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Quantifying Germany's natural gas import risks: A portfolio model

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Preface

Natural gas imports are of vital importance to the German economy, while calls for diversification of Russian imports are intensifying. Because a reliance on Russian gas imports raises energy security concerns to many, the aim of this thesis is to assess the effectiveness of supplier diversification. The relationship between diversification and import risks is established by implementation of a portfolio model isolating systematic and specific risks of the German import portfolio over the period from 2000 to 2015. The results indicate high systematic risk in 2009 as well as lower yet slightly increasing specific risks with amplitudes in 2011 and 2014. Hypothetical changes to the import portfolio are applied to identify the potential of a set of diversification strategies. It is demonstrated that by a 15 percent point diversification of Russian imports to other supplier countries the specific risk of the portfolio can be reduced by 13%, whereas the grade of reduction depends on a risk assessment of current and potential suppliers.

Corresponding to section 8.2 of the *Guide for the Master Thesis*, this thesis is written as a scientific article preceded by an introductory chapter. The layout of the article is oriented towards the guidelines of the journal *Energy Policy*, which can be found in the appendix of this work. The preceding introductory chapter aims at providing additional insights into the study’s background and its theoretical frame while also commenting on applied methodologies and limitations.

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Part 1: Introduction

The introductory chapter of this thesis lays special emphasis on the presentation of foundational elements of the succeeding article, while further outlaying its theoretical background, providing for a reflection on used methodologies as well as for an analysis of the article's limitations.

1 Background and theoretical frame of reference

1.1 Growing significance of gas supply in Germany

Because the supplier portfolio is not merely an elementary part of the analysis but also a motivational factor for the creation of this study, the introductory chapter starts with an analysis of the growing importance of gas imports and historical diversification among suppliers. Next pricing of natural gas imports is examined after which the applied portfolio model is integrated in its theoretical context of measuring energy security.

Figure B.1 (appendix B) shows the increasingly significant role that natural gas plays in Germany's import of energy sources. While in the year 2000 the import share of natural gas amounted to 22.5% in gross imports, this figure grew to 30.6% in 2015 (AGEB, 2018). Figure B.1 further indicates a decreasing import share of nuclear energy as well as a still significant yet reducing role of crude oil imports. Figure B.2 indicates that the growth in relative import shares of natural gas is also mirrored by rising absolute import quantities. While Germany imported a total of about 796TWh of natural gas in 2000, this figure had grown to about 1190TWh by 2015 (BAFA, 2019)[1]. In addition to an already apparent growth in natural gas imports Germany's energy transition and the coal phase-out are believed to be leading to further demand growth in the future (Strunz and Gawel, 2016). The role of gas is thereby manifested because of gas power plants' integral part in Germany's double-structure buffering system used for balancing the intermittency of renewable energy because of their quick response time (Sinn, 2017).

At times of increasing significance of gas supplies however, the share of domestic production decreased from 25% in 2000 to only 6% in the year 2015 (BAFA, 2019). Furthermore, in 2015 about 97.5% of Germany's annual gas imports were sourced from the three countries Russia, Norway and the Netherlands alone (BAFA, 2019). Figure B.3

[1] Conversion according to Norwegian Petroleum Directorate, see appendix E

indicates that over the period from 2000 to 2015 the German natural gas import portfolio experienced only little variation. While overall a slight increase in Norwegian imports is observable, the share of Russian gas imports to Germany decreased from making up about 45% in the year 2000 to 34.6% in 2015 (BAFA, 2019). Alas, although still publishing statistics on total import quantities, no official government data is available on details of the natural gas supplier composition past 2015.

While a first look might indicate a slight improvement in diversification by increasingly equal shares of suppliers (Figure B.3), imports remain clustered among only three main suppliers throughout the entire timeframe of this study. Furthermore, the discontinuation in publishing of details of the supplier composition after 2015 coincides with a potential increase in the market share of Russian supplies. A combination of official total import numbers for 2018 with Gazprom's export statistics suggests that Russian imports to Germany in 2018 could have amounted to a record level of about 53% (BAFA, 2019) (Gazprom Export LLC, 2019). Alas, Germany's federal office for economic affairs and export control (BAFA) has stated that for the years following 2015 the origin of gas imports will not be published due to privacy regulation. Although highly indicative, it therefore remains to some extent unclear whether import levels past 2015 also led to an increase in the relative supply share of Russian imports to Germany.

Whereas energy policy has long been considered merely a matter of national interest, member states of EU today seek to establish a joint European energy policy as well. Supply security is to be enhanced by diversification of supplier countries and routes as well as by the creation of an internal energy market with infrastructure links (European Commission, 2014). Criticism that a conceivable growth in Russian imports because of the Nord Stream II pipeline could provide Russia with political leverage over Germany and threaten the diversification goals of the EU (Hedberg, 2017), might indicate that European market integration has not reached a satisfactory level. Supply diversification therefore remains a matter of national interest, while decreasing imports from the Netherlands as a consequence of the phase-out of the Groningen field (van 't Hof, 2018) are making the need for supplier diversification even more apparent.

It becomes clear that the question of supply diversification, besides its economic implications, also touches upon a wide political debate. While this discussion certainly played a role in drawing interest to the investigated subject matter, the article itself aims to provide for an economic angle on the question of natural gas supplier diversification only.

1.2 Changes in European gas price formation 2000 - 2015

Over the analysis timeframe of this study major changes in the pricing of natural gas in Europe occurred. When first discovered in the Netherlands and in the North Sea in the 1960s, production and transport of natural gas reserves required the construction of transport infrastructures and pipelines. The necessity for transport infrastructures for gas contributed to the existence of multiple physically-separated trading theatres and the absence of a unified gas market in Europe. Because of large financing costs needed for these pipeline infrastructures buyers and sellers alike yearn for security which greatly impacts the pricing of natural gas. Exchange of natural gas therefore traditionally makes use of long-term contracts (LTCs), whereby over a specified timeframe minimum and maximum delivery quantities are specified. As individual and private agreements, these contracts serve as a mechanism of sharing business risk between supplier and buyer to avoid opportunistic behaviour through vertical integration (Treeck, 2009).

With regard to price setting in LTCs, the emergence of natural gas initially as a by-product and to an extent replacement fuel for oil lead to the occurrence of oil-indexation in natural gas pricing. Hereby the price in contracts for gas is linked to relative price development of replacement fuels such as gasoil or heavy fuel oil (Konoplyanik A. , 2018). A basic example of an indexation formula using light fuel oil and gas oil as benchmarks is the traditional Groningen formula, after which the price for oil is to 60% percent determined by price changes of light fuel oil and to 40% to the development of heavy fuel oil (Konoplyanik A. , 2010). While the Groningen formula is the basic example for oil-indexation in natural gas pricing, indexation to price developments of other energy commodities such as crude oil, coal or electricity exist as well. The United Kingdom for instance, having already liberalized its gas market in the late 1980s, traditionally shows larger degrees of gas-indexation to its own gas hub, the Natural Balancing Point (NBP) (Konoplyanik A. , 2010).

Important to the mechanism of LTC formulas is that not daily price changes of index fuels are applied to the pricing of gas, but rather average prices of a longer reference period. After all, the need for appliance of an LTC stems from companies' need for reliance and a desire to share business risks. Figure 1 indicates the basic mechanism of an indexation formula, in which over a specified reference period price developments of index commodities are measured. Separated by a lag period, measured prices are then applied for the duration of a specified application period, adjusted on a regular basis.

Surging oil prices before the financial crisis of 2008 however, led to a decoupling of oil and gas prices largely prevailing to the present day. Prices for oil and gas as traded on energy exchanges further diverged in 2012, leading gas importers to demand renegotiations of contracts and the appliance of larger degrees of gas indexation (Franza, 2014). The transition towards gas-indexation marks an increase in transparency because instead of price changes in other energy commodities now actual demand and supply of natural gas are the primary drivers of price behaviour. While German hubs are growing in traded volumes, contracts in the European market have to a larger extent historically been indexed to the prices of the more mature energy hubs of the Dutch Title Transfer Facility (TTF) or the beforementioned British NBP (IGU, 2018).

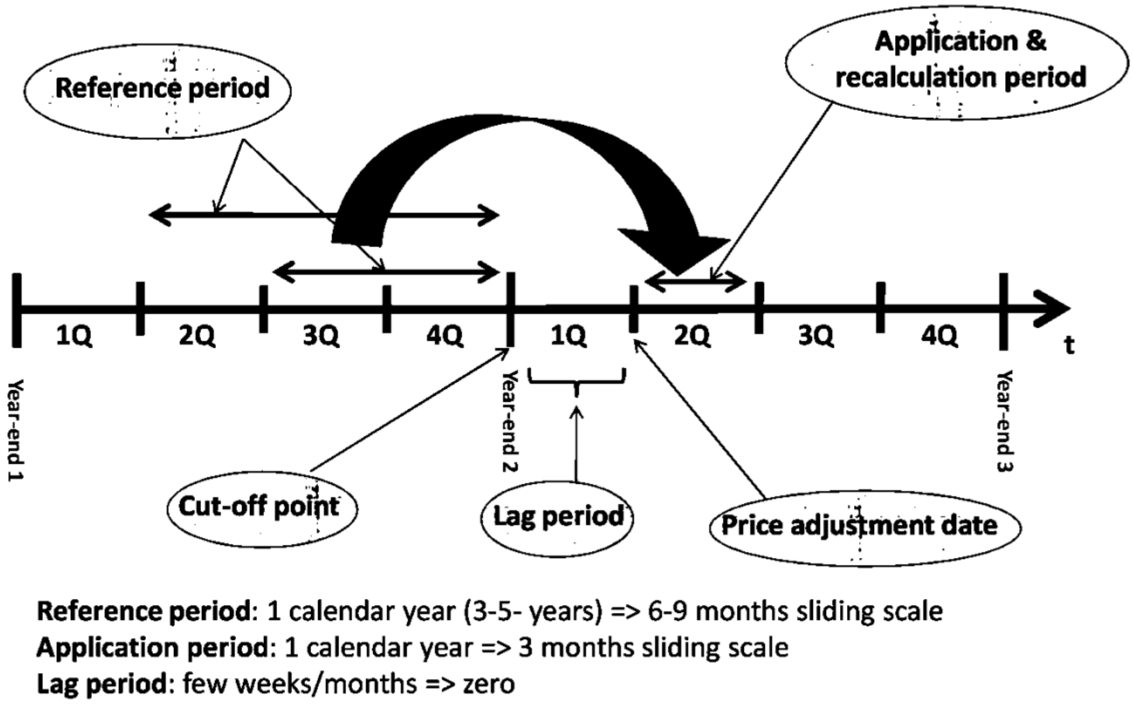

Figure 1: Basic mechanism of an indexation formula (Konoplyanik A. , 2010)

