Dijk, Y. and Blijleven, R. (2014), Distribution of endemic cetaceans in relation to hydrocarbon development and commercial shipping in a warming Arctic, *Marine Policy*, 44, 375-389.

Reuters (2017), Russia's Putin gives order to start loading first tanker at Yamal LNG project [Online] URL: https://www.reuters.com/article/idUSR4N1O600D [retrieved May 3, 2018]

Russian Government, (informational site on legislation) (2017), Main Page > Publications > Calendar > 27. December 2014 > N 2737-p [Online] URL: http://pravo.gov.ru/proxy/ips/?docbody=&nd=102366055&intelsearch=yamal [retrieved May 15, 2018], [own translation].

Schach, M. and Madlener, R., (2017), Impacts of an Ice-Free Northeast Passage on LNG Trading: Transport Routes and Optimal Capacity Planning, *FCN Working Paper* No. 12/2017, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University.

Schach M. and Madlener R. (2018). Economic and Geopolitical Impacts of the LNG Supply-Side Competition Between the USA and Russia, *FCN Working Paper* (in prep.).

Shi, X. and Padinjare Variam, H., (2016), Gas and LNG trading hubs, hub indexation and destination flexibility in East Asia, *Energy Policy*, 96, 587-596.

Shim, C. and Hong, J. (2016), Impact of a national plan for future electricity supply on ambient air quality in South Korea, *Energy Policy*, 88, 278-288.

Sidortsov, R., Ivanova, A. and Stammler, F. (2016), Localizing governance of systemic risks: A case study of the Power of Siberia pipeline in Russia, *Energy Research & Social Science*, 16, 54-68.

SIPRI, Stockholm International Peace Research Institute (2018), Shipping along the Arctic's Northern Sea Route will be determined by Russia-China cooperation in the region. [Online] URL: https://www.sipri.org/commentary/expert-comment/2018/shipping-along-arctics-northern-sea-route-will-be-determined-russia-china-cooperation-region [retrieved May 3, 2018].

Staalesen, A. (2016), China starts construction of new icebreaker. *The Independent Barents Observer*, [Online] URL: https://thebarentsobserver.com/en/arctic/2016/12/china-starts-construction-new-icebreaker [retrieved May 15, 2018].

Stephenson, S., Brigham, L. and Smith, L. (2013), Marine accessibility along Russia's Northern Sea Route. *Polar Geography*, 37(2), 111–133.

Stern, J. (2016), The Japanese LNG strategy: a major step towards hub-based gas pricing in Asia, *Oxford Energy Comment*, June 2016, Oxford Institute for Energy Studies, Oxford, UK.

S&P Global Platts (2016), *LNG Daily*. 23. September 2016 [Online] URL:https://online.platts.com/PPS/P=m&s=1029337384756.1478827&e=1474933439284.5 32211100888081207/ [retrieved May 15, 2018].

S&P Global Platts, (2017), Main Page > News & Analysis > Latest News Headlines > Qatar to raise LNG production by 30% to 100 million mt/year by 2024: QP CEO [Online] URL: https://www.platts.com/latest-news/natural-gas/dubai/qatar-to-raise-lng-production-by-30-to-100-million-27853035 [retrieved May 3, 2018].

Yamal LNG (2017a), Main Page > Project > About the Project [Online] URL: http://yamallng.ru/en/project/about/ [retrieved May 15, 2018].

Yamal LNG (2017b), Main Page > Project > Resource Base [Online] URL: http://yamallng.ru/en/project/resource-base-utm/ [retrieved May 15, 2018].

Yamal LNG (2015c), Main Page > Press Center > 2015 > Gazprom Marketing & Trading Singapore and Yamal Trade conclude long-term LNG supply agreement [Online] URL: http://yamallng.ru/en/press/news/311/ [retrieved May 15, 2018].

Yamal LNG (2014d), Main Page > Press Center > 2014 > Binding contract on LNG supply concluded with CNPC [Online] URL: http://yamallng.ru/en/press/news/283/ [retrieved May 15, 2018].

Yamal LNG (2013e), Main Page > Press Center > 2013 > Yamal LNG and Gas Natural Fenosa sign long-term LNG supply contract [Online] URL: http://yamallng.ru/en/press/news/283/ [retrieved May 15, 2018].

Yamal LNG (2015f), Main Page > Press Center > 2015 > Yamal LNG and Fluxys LNG sign contract for LNG transshipment services at Zeebrugge LNG terminal [Online] URL: http://yamallng.ru/en/press/news/310/ [retrieved May 15, 2018].

Yamal LNG (2013g), Main Page > Press Center > 2013 > Yamal LNG names tender winner among shipyards and signs agreement to build LNG tankers [Online] URL: http://yamallng.ru/en/press/news/279/ [retrieved May 15, 2018].

Yonhap News Agency (2016), S. Korea to invest 42 tln won in renewable energy industry by 2020, *Yonhap News Agency*. 05. July, 2016 [Online] URL: http://english.yonhapnews.co.kr/news/2016/07/04/0200000000AEN20160704008951320.html?input=www.tweeter.com [retrieved May 15, 2018].

Yoshikawa, K., Leuschen, C., Ikeda, A., Harada, K., Gogineni, P., Hoekstra, P., Sawada, Y. and Marsuoka, N. (2006), Comparison of geophysical investigations for detection of massive ground ice (pingo ice), *Journal of Geophysical Research: Planets*, 111(E06S19), 1-10.