Figure 2 shows the trend towards gas-indexation, whereby gas-on-gas competition in addition to gas-indexation also includes an increasingly important share of spot prices in the pricing of natural in Europe (Orlova, 2017). Changes in pricing behaviour find their representation in shifting strategies of industry players such as Equinor, formerly Statoil. Similar to Shell, Total or BP, Equinor has transitioned from a pure production strategy to an integrated production, supply, trading and marketing strategy (Chi-Chyong, 2015). Goals of this strategy include the reduction of earnings volatility and the capturing additional value by increasingly including spot-indexation (Chi-Chyong, 2015). While Equinor until the year 2017 for the largest part had already transitioned from oil-indexation to gas-indexation in

LTCs (Equinor, 2018), Gazprom for the first time was selling gas via an auction process at a higher price than in LTCs in September 2015 (Hafner and Tagliapietra, 2017). This is especially remarkable as only in 2010 then-deputy CEO Alexander Medvedev noted that using spot prices was insufficient when planning investments and pipelines would not be built and gas not produced if not previously sold (Konoplyanik A. , 2010). Although Gazprom long resisted a reduction in oil-indexation, in 2018 the share of oil-indexation in the export portfolio had reduced to only 20% (Interfax Europe, 2018). Changes in pricing behaviour of both Gazprom and Equinor are thereby of great importance for German gas supply, as the combined export volumes of both companies' host countries contributed an average of 72.2% of total German natural gas imports over the period from 2000 to 2015 (BAFA, 2019).

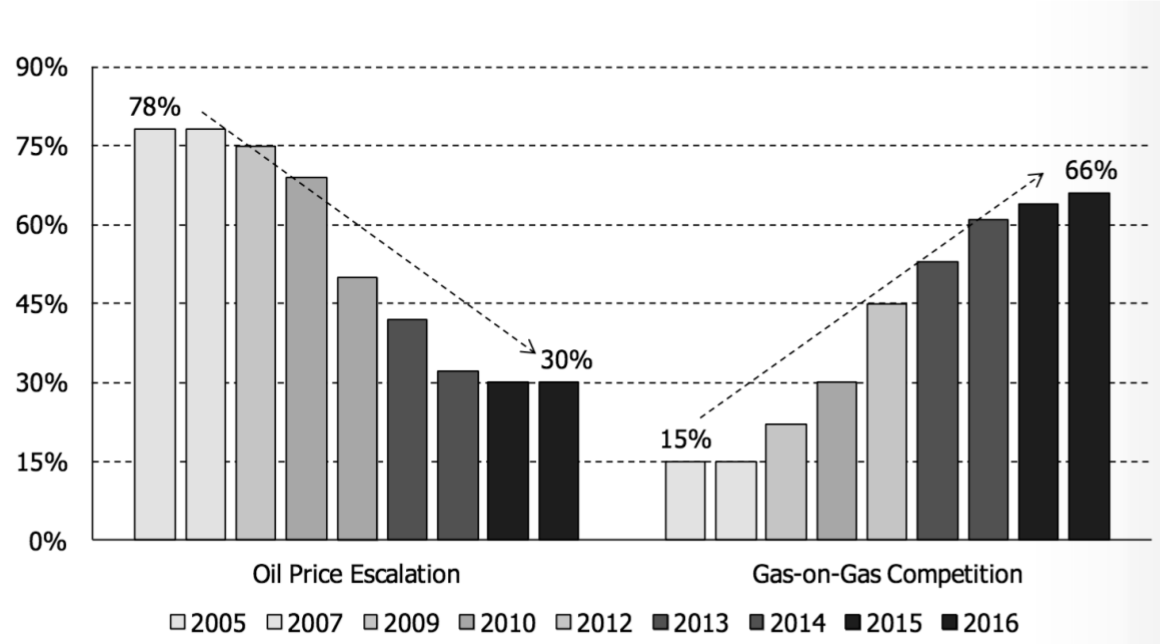

Figure 2: The demise of oil price escalation and the emergence of gas-on-gas competition in Europe (Orlova, 2017)

Germany states the importance of stable relationships to suppliers and of long-term supply contracts in guaranteeing security of future gas supplies (BMWi, 2018). As pointed out however, scholars argue that new LTCs will be shorter, much more flexible than their predecessors and bound to hub-based prices (Stern and Rogers, 2011). It therefore remains to be seen whether a switch to gas-indexation and growing spot-driven contracts can deliver on the promise of ensuring greater security in gas supplies.

1.3 Theoretical frame: Measurement of energy security

A theoretical starting point in the creation of this study has been the work of Månsson, Johansson, & Nilsson (2014), providing for an overview of methodologies previously applied for the quantitative measurement of energy security. According to Månsson et al. (2014) a variety of methodologies exists for the analysis of energy security because reaserchers stem form different scientific fields. Because of their different background researchers may use approaches stemming from the fields of economics, engineering, political and natural science (Månsson et al., 2014). However, no uniqe and best way of measuring energy security exists and model suitability is ascribed by the research question. Besides an economic approach taken by this study, studies from engineering for instance can be pointed at the analysis of reliability of power systems, while research from political science could center around international relations and distribution of power (Månsson et al., 2014). Economic approaches are thereby recognized for their objective of monetizing risk effects such as macroeconomic welfare effects. Besides a variety of methods drawing form a multitude of research disciplines, also choices exist as to which focus point the analysis of energy security is to be applied at.

According to Månsson et al. (2014) measurement of energy security can be directed at either the supply of primary energy, the supply from the upstream market or at the domestic market and infrastructure. Figure 3 indicates these different measurements points, whereby integrated methods denote those methods streching in their analysis over muliple focus points of the energy supply chain.

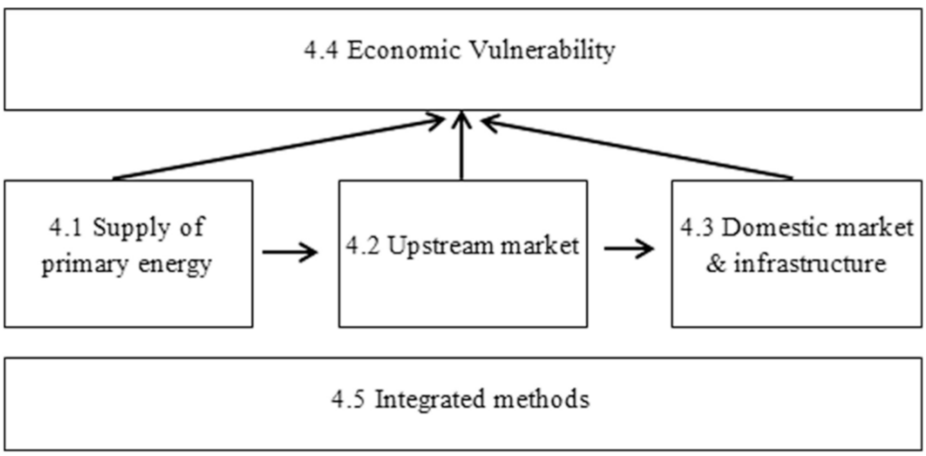

Figure 3: Evaluating energy security along the supply chain (Månsson, Johansson, & Nilsson, 2014)

Because, as outlined in section 1.1, Germany's domestic production of natural gas reduced to making up only 6% of total annual consumption in 2015 (BAFA, 2019), estimating energy security by measuring the endowment with primary energy recourses would serve to be futile. Besides an analysis of the resource supply from the upstream market applied in this study, also domestic market and infrastructure are suggested measurements points. Little risks from domestic market infrastructures however are suggested by the fact that Germany shows fewer than two minutes of average supply disruption per end consumer between the 2006 and 2017 (Volk, 2018). This small rate of disruption is made possible by Germany's operation of 47 natural gas underground storage facilities with a combined capacity of about 255.6TWh. (INES, 2018). Equating about 22% of yearly gas imports in 2015, gas storage facilities therefore play a large part in securing Germany's natural gas supply from a domestic perspective by buffering out seasonality and demand peaks.

Although, because of this storage capacity, Germany might be able to withhold a supply disruption for some time, dependence on foreign imports and supplies from the upstream market constitute the largest identifiable risk factor in the supply chain. Considering the upstream market as a focus point research points out that a country's vulnerability to supply disruption can be reduced by diversification in supply sources (Cohen, Joutz, & Loungani, 2011). Numerous studies have therefore adopted diversification indices originating from financial portfolio theory such as the Herfindahl-Hirschman index (Blyth and Lefevre, 2004) (Le Coq and Paltseva, 2009) or the Shannon-Weiner concentration index (Neumann A. , 2007) . According to the basic mechanism of a concentration index, higher supplier concentration in the market yields higher values for the corresponding concentration index and therefore higher risks. Blyth and Lefevre (2004) further suggest that a country's size and the magnitude of imports can be a significant factor in import vulnerability, which would imply increasing risks for the German import portfolio. When analysing energy security for natural gas imports in OECD countries, it has been shown that an increased supplier diversification in combination with high importance of natural gas in world energy use suggests an increase in overall energy security (Cohen et al., 2011).

Besides risk reduction through diversification Månsson et al. (2014) also suggest an analysis of reliable supply and transit routes. This approach for instance taken by Le Coq and Paltseva (2009) adds political stability factors and bargening power assessments between importers, exporters and transit countries to a diversificaion assessment. Most relevant for this study however is the suggestion of risk reduction through financial portfolios, further outlined in the following section.

1.4 Measuring import security with a portfolio model

As pointed out by Volk (2018), natural gas end consumers in Germany annually experienced fewer than two minutes of average supply disruption between 2006 and 2017. Therefore, while clearly indicative of disruption risk, a concentration index alone might be insufficient in expressing also those types of risks present before an entire discontinuation of supply form a specific supplier country or a disruption to end consumers comes into existence. Lesbirel (2004) suggests the analysis of market prices as an indicator for risks, because of their representativeness for supply disruptions. A supply disruption can be described as any incident bringing an imbalance to supply and demand in the market. This imbalance could be the consequence of either politicisation of the energy market therefore a political decision, a market event or a random accident, whereby simultaneous disruptions from multiple supply sources are possible (Lesbirel, 2004). Wieczorkiewicz (2014) similarily states that gas prices can surge in case of a supply shock (Wieczorkiewicz, 2014). Thus, prices might be indicative of disruption risks which the level of diversification alone might not be able to fully express, partly due to Germany's high level of natural gas storage.

The application of a portfolio model for the quantification of energy security is recognised for its ability to separate *specific* risks from *systematic* risks, while an underlying assumption is that historical volatility provides for a valid representation of future risks (Månsson et al., 2014). Figure 4 indicates these risk components of the portfolio model, whereby boxes with vertical lines represent exporters, those with horizontal lines represent importers and the market is represented by a dotted area. Månsson et al. (2014) also identify a third risk category referred to as the *systemic* risk, which describes the risk of market collapse originating from unstable or metastable systems.

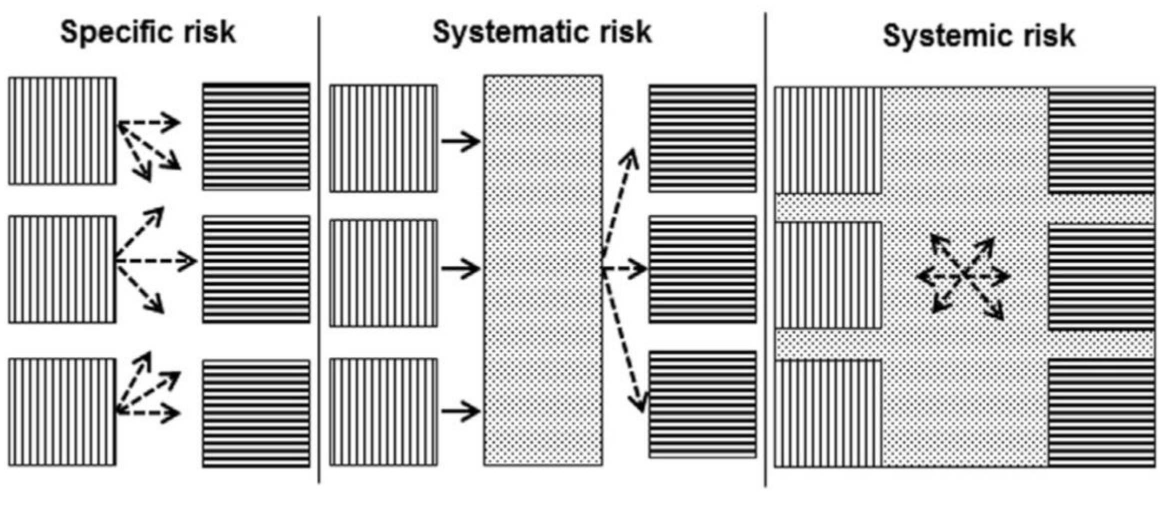

Figure 4: Specific and systematic risks (Månsson et al., 2014)

Portfolio models find their typical application in financial theory where a set of more and less risky assets is to be examined for its integration in a portfolio. A transfer of this approach to energy markets consequently allows for an examination of different choices of supply sources and the relationship between diversification and energy security risk (Lesbirel, 2004). A basic conception is that the risk of a combination of import sources in a portfolio can differ from the risk of relying only on one particular supply source. Within the analysis of import risks with a portfolio model, the separation of *systematic* and *specific* risks results from an analysis of market prices against import prices. Because market prices can surge as a result of a supply shock (Wieczorkiewicz, 2014), their measurement allows for an esimation of *systematic* risks. A disruption has been identified as any imbalance between supply and demand and could therefore find its origin not only on the supply side of the market, but also on the demand side. An abrupt decline in demand as a consequence of a policy measure for instance could trigger a disruption leading to an imbalance to the market equilibrium. Prices are capable of reflecting imbalances on both the supply- and the demand side and are therefore reflective of the risk of disruptions (Lesbirel, 2004). Building on the understanding that diversification can principally reduce the risk of disruption from a particular supply source, the applied portfolio approach uses price variance as a measure for risk.

Systematic risks are thereby described as those risks which are fundamental to the underlying market. Because all suppliers in the market are affected by it, diversification of supply sources cannot reduce systematic risk, which is therefore oftentimes referred to as undiversifiable risk. A cold winter across Europe for instance could lead to an increase in gas demand and thus price increases across the whole European market. Because market prices of all suppliers are likely to be affected, diversification cannot mitigate systematic risk.

Deviations from market prices are indicative of risk elements not experienced by other importers or the underlying market. *Specific risks are* inherent to a specific supply source for which diversification is effective in its mitigation. A supply disruption from a particular supply source for example could be the result form an accident or a politically-motivated supply stop. Because it is not impacting the behaviour of other supply sources and the underlying market specific risk is also referred to as diversifiable risk (Lesbirel, 2004).

Thus, the overall portfolio of Germany’s natural gas imports encompasses both an unavoidable risk component due to market exposure and a risk component specific of the German import portfolio. As pointed out, portfolio models are capable to indicate the risk of disruptions through the analysis of market- and import prices. Compared to simple measures such as diversification indices for instance, “portfolio measures provide a much more theoretically and methodologically robust indicator of energy import security" (Lesbirel, 2004, p. 1). Research on the impact of supply diversification on crude oil import risk indicates that diversification of supply sources contributes to import risk mitigation (Wabiri and Amusa, 2010). It is further stated however, that should this diversification lead to an increased supply from "relatively risky oil producing regions", the specific risks of South Africa's oil imports in this example can also be enhanced. When applying a portfolio approach for gas imports, peculiarities of the gas market need to be considered. While Wabiri and Amusa (2010) refer to the price of Brent crude oil in order to derive an understanding of the relationship between variations of local import prices and those of globally-traded oil prices, no such unique market price exists for the relevant German gas market. Extending the work of Wabiri and Amusa (2010) the methodology of this study therefore includes the modelling of relevant market prices to allow for an analysis of natural gas import risk.

2 Methodological assessment

2.1 Data

Data on Germany's natural gas imports is thereby derived from Germany's federal office for economic affairs and import control (BAFA). Besides border crossing prices until 2018, also details on the supplier composition until 2015 are available from BAFA. After 2015 however, no information on the composition of the supplier portfolio is available, marking 2015 as the latest year of analysis.

Data on analysed futures contracts is derived from Quandl, a commercial data provider also offering free data sets[2]. Raw data on futures contacts derived from Quandl originates from data published by the Intercontinental Exchange (ICE), whereby single contract data for delivery in a specific month (e.g. January futures) is aggregated in a continuous contract as outlined in the succeeding article. Quandl was chosen as a data provider because via the ICE itself only data on currently-traded contracts is freely-available. Similar to other trading hubs or data providers such as the European Energy Exchange, ICIS or the CME group, the ICE offers historical trading data only against a substantial free, arguably suitable for professional traders but in its extent highly inadequate for the purpose of a master thesis. Testing data derived from Quandl against recent data publicly available on the ICE's websites also indicated conformity between data published by the exchange itself and the aggregate Quandl data.

[2] See https://www.quandl.com

2.2 Modelling of market price basket

As outlined in section 1.2, over the period from 2000 to 2015 natural gas pricing transitioned from oil-indexation towards gas-on-gas competition, i.e. the inclusion of gas indexation and spot-prices in the pricing of natural gas. Because no single index or market price would be representative for effective market prices for the entire timeframe of analysis, the study models an evolving market price basket. This price basket is based on the beforementioned changes in natural gas pricing in Europe and therefore reflects relative price changes of a changing selection of indexation fuels. Konoplyanik (2018) was instrumental in the basic design concept of the index basket, for which ICE's low sulphur gasoil futures were integrated as a representative of light fuel oil.

Alas, no sufficient data on heavy fuel oil was available, leading to the integration of Brent crude oil futures as the second index element in the applied LTC formula. The third element used in market price modelling are UK natural gas futures (NBP). Figure 5 shows trading volumes of European gas hubs between 2007 and 2013. While the German hubs NetConnect Germany (NCG) and GasPool (GSL) only in more recent years show increases in trading volume and no sufficient data for them was available, the study uses the British NBP, which has long been the reference point for European hub prices, much like Henry Hub in the United States of America.

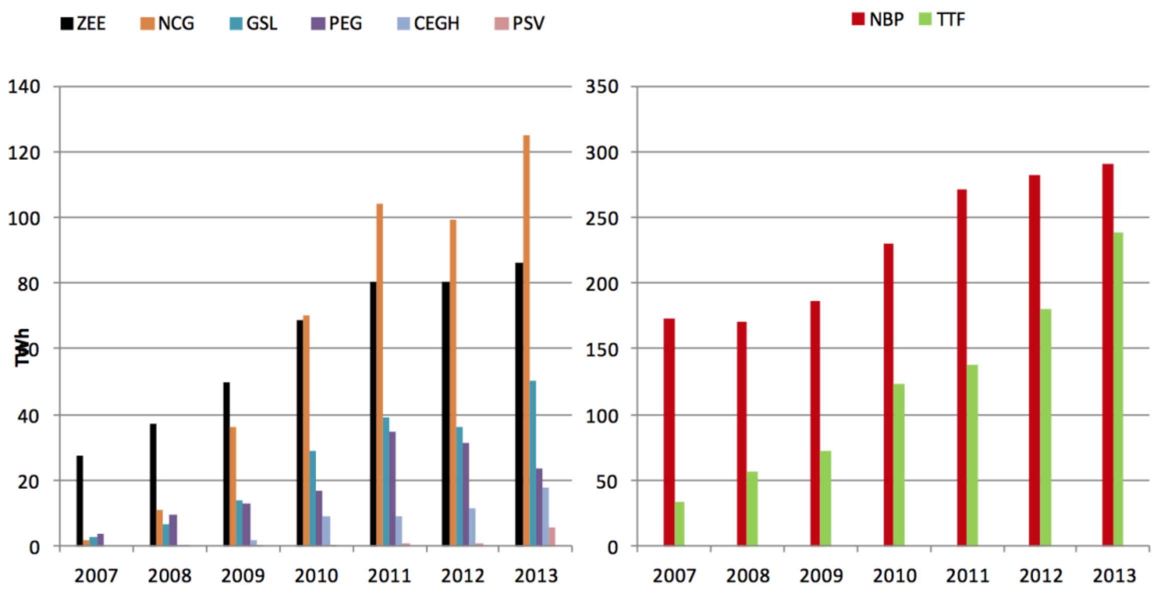

Figure 5: Trading volume of European gas hubs (Petrovich, 2014)

Because, as previously outlined, natural gas pricing in Europe shifted towards hub-traded prices, the modified market price changes in its composition accordingly. The usage of

NBP futures as a price indicator for German market prices can be considered reasonable because of overall high correlation, although decreasing after 2013, with newly-developing German hubs (Petrovich, 2014). As indicated by Figure 5, the British NBP also shows the largest trading volume of all European gas hubs until 2016 (Heather and Petrovich, 2017). GasPool futures data started to be available from the beginning of 2013 suggesting replacement of NBP futures for the later years of the analysis timeframe. However, testing for correlation between continuous futures data on GasPool and NBP between 2013 to 2015 indicated a price correlation of 97.9%. Therefore, no substitution was applied and NBP futures continued to function as a proxy for spot price elements in the modified German gas market prices.

A multitude of LTC formulas exist, corresponding to the mechanism outlined in Figure 1. Between other formulas applied in private contracts such as 3-1-1, 6-1-1 or 6-3-3 (Müller, Hirsch, & Müller, 2015), the chosen formula was selected for goodness of fit (R^2) to German import prices. Because only one formula could be applied acting as a proxy for the multitude of actually-applied formulas in the market, possible changes in formulas applied by private companies in the market over the analysis timeframe cannot be accounted for. The applied 6-3-1 type formula however, to which details can be found in the main article (section 2.2.1) as well as in appendix B, acts as an aggregate estimation of formulas applied by companies in the market.

Figures 6 and 7 show the modelling of market prices according to the outlined changes in natural gas pricing. First (Figure 6) indexed components are aggregated to a cumulative price index capturing the relative price development of Gasoil, Brent and NBP futures. The share to which each component is represented in this indexation basket is oriented towards the outlined changes in natural gas pricing. A figurative description of the share of index components in the indexed price component is available in Figure B.2. Secondly, Figure 7 depicts the mechanism of the applied 6-3-1 formula for completion of the calculation of the indexed price component. It must be noted that reference, lag and application period are equal for all indexed price components. Lastly, for calculation of the final market price the indexed price component is combined with a spot component mirrored by NBP futures for next month delivery. In the aggregate futures data a current day's market price thereby corresponds to the futures price for a contract with equal delivery in the succeeding month. The increasing share of the spot component (Figure B.2) is combined with the indexed price component which was previously brought to absolute terms by multiplication to the average January price of 1999 UK natural gas futures (NBP).

		LTC to Spot						Final Price			
		Indexation	Spot price co	NBP GBP	Gasoil	Brent	LTC INDEX	Index	Gasoil	Brent	NBP
2006	Apr	87,5%	13%	423%	575%	597%	570%	513,73%	45%	45%	10%
	Mai	86,7%	13%	374%	565%	570%	548%	516,75%	45%	45%	10%
	Jun	85,8%	14%	391%	571%	565%	550%	519,58%	45%	45%	10%
	Jul	85,0%	15%	417%	583%	606%	577%	521,31%	45%	45%	10%
	Aug	84,2%	16%	374%	587%	597%	570%	519,07%	45%	45%	10%
	Sep	83,3%	17%	416%	516%	508%	503%	526,89%	45%	45%	10%
	Okt	82,5%	18%	513%	495%	478%	489%	542,74%	45%	45%	10%
	Nov	81,7%	18%	505%	479%	475%	480%	543,34%	45%	45%	10%
	Dez	80,8%	19%	417%	484%	493%				45%	10%
2007	Jan	80,0%	20%	313%	442%	431%	=Z104*T104+AA104*U104+S104*AB104			45%	10%
	Feb	80,0%	20%	201%	463%	459%	435%	471,77%	45%	45%	10%
	Mär	80,0%	20%	209%	477%	489%	455%	464,24%	45%	45%	10%
	Apr	80,0%	20%	174%	502%	521%	478%	448,19%	45%	45%	10%
	Mai	80,0%	20%	236%	507%	519%	485%	440,14%	45%	45%	10%
	Jun	80,0%	20%	198%	532%	552%	508%	414,58%	45%	45%	10%
	Jul	80,0%	20%	299%	544%	585%	538%	428,63%	45%	45%	10%
	Aug	80,0%	20%	264%	532%	542%	510%	420,09%	45%	45%	10%
	Sep	80,0%	20%	337%	570%	578%	550%	435,27%	45%	45%	10%
	Okt	80,0%	20%	474%	580%	603%	580%	466,13%	45%	45%	10%
	Nov	80,0%	20%	522%	651%	657%	641%	490,94%	45%	45%	10%
	Dez	80,0%	20%	518%	632%	651%	630%	500,16%	45%	45%	10%

Figure 6: Example in the process of market price modelling: Calculation of LTC index

	Final Price							LTC PRICE INDEX
LTC INDEX	Index	Gasoil	Brent	NBP				
570%	513,73%	45%	45%	10%		2006	Apr	526,72%
548%	516,75%	45%	45%	10%			Mai	538,71%
550%	519,58%	45%	45%	10%			Jun	540,80%
577%	521,31%	45%	45%	10%			Jul	539,74%
570%	519,07%	45%	45%	10%			Aug	546,37%
503%	526,89%	45%	45%	10%			Sep	549,00%
489%	542,74%	45%	45%	10%			Okt	549,08%
480%	543,34%	45%	45%	10%			Nov	552,04%
481%	531,20%	45%	45%	10%			Dez	558,24%
424%	504,96%	45%	45%	10%		2007	Jan	552,90%
435%	471,77%	45%	45%	10%			Feb	539,49%
455%	464,24%	45%	45%	10%			Mär	
478%	448,19%	45%	45%	10%			Apr	=MITTELWERT(V98:V103)
485%	440,14%	45%	45%	10%			Mai	491,24%
508%	414,58%	45%	45%	10%			Jun	468,77%
538%	428,63%	45%	45%	10%			Jul	460,92%
510%	420,09%	45%	45%	10%			Aug	459,01%
550%	435,27%	45%	45%	10%			Sep	459,85%
580%	466,13%	45%	45%	10%			Okt	464,21%
641%	490,94%	45%	45%	10%			Nov	483,16%
630%	500,16%	45%	45%	10%			Dez	495,58%

Figure 7: Example in the process of market price modelling: Reference period, lag and application of the LTC formula.

Because the final market price is bound to this average price, the modified market price is rather inapt for a comparison of absolute price levels to Germany's border crossing prices at specific points in time. Although representing the most fluidly-traded European gas hub, average prices for the UK in 1999 have only limited representativeness for actual market prices in Germany that year. However, bringing the indexed price component back to absolute terms allows for the integration of spot price components needed for the computation of a realistic final market price. While relative price changes are sufficient and according to the analysis of the succeeding article indicative of import prices, the computation of market prices certainly bases the validity of these market prices on the assumptions of the research referred to in the analysis of changes in natural gas pricing (section 1.2). The applied methodology guarantees however that the outlined mechanism of indexation but also spot price components can adequately be represented in the final market price. A model relying on only one price component such as Wabiri and Amusa (2010) and the analysis of Brent crude oil certainly refrains from possible computation errors. However, the lack of a single significant market price might be a factor why to the author's knowledge no comparable study has been conducted for natural gas in Germany. Furthermore, changes in the composition of market prices which the modified market price is able to depict might be indicative of changes in analysed portfolio risk, as outlined in the preceding main article.

2.3 Diversification index

Building on the work of Wabiri and Amusa (2010) the Hirschman-Herfindahl-Agiobenebo (HHA) concentration index is applied for the measurement of supplier composition (Agiobenebo, 2004). As pointed out in section 1.3, diversification is adapted for the measurement of energy security in numerous studies, whereby typically the traditional Hirschman-Herfindahl index (HH) is applied. Figure 8 indicates on independent axes a similar development of diversification of Germany's natural gas imports by both the HH index on the right axis and the HHA index applied by this study on the left axis. Because the HHA index modifies the HH index by taking the square root of the sum of countries' squared supply shares (equation (1)), the HHA-index shows a diversification improvement of 1.9%, while the HH-index shows an overall improvement between 2000 and 2015 of 3.82%.

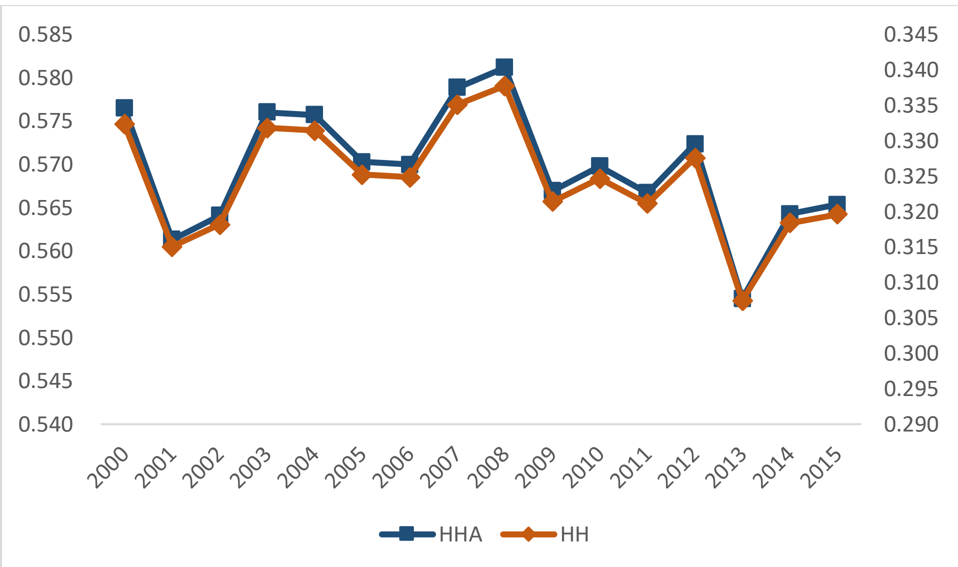

Figure 8: The applied Hirschman-Herfindahl-Agiobenebo (HHA) concentration index vs the original Hirschman-Herfindahl index (HH)

2.4 Portfolio model

Because this research aims at providing for an understanding of which effect diversification in upstream supplier composition has on Germany's natural gas import risks, the portfolio model does not take into account the domestic supply of primary energy as well as the state of domestic market infrastructures. For estimation of import risks the applied portfolio model analyses diversification in the supplier composition and the relationship between market- and import prices. Table 1 (Part 2, section 3.2.1) outlines the relationship between market prices and import prices, whereby a β-coefficient of about 0.9 indicates that in case of disruptions in the market import prices will closely track the movement of market prices. Although appearing highly significant with an adjusted R-squared of about 0.98, the original logarithmically transformed model (equation (2)) shows autocorrelation in the error terms with a Durbin-Watson d-statistic of about 0.5435 (Figure 9 (STATA data output)).

```
Durbin-Watson d-statistic(  2,   192) =  .5434557


Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of LNImport

         chi2(1)      =     0.03
         Prob > chi2  =   0.8723

White's test for Ho: homoskedasticity
         against Ha: unrestricted heteroskedasticity

         chi2(2)      =     3.39
         Prob > chi2  =   0.1836

Cameron & Trivedi's decomposition of IM-test
```

Source	chi2	df	p
Heteroskedasticity	3.39	2	0.1836
Skewness	5.52	1	0.0188
Kurtosis	0.61	1	0.4338
Total	9.52	4	0.0494

Figure 9: Statistical tests for the logarithmically-modified model (STATA graphical layout), equation (2)

The specific risk index of the import portfolio (equation (7)) is driven by error term variation. Therefore heteroskedasticity is to be avoided to provide for a valid represenation of the experienced import risks. Figure 9 shows the results of the application of the Breusch-Pagan and the White test. Both tests indicate that no significant level of heteroskedasticity is present in the error terms. First-order autocorrelation is adjusted for by a Cochrane-Orcutt transformation, yielding a new Durbin-Watson statistic of about 1.87 (Table 2). While it is possible and to an extent likely that correlation also of higher orders might be present because of the 6-months long reference period in the applied indexation formula, no further adjustments are undertaken. Figure 10 indicates, that the residuals of the final model adjusted for autocorrelation of the first order (equation (3)) are normally distributed.

Shapiro-Wilk W test for normal data

Variable	Obs	W	V	z	Prob>z
LogCorcResid	**192**	**0.99340**	**0.950**	**-0.117**	**0.54674**

Figure 10: Shapiro-Wilk test for normal distribution

3 Findings discussion

The results show especially high systematic risks in 2009, linked to first surging and then sharply declining market prices surrounding the financial crisis. Specific risks (about 38.6% of total portfolio risk between 2000 and 2015) are particularly high in 2011, when the shut-off of eleven German nuclear power plants coincided with oil and gas supply disruptions to Europe related to the Arab spring. The second highest point in specific portfolio risk is reached in 2014, possibly linked to that year’s Russian-Ukrainian gas dispute. With a 1.9% improvement in the applied diversification index only minor changes in supplier diversification between 2000 and 2015 are observable. As further outlined in section 3.2.2 of the succeeding article, the analysis shows that because of these only marginal changes in diversification no relationship between experienced improvements in diversification and lower specific risks is observable (Figure 18). While the original HH index may indicate a greater improvement in diversification (3.82%) (section 2.3), mapping historical specific risks against the development of the original HH index yields the same results (Figure A.2), as the mapping of specific risks against the applied HHA index (Figure 18).

Historical portfolio risks can therefore be primarily attributed to market price variances and error variances. Figure 11 denotes the relationship between the specific risk index of the portfolio (equation (9)) and the error variance. Because the index term utilizes a square root in its calculation, the relationship between error variance and the specific risk index appears to follow a polynomial trend. Two data points stand out, whereby the highest error variance and thus specific risk is observable in year 2011 and the second highest in 2014 (see Figure 17).

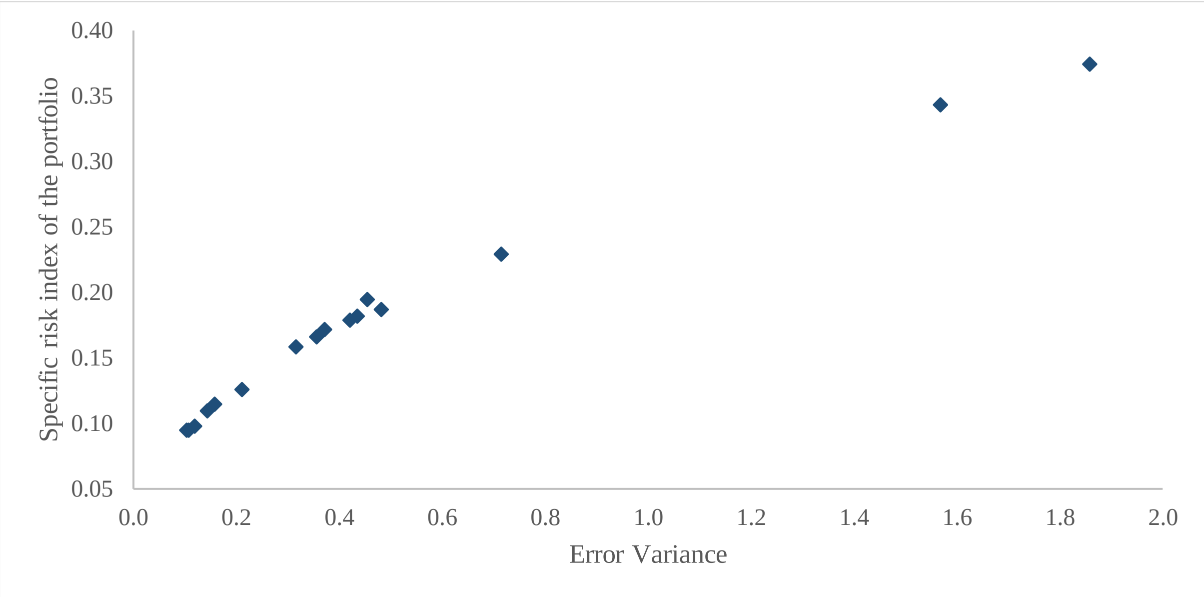

Figure 11: The relationship between error variance and specific risk index of the portfolio

The discussion of the succeeding paper shows the potential of diversification in reducing specific risks of the portfolio. When hypothetically transferring percentage points of the market share of Russian imports to other supply sources, constant and transferrable market- and import price relationships are assumed. The degree to which diversification strategies can alter the specific risk of the portfolio is thus dependent on the assigned risk weights (Table 3 and appendix D). A number of diversification strategies is outlined to assess the potential of diversification in specific risk mitigation. Thereby a strategy implying equal 25% import shares of all supplier countries yields a 10.7% decrease in specific risks, while an applied 15 percent point transfer of Russian supply shares solely to *other* supplier countries yields a 13% reduction. With the assigned relative risk weight for each supplier country a maximum reduction in the specific risk index of the portfolio of 15.4% is attainable. Such reduction in specific risks would hypothetically assume a constant supply share from every supplier country for every year between 2000 and 2015. This maximum reduction in specific risks would require Russian import shares to amount to 18.3%, Norwegian imports to 39.8%, Dutch supplies to 24.4% and supplies from *other* supply sources to 17.5%.

Drawing on these conclusions policy makers are encouraged to provide for policy measures favouring a reduction of import risks. Because natural gas is not imported by the country as an actor itself but rather by private businesses, the role of the government could be the setting of suitable financial incentives. These incentives could favour infrastructure investments such as new pipeline projects whereby the government could act as a guarantor of loans taken by businesses operating these projects. Because of the decreasing marginal utility of diversification (Figure A.1), costs and limits of such strategies must be accounted for.

4 Limitations

The applied portfolio model analyses the effect of diversification on systematic and specific portfolio risks. Månsson et al. (2014) also identify a third risk category, the risk of market collapse, referred to as systemic risk. Originating from events in instable or metastable systems, systemic risks are not accounted for in the portfolio model applied in this study under the assumption of stable systems.

As outlined in section 1.2, this study utilizes a modified market price for the construction of the portfolio model. While an adjusted R-squared of 0.9837 appears to suggest that this research-based market price basket is highly indicative of import prices, the market price remains to an extent assumption-based. Therefore, the portfolio model assumes that the modified market price acts as if a single market price had been available. The market switch towards gas-on-gas competition in natural gas pricing is undertaken to increase price transparency with prices being linked to actual supply and demand. The development of UK natural gas futures prices (NBP) might especially in 2005 and 2007 show developments specific for demand and supply of natural gas in the United Kingdom only (Conforto, 2010), with only limited viability for market prices in Germany. Over the entire timeframe of the study NBP futures can be regarded as a valid price component however, not only because of limited usage of NBP prices in the calculation of the German market price basket in 2005 and 2007. Also high correlation with German hubs between 2013 and 2015 (97.9%) and the highest trading volume of all European gas hubs during the study's timeframe justify the adequate appliance of NBP prices. As discussed in section 2.4 autocorrelation of the first order is corrected for by applying the Cochrane-Orcutt method. Autocorrelation, arguably to a lesser extent, of higher orders can however not be ruled out in the market price term because of the 6-months long reference period applied in the indexed price component. When implementing German hub prices and computing a basket price, further research might test if similar behaviour in prices exists also with data accessed directly from the ICE, while the succeeding study can only access ICE data freely-available via Quandl because of financial restrictions.

Risk weights (appendix D) applied according to an assessment of supplier countries' perceived performance towards the 4A concept of energy security play a significant role in assessing the limits and the potential of diversification strategies. While they allow for a quantitative expression of supplier risk weight in the portfolio model, they constitute a subjective judgment. As suggested by some, alternative judgment criteria for the selection of supplier routes could also centre around transit risk and accessibility factors (Ritter, 2011) or use other metrics such as the International Country Risk Guide (ICRG) applied by Cohen et al. (2011). Especially the category *Availability* in the applied analytical hierarchical process (appendix D) leaves room for debate as to which extent decision makers in the past were able to foresee the full scope of their future gas availability (e.g. phase-out of the Groningen field in the Netherlands).

The applied portfolio model analyses the historical supplier composition in the context of historical prices. In order to assess the extent to which diversification can mitigate import risks it is assumed that the relationship between the number of suppliers and prices, but also the relationship between market- and import prices is constant when applying hypothetical shifts to the supplier portfolio. The analysis of diversification in the reduction of risks is limited because of this assumption of transferability of the relationships because it only allows for variations in the historical supplier set to be tested. The analysis of historical risks applies relative risk weights for existing suppliers and therefore the same model only allows for those changes to be tested for which are applied to the existing supplier portfolio. Clearly, the inclusion of new supplier routes such as LNG supplies would yield additional benefits to specific risks, which might have to be measured for by application of another model.

Because energy- and import security can be assessed in multiple ways, the study does not claim exclusivity and universality in its findings. The aim of the study is rather to provide for an additional angle on the question of supplier diversification and import risk. Lastly, while also a relationship between the decreased usage of price indexation and higher specific risks is provided, the study does not suggest that lower specific risks would have occurred had oil-indexed prices been applied in times of higher risks.

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Part 2: The scientific article

Quantifying Germany's natural gas import risks: A portfolio model

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Highlights

- The risk of German natural gas imports between 2000 and 2015 is analysed
- A historic link between diversification and import risk is provided
- A 15%-point reduction of Russian supplies yields a 13% decrease in specific risk
- The grade of risk reduction depends on supply route risk assessment

Abstract

Natural gas imports are of vital importance to the German economy, while calls for diversification of Russian imports are intensifying. Because a reliance on Russian gas imports raises energy security concerns to many, the aim of this paper is to assess the effectiveness of supplier diversification. The relationship between diversification and import risks is established by implementation of a portfolio model isolating systematic and specific risks of the German import portfolio over the period from 2000 to 2015. The results indicate high systematic risk in 2009 as well as lower yet slightly increasing specific risks with amplitudes in 2011 and 2014. Through sensitivity analysis hypothetical changes to suppliers' import shares are applied to identify the potential of three possible diversification strategies. It is demonstrated that by a 15 percent point diversification of Russian imports to other supplier countries the specific risk of the portfolio can be reduced by 13%, whereas the grade of reduction depends on a risk assessment of current and potential suppliers.

Keywords: Energy security, Natural gas, Import risk, Portfolio theory, Diversification

1 Introduction

Germany's *Energiewende* marks the country's goal of transitioning towards an environmentally sound, reliable and affordable energy supply (BMWi, 2010). The growing importance of gas in this transition is mirrored by a rise in the share of natural gas in total gross energy imports from 22. 5% to 30.6% over the period from 2000 to 2015 (AGEB, 2018). In absolute terms imports of natural gas show an increase from about 796TWh in the year 2000 to around 1190TWh in 2015 (BAFA, 2019)[3]. A stable import supply appears to be of increasing importance to the economy, while the share of the domestic production decreased from 25% in 2000 to only 6% in the year 2015 (BAFA, 2019). Germany voices support for the liberalization of the gas market and of competition within it (BMWi, 2010, p. 14). In the year 2015 however, 97.5% of Germany's natural gas imports originated from only Norway, Russia and the Netherlands (BAFA, 2019).

In addition to what already appears to be a high dependence on gas imports, Germany's energy transition and the coal phase-out are considered to be leading to growing gas demands in the future (Strunz and Gawel, 2016). Besides its usage in heat generation gas power plants are a vital element of the country's double-structure buffering system necessary for balancing out the intermittency of renewable energy because of their quick reaction time to demand fluctuations (Sinn, 2017). An increase in required import quantities in combination with only a small number of supplier countries raises the question of import dependency and a need for diversification of Germany's natural gas supplies.

While diversification is to be increased through new supplier routes such as the southern gas corridor or an increase in LNG supplies (BMWi, 2010), energy security has also become a key element of the energy policy of the European Union (EU). As such, the establishment of a unified and interconnected gas market has been identified as a key objective of the EU's new cohesive energy strategy in response to the Russian-Ukrainian gas crises of 2006 and 2009 (Umbach, 2017). Critics claim that a high level of import dependency paired with a conceivable growth in Russian imports in light of the Nord Stream 2 pipeline construction could provide Russia with political leverage over Germany and threaten the diversification goals of the EU (Hedberg, 2017). Increased connectivity of the European gas market on the other hand could allow Germany to develop into a hub for distributing gas across the continent and thereby decrease risks of supply disruptions for other member states of the EU.

[3] Conversion according to Norwegian Petroleum Directorate, see appendix E

While political perspectives have to be considered in order capture the discussion of gas import security in its entirety, this study aims to shed light on the effects of supplier diversification and gas price constitution on gas import risks. An economic approach is chosen in order to provide answers to the following research questions:

- What is the relationship between available market- and import prices?
- How does variation in market- and import prices impact import security?
- How do risks specific to German imports develop against systematic market risks?
- To which extent can a diversification strategy mitigate import risks?

A portfolio model is applied analysing how changing market prices and import dynamics between the years 2000 and 2015 affect Germany's import risk for natural gas. This framework serves as a foundation to discuss to which extent diversification among the existing set of suppliers can reduce import risks for Germany. Understanding the analysed effects allows for an evaluation of their integration in policy measures.

The study draws on the work by Wabiri and Amusa (2010) applied for the analysis of South Africa's crude oil import risks and transforms its model for the purpose of assessing Germany's natural gas import risks. A market price basket is created serving as a proxy for market prices of importable quantities. This unified market price basket mirrors in its composition the overall shift from oil price-indexation towards gas-indexation and hub-pricing in natural gas across Europe. Building on the work of Wabiri and Amusa (2010) quantitative risk weights are assigned to each supplier country using an analytical hierarchical process (AHP) (Saaty, 1980). The obtained judgements thereby represent a qualitative assessment of each supplier country with regards to the 4A approach to energy (Affordability, Availability, Accessibility and Acceptability) (Kruyt, van Vuuren, H.J.M., & Groenenberg, 2009). Integrating these risk weights into the portfolio model allows for an impact analysis of shifting supply shares on specific risks of the portfolio.

Following this introduction, the paper follows the following structure: The second section outlines the data and methodology of the study. The third section contains the empirical results and their analysis. Possible diversification strategies are discussed in section four, while section five is the conclusion of the paper.

2 Methodology and data

2.1 Data

The analysis requires data on Germany's natural gas imports such as border crossing prices as well as market prices for available quantities of natural gas. The former, including details on the supplier portfolio available until 2015, is derived from Germany's federal office for economic affairs and import control (BAFA), published in €/TJ. The market price basket for the years 1999 to 2015 is compiled using data published on Quandl, a commercial data provider. Aggregate continuous futures data is used, in which a given date's settlement price corresponds to the price of a future contract for equal delivery throughout the following month (spot month). Monthly averages are formed of these daily settlement prices with no weight factor for trade volume. In the composition of the price basket the following fuel prices derived from Quandl are used as traded on the Intercontinental Exchange (ICE):

1) Brent Crude Futures
2) UK Natural Gas Futures (NBP)
3) Low Sulphur Gasoil Futures

Relative price changes of the above commodities are measured to their respective average price of January 1999. Nominal prices across this study are expressed in €/MWh, whereby unit conversions factors originate from the energy calculator of the Norwegian Petroleum Directorate (2019). Currency conversion is in accordance to data from the Pacific Exchange Rate Service operated by the University of British Columbia (The University of British Columbia, 2019).

2.2 Methodology

2.2.1 Market price basket for importable gas

Because of the inherent nature of natural gas pricing in Europe and the absence of a unified European gas market Germany's import prices cannot be directly compared to one particular market price. Rather, the price for natural gas has historically been linked to oil prices via long-term contracts (LTCs). Over a specified contract length the price is thereby proxied by relative price changes in replacement fuels such as heavy or light fuel oils as under the traditional Groningen formula (Konoplyanik A. , 2018). This study makes use of a modified basket price, whereby in the applied LTC pricing formula low sulphur gasoil futures represent light fuel oil, while Brent crude futures are used in the absence of sufficient data on heavy fuel oil futures. Between the years 2000 and 2015 pricing for imports of natural gas is becoming increasingly determined by spot gas and hub prices such as from the Title Transfer Facility (TTF) or the Natural Balancing Point (NBP) (IGU, 2018), mirrored by an increased usage of spot-indexation in applied contracts in the market (Equinor, 2018). UK natural gas futures therefore represent this increasingly important spot-price component in the applied LTC pricing formula of this study. Representativeness for German spot prices is given by high correlation, although declining after 2013, with newly-developing German hubs (Petrovich, 2014) and the British NBP showing the largest trade volume across all European gas hubs until 2016 (Heather and Petrovich, 2017).

The applied pricing formula consists of three components:

1. **Reference period**, number of months for which an average price of basket fuels is calculated: 6 months
2. **Lag period** between reference period and validity period: 3 months
3. **Validity period** of price application: 1 month

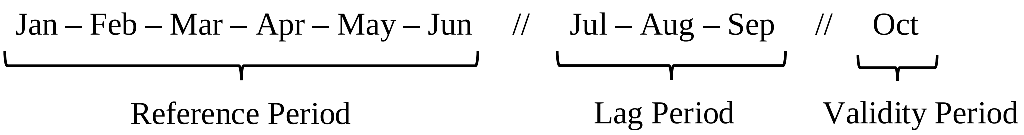

Figure 12: Example of the applied 6-3-1 price formula

The application of the LTC formula moves on a rolling basis, whereas the price for November is consequently determined by average prices of basket fuels for the months February, March, April, May June and July, with a lag period of August, September and October. While details on formulas applied in specific contracts are not accessible to the public, the applied formula was selected for goodness of fit (R^2) to German import prices. Corresponding to the mechanism of the chosen 6-3-1 formula other commonly used forms in contracting are 3-1-1, 6-1-1 or 6-3-3 (Müller, Hirsch, & Müller, 2015) (Konoplyanik A. , 2010).

The average price for January 1999 UK natural gas futures serves as a base price to which relative price changes of all basket fuels are applied. Thus, while indicative of relative price changes for importable gas quantities over time, the compiled price basket is rather inapt for a comparison of absolute price levels to Germany's border crossing prices in specific points in time. Particularly since 2012 a decoupling of gas and oil prices occurred, leading gas importers to demand larger degrees of indexation to gas hub prices in new and renegotiated contracts (Franza, 2014). The price basket for available gas is adjusted in its composition to the increase in gas-indexation and a growth of spot-traded gas (IGU, 2018). Changes in the evolving structure of the price basket (appendix C) are:

1. Increase in gas-on-gas competition and decrease in usage of LTCs
   i. 2000 – 2004: 100% LTC – 0% spot gas
   ii. 2005 – 2006: (Uniform shift)
   iii. 2007 – 2011: 80% LTC – 20% spot gas
   iv. 2012: (Uniform shift)
   v. 2013 – 2015: 50% LTC – 50% spot gas

2. Increasing level of gas-indexation and decreasing level oil-indexation in LTCs
   i. 2000 – 2010: 90% oil indexation – 10% gas indexation
   ii. 2011 – 2013: (Uniform shift)
   iii. 2014 and after: 50% oil indexation – 50% gas indexation

2.2.2 Diversification index

Because Germany is heavily dependent on imports of natural gas, the goal of an import policy should be a high degree of diversification. Through diversification and ideally an equal distribution of supply shares among all supplier countries the impact of a supply disruption from one particular country can be mitigated. To measure the effectiveness of supplier diversification in Germany's gas import portfolio an industry concentration index is used which modifies the original Hirschman-Herfindahl index by taking its square root (Hirschman-Herfindahl-Agiobenebo (HHA) concentration index) (Agiobenebo, 2004). Thus, the diversification index for Germany's natural gas imports (I_{div}) can be expressed as:

$$I_{div} = \sqrt{\sum_{i}^{n} S_i^2} \quad (1)$$

where S_i is the relative share of natural gas imports from country *i*. While first insights into diversification and thereby Germany's susceptibility to supply disruption can be obtained, the index falls short of providing a linkage between the level of diversification and experienced risks. Furthermore, Germany already shows fewer than two minutes of average supply disruption per end consumer between the 2006 and 2017 (Volk, 2018). Although potential disruptions would be to an extent compensated for by storage and an increase in supplies from other countries, it appears that a diversification index alone is insufficient in expressing the explicit risk contributions of diversification from the upstream market. The next section addresses the application of portfolio theory in order to derive a more germane measure for import risk.

2.2.3 Portfolio theory approach

Portfolio theory finds its typical application in a financial context where a set of more and less risky assets is to be examined for its integration in a portfolio. Transferring this theory to energy markets consequently allows for an examination of different choices of supply sources and the relationship between diversification and energy security risk (Lesbirel, 2004). Building on the understanding that import prices are capable of reflecting imbalances on both the supply- and the demand side and are therefore reflective of the risk of disruptions, the applied portfolio approach uses price variance as a measure for risk. Analysing the relationship between import- and market prices may further indicate whether the shift towards spot-indexation and exchange hub pricing has an effect on the risks of the overall import portfolio.

In the applied portfolio model (section 3.2.2) a principal distinction between *systematic* and *specific* risks is made. *Systematic* risks are thereby described as those risks which are fundamental to the underlying market. Because all suppliers in the market are affected by it, diversification of supply sources cannot reduce systematic risk, which is therefore oftentimes referred to as undiversifiable risk. A cold winter across Europe for instance could lead to an increase in gas demand and thus price increases across the whole European market. Because market prices of all suppliers are likely to be affected, diversification cannot mitigate systematic risk.

Specific risk on the other hand is risk inherent to a specific supply source for which diversification is effective in its mitigation. A supply disruption from a particular supply source for example could be the result from an accident or a politically-motivated supply stop. Because it is not impacting the behaviour of other supply sources and of the underlying market specific risk is also referred to as diversifiable risk (Lesbirel, 2004). Thus, the overall portfolio of Germany's natural gas imports encompasses both an unavoidable risk component due to market exposure and a specific risk component exclusive to the German import portfolio.

In order to generate a separation between systematic and specific risks, a model is specified formulating the relationship between Germany's border crossing prices and market prices for available natural gas. This model, which applies a logarithmic transformation of both price terms, yields:

$$\log[P_G] = \alpha + \beta \log[P_M] + \varepsilon \qquad (2)$$

where P_G is the monthly border crossing price of natural gas in €/MWh and P_M stands for the monthly market price of available gas in €/MWh. α and β are parameters and ε is the error expected to fulfil the traditional properties of a residuals term.

The model provides two basic insights into the relationship between Germany's market- and import prices. Firstly, to the degree of β import prices follow and are exposed to the development of market prices. In other words, the coefficient β describes the degree to which a percentage change in market prices (P_M) subsequently leads to a percentage change in the price for Germany's imports (P_G). Because of the expressed dependence of import prices on market prices β is a measure of systematic risks impacting all importers in the market. The error coefficient ε on the other hand is indicative of those risks unexplained by changes in the overall market price, thus specific risks. Large variations in the error term are indicative of risks inherent to Germany's import portfolio, because they describe an extent of price variation which cannot be explained by changes in market prices.

Because the modified market price applies a lagged price component, first order auto-correlation of the error term is corrected for by application of the Cochrane-Orcutt method (see Wooldridge (2013)). This approach yields:

$$\log[P_G]_t - \rho \log[P_G]_{t-1} = \alpha\,(1-\rho) + \beta(\log[P_M]_t - \rho \log[P_M]_{t-1}) + \varepsilon_t \qquad (3)$$

where ρ denotes the autocorrelation coefficient. A parameter estimation with equation (3) then allows for a risk statement of Germany's natural gas imports. Using import price variance as a measure for the risks of disruptions (Lesbirel, 2004) the aggregate risk of Germany's natural gas imports in year *t* is expressed as:

$$\sigma_{G_t}^2 = \beta^2 \sigma_{P_{Mt}}^2 + \sigma_{\varepsilon_t}^2 \qquad (4)$$

where $\sigma_{G_t}^2$ is the total risk of Germany's natural gas imports in year *t*. $\beta^2 \sigma_{P_{Mt}}^2$ provides a measure for systematic (non-diversifiable) risk, while $\sigma^2_{\varepsilon_t}$ provides a measure for specific (diversifiable) risks (error variance). $\sigma^2_{P_{Mt}}$ is the monthly variance in market prices in year t. Equation (4) states the total import risk as the sum of price variation explained by variance in market prices (systematic) and those variations which cannot be explained by movements in commodity markets (specific). To assess the impact of diversification equation (4) can be used to integrate the amount of imported gas quantities for a separate statement of both the systematic risks and specific risks of the portfolio. The systematic (undiversifiable) risk of the portfolio can be expressed as:

$$\sigma^2_{PG_t} = \sum_{i=1}^{n} \sum_{j=1}^{m} \sigma^2_{P_{Mt}} X^2_{ij} \beta^2 \qquad (5)$$

where $\sigma^2_{PG_t}$ is the systematic risk of the portfolio in year *t* and $\sigma^2_{P_{Mt}}$ is the monthly variance in the market price in year *t*. X_{ij} are import quantities from supply country *i* in month *j*, while β is the coefficient. Incorporating import quantities in the corresponding segment for specific risks in equation (4) yields the following statement for the specific (diversifiable) risk of the portfolio:

$$\sigma^2_{SG_t} = \sum_{i=1}^{n} x^2_i \sigma^2_{\varepsilon_t} \qquad (6)$$

where $\sigma^2_{SG_t}$ is the specific risk of the portfolio in year *t*, x_i are import quantities from supply country *i* and $\sigma^2_{\varepsilon_t}$ is the error variance in year *t*. In order to generate a better understanding of the risk contribution of each supplier country to the portfolio and the effectiveness of diversification in enhancing import security, an analysis of import quantities alone is insufficient. Equation (6) is therefore extended by a quantitative measure descriptive of the security risks of each supplier country. Determined through an analytical hierarchical process (AHP) (Saaty, 1980) these risk factors represent a subjective assessment of each supplier country's risk with regards to the 4A approach to energy security (Affordability, Availability, Accessibility and Acceptability) (Kruyt et al., 2009). Incorporating this risk factor in eqaution (6) brings the following statement for the specific risks of the import portfolio:

$$\sigma^2_{SG_t} = \sum_{i=1}^{n} w_i x^2_i \sigma^2_{\varepsilon_t} \qquad (7)$$

where w_i is the risk weight associated with supplier country *i*. In the period from 2000 to 2015 Germany's imports of natural gas grew from 796TWh to approximately 1190TWh (BAFA, 2019). Following equations (5) and (7) this import growth would subsequently lead to a growth in both systematic and specific risks of the portfolio. The appliance of growing absolute import quantities impedes the assessment of risk contribution of the parameters β, $\sigma_{P_{Mt}}^2$ and $\sigma_{\varepsilon_t}^2$. Therefore, absolute import terms in equations (5) and (7) are substituted by relative import shares. The index for systematic risk, I_{PG_t}, is expressed as:

$$I_{PG_t} = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{m} \sigma_{P_{Mt}}^2 S_{ij}^2 \beta^2} \tag{8}$$

where S_{ij} is the relative import share from supply country *i* in month *j*. Similarly substituting absolute import quantities by relative import shares the specific risk index of the portfolio can be written as:

$$I_{SG_t} = \sqrt{\sum_{i=1}^{n} w_i s_i^2 \sigma_{\varepsilon_t}^2} \tag{9}$$

where s_i is the relative import share from supply country *i* in year *t*.

3 Results and analysis

This section provides a presentation of the results to the methodologic approaches introduced in sections 2.2.2 and 2.2.3. Results of the diversification index are examined (section 3.1), before the analysis of market- and import prices (section 3.2.1) leads to the calculation of Germany's natural gas import risk by application of the portfolio model in section 3.2.2. The demonstration of risk components of the portfolio model contains an inspection of observable trends and a brief assessment of major incidents occurring over the timeframe of the analysis. Lastly, the results of the diversification index are combined with findings of the portfolio model to examine the historic relationship between supplier diversification and the specific risk index of the portfolio.

3.1 Diversification Index of Germany's natural gas imports

Figure 13 indicates only minor changes in the diversification index in the period from 2000 to 2015. While high values denote a low level of diversification and vice versa, a slight downward trend is visible and thus until 2015 a slightly higher degree of diversification is reached. This development can primarily be explained by a decline in Russian imports from 45.7% in the year 2000 to 34.6% in 2015 and a simultaneous rise in Norwegian imports from 26.7% to 34.1%. However, only a 1.9% improvement in the diversification index between 2000 and 2015 is observable, while 2015 97.5% of Germany's natural gas imports were sourced from the Netherlands, Norway and Russia (BAFA, 2019).

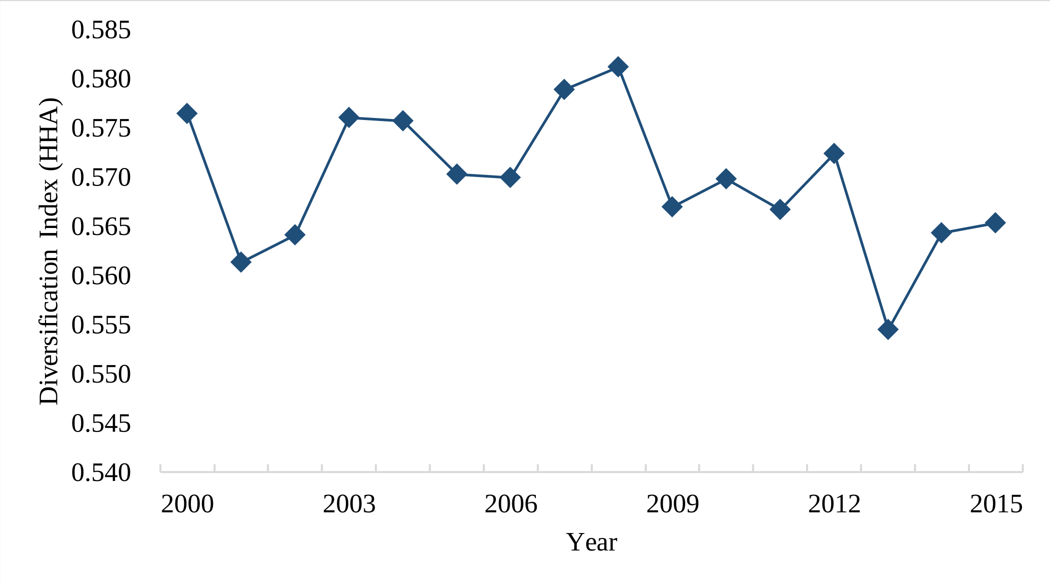

Figure 13: Diversification index of Germany's natural gas imports: 2000 – 2015

While minor their amplitude, the diversification index shows three main alterations. First a drop between 2000 and 2003, a rise between 2006 and 2009 and finally a relatively strong decline in 2013. The first two movements can largely be explained by shifts in relative contributions from Russia, while the decline from 2012 to 2013 is caused by a decline in Norwegian imports, falling from 35,3% to only 29,4% in 2013 (BAFA, 2019).

Germany names diversification in supply sources and transport routes as means of ensuring security in gas supplies (BMWi, 2019). However, as the analysis of the index indicates, between 2000 and 2015 only a marginal improvement in diversification is noticeable. Next, import shares are incorporated into the portfolio model to investigate whether this slight betterment in diversification can be linked to improved import security as measured by the portfolio model.

3.2 Germany's natural gas import risks

3.2.1 Relationship between Germany's import prices and market prices

Figure 14 indicates a close relationship between German import prices and the modelled market prices for natural gas. Because the applied LTC formula relates relative prices changes of all basket fuels to the average January 1999 price for UK natural gas futures (NBP), absolute values for market prices are rather inapt for a direct comparison to import prices. Sufficient for the analysis however is the measurement of relative price development as price variance serves as an indicator for risk.

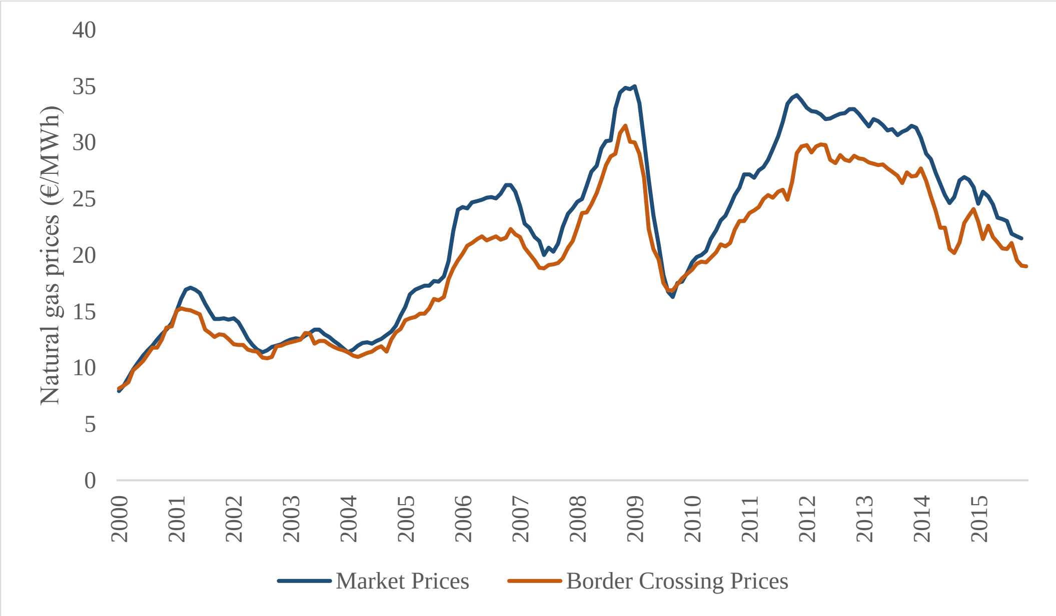

Figure 14: Germany's border crossing prices and market prices for natural gas 2000 – 2015

While oil-indexation was the primary determinant of German import prices until 2009, after the financial crisis and the decoupling of oil and spot-gas prices after 2012 (IGU, 2018) hub prices are becoming an increasingly significant driver of import prices (see section 2.2.1). Starting in 2005 rising prices are observable, before prices rapidly decline after reaching their highest point before the financial crisis of 2008. Recovery to almost pre-crisis levels by 2012 and the beginning decoupling of oil- and gas prices marks a period of falling prices until 2015, with a sharper decline in 2014.

The government of Germany acknowledges the importance of competitive energy prices and supply security for manifesting its role as a competitive industrial player (BMWi, 2010). Because prices are indicative of disruptions caused by either the supply or demand side the analysis of the relationship between market- and import prices can indicate the level of experienced import risks. Equation (2) describes the logarithmically-transformed relationship between market prices and border crossing prices to which results are presented in Table 1.

Table 1: Logarithmically-transformed regression, equation (2)

Parameter	Coefficient	Standard Error	t-value
Constant	0.1919	0.0256	7.49
β	0.9033	0.0084	107.25
ρ	0.5588		
Adjusted R-squared	0.9837		

Notes: ρ denotes the autocorrelation coefficient

Due to the nature of the applied LTC formula and the application of average prices within it (section 2.2.1), error terms of the logarithmically-transformed model are autocorrelative. For the purpose of correcting for first order autocorrelation the Cochrane-Orcutt method is applied (equation (3)). With parameter estimations from Table 1, the formula provides:

$$\log[P_G]_t - 0.5588\log[P_G]_{t-1} = 0.1919\,(1 - 0.5588) + 0.9033(\log[P_M]_t - 0.5588\log[P_M]_{t-1}) + \varepsilon_t \quad (10)$$

Table 2: Regression after the Cochrane-Orcutt transformation, equation (3)

Parameter	Coefficient	Standard Error	t-value
Constant	0.2695	0.0648	4.16
β	0.8775	0.0212	41.41

Adjusted R-squared after AR(1) correction	0.9057
F-statistic	1836.25
Durbin-Watson statistic	1.87
rho-value	0.7264
Breusch-Pagan test for heteroskedasticity (prob.)	0.8723

An adjusted R-square of 0.9057 suggests that over the period from 2000 to 2015 relevant market prices are indicative of import prices. The β-coefficient of 0.8775 indicates a high degree to which import prices follow the movement of market prices in case of price surges or price declines. Specifically, a one percent increase in market prices yields a 0.88% increase in import prices. A Durbin-Watson statistic of 1.87 and a rho-value of 0.7264 thereby indicate that autocorrelation of the first order is appropriately resolved in the adjusted model.

3.2.2 Calculating Germany's natural gas import risk

As indicated in section 2.2.3 through an analytical hierarchical process (AHP) risk weights for all four supplier countries are generated. Details about the process are provided in appendix D. Corresponding to the 4A approach to energy security (Kruyt et al., 2009) the following assessment of each supplier country is provided:

Table 3: Risk coefficient w_i for supplier countries (appendix D)

Country	Netherlands	Russia	Norway	*Other*
w_i	0.23	0.31	0.14	0.32

Implementing these risk coefficients into equations (5) and (7) then allows for the assessment of systematic and specific risks of the portfolio. The aggregate results of the analysis are presented in Table 4.

Table 4: The risks of Germany's natural gas imports 2000 – 2015

Year	Gas imports (TWh)	$\sigma^2_{P_{Mt}}$ Price variance	$\sigma^2_{\varepsilon t}$ Error variance	σ_{PG_t} Systematic risk (a)	σ_{SG_t} Specific risk (b)	Portfolio risk (a + b)	I_{PG_t} Systematic risk index	I_{SG_t} Specific risk index
2000	789.4	3.93	0.10	235.79	75.26	311.04	3.59	0.09
2001	819.8	1.29	0.37	135.93	141.56	277.49	1.98	0.17
2002	851	0.96	0.36	122.93	137.75	260.68	1.72	0.17
2003	885.4	0.25	0.14	66.09	90.02	156.10	0.89	0.11
2004	941.6	0.84	0.11	128.97	83.89	212.86	1.64	0.09
2005	950.2	6.05	0.32	344.98	152.23	497.21	4.33	0.16
2006	977.5	0.43	0.12	95.44	92.38	187.82	1.15	0.10
2007	923.2	2.22	0.16	205.77	110.16	315.93	2.66	0.11
2008	966.8	14.01	0.46	542.75	179.32	722.08	6.71	0.19
2009	986.5	46.36	0.72	990.28	235.92	1226.21	11.90	0.23
2010	1.036.4	6.85	0.44	401.91	176.38	578.28	4.59	0.18
2011	1.010.4	8.38	1.86	433.17	389.14	822.30	5.06	0.37
2012	1.012.4	0.10	0.42	47.31	180.23	227.54	0.56	0.18
2013	1.040.2	0.19	0.21	63.89	128.36	192.24	0.74	0.13
2014	1.001.3	2.86	1.57	246.70	356.59	603.29	2.93	0.34
2015	1.189.8	2.39	0.48	265.21	190.59	455.81	2.67	0.19

Figure