FCN | Future Energy Consumer Needs and Behavior

E.ON Energy Research Center

RWTH AACHEN UNIVERSITY

List of the latest FCN Working Papers

2017

Demikhovskiy M., Madlener R., Garbuzova-Schlifter M., Golov R. (2017). Energy Performance Contracting in Russia: A Real Options Approach on Project Valuation, FCN Working Paper No. 1/2017, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January.

Frieling J., Madlener R. (2017). Fueling the US Economy: Energy as a Production Factor from the Great Depression Until Today, FCN Working Paper No. 2/2017, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February (revised May 2017).

Risthaus K., Madlener R. (2017). Economic Analysis of Electricity Storage Based on Heat Pumps and Thermal Storage Units in Thermal Power Plants, FCN Working Paper No. 3/2017, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Schach M., Madlener R. (2017). Impacts of an Ice-Free Northeast Passage on LNG Markets and Geopolitics, FCN Working Paper No. 4/2017, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April (revised June 2018).

2016

Frieling, J., Madlener, R. (2016). Estimation of Substitution Elasticities in Three-Factor Production Functions: Identifying the Role of Energy, FCN Working Paper No. 1/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March (revised September 2016).

Al-Saad F., Madlener R. (2016). The Role of Shale Gas in the EU Decarbonization Process, FCN Working Paper No. 2/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

De Graaf X., Madlener R. (2016). Optimal Time-Dependent Usage of Salt Cavern Storage Facilities for Alternative Media in Light of Intermittent Electricity Production and Carbon Sequestration, FCN Working Paper No. 3/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Weida J., Kumar S., Madlener R. (2016). Economic Viability of Grid-Connected Solar PV and Wind Power Systems in Germany: A Multi-Region Analysis, FCN Working Paper No. 4/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Franzen S., Madlener R. (2016). Optimal Expansion of a Hydrogen Storage System for Wind Power: A Real Options Analysis, FCN Working Paper No. 5/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Hammann E., Madlener R., Hilgers C. (2016). Economic Feasibility of Compressed Air Energy Storage Systems: A Real Options Approach, FCN Working Paper No. 6/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Kirmas A., Madlener R. (2016). Economic Viability of Second-Life Electric Vehicle Batteries for Energy Storage in Private Households, FCN Working Paper No. 7/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Peters L., Madlener R. (2016). Economic Evaluation of Maintenance Strategies for Ground-Mounted Solar Photovoltaic Plants, FCN Working Paper No. 8/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Falcke L.F., Madlener R. (2016). Potential Impacts of the Planned Market Stability Reserve on Speculators' Behavior in the EU Emissions Trading System. FCN Working Paper No. 9/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Glensk B., Madlener R. (2016). Evaluating the Enhanced Flexibility of Lignite-Fired Power Plants: A Real Options Analysis, FCN Working Paper No. 10/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Galassi V., Madlener R. (2016). Some Like it Hot: The Role of Environmental Concern and Comfort Expectations in Energy Retrofit Decisions, FCN Working Paper No. 11/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Köllner L., Madlener R. (2016). Market Evaluation for Virtual Power Plants in Europe with a Special View at Incentive-Based Policy Instruments, FCN Working Paper No. 12/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Broering H., Madlener R. (2016). Beyond Grid Parity: Conceptualization of the Merit of Cloud Energy Storage for Prosumers, FCN Working Paper No. 13/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Broering H. (2016). Direct Marketing and Cloud Energy Storage in Liberalized Markets: The German Regulatory Framework as a Benchmark, FCN Working Paper No. 14/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Broering H., Madlener R. (2016). Simulating the Spatial Heterogeneity of Cloud-based Prosumer Battery Systems, FCN Working Paper No. 15/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Broering H. (2016). The Benefits of Perfect Foresight in Prosumer Battery Clouds, FCN Working Paper No. 16/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Heesen F., Madlener R. (2016). Consumer Behavior in Energy-Efficient Homes: The Limited Merits of Energy Performance Ratings as Benchmarks, FCN Working Paper No. 17/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Atasoy A. T. (2016). Behavioral Responses of Green Builders to Discontinuous Certification Schemes, FCN Working Paper No. 18/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Galassi V., Madlener R. (2016). Shall I Open the Window? An Experiment on Effort and Habits in Thermal-Comfort Adjustment Practices, FCN Working Paper No. 19/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Von Hülsen H., Madlener R. (2016). Techno-Economic Selection and Evaluation of Generation-Storage Portfolios for Partially Self-Sufficient Energy Municipalities, FCN Working Paper No. 20/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Tran J., Madlener R., Fuchs A. (2016). Economic Optimization of Electricity Supply Security in Light of the Interplay Between TSO and DSO, FCN Working Paper No. 21/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Gürses G., Garrison J., Madlener R., Demiray T. (2016). Economic and Operational Assessment of Reserve Methods and Metrics for Electric Grids with High Shares of Renewables, FCN Working Paper No. 22/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Löbberding J., Madlener R. (2016). Techno-Economic Analysis of Micro Fuel Cell Cogeneration and Storage, FCN Working Paper No. 23/2016, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

FCN Working Papers have been published since 2008 and are free of charge. They can mostly be downloaded in pdf format from the FCN / E.ON ERC Website (www.eonerc.rwth-aachen.de/fcn) and the SSRN Website (www.ssrn.com), respectively. Alternatively, they may also be ordered as hardcopies from Ms Sabine Schill (Phone: +49 (0) 241-80 49820, E-mail: post_fcn@eonerc.rwth-aachen.de), RWTH Aachen University, Institute for Future Energy Consumer Needs and Behavior (FCN), Chair of Energy Economics and Management (Prof. Dr. Reinhard Madlener), Mathieustrasse 10, 52074 Aachen, Germany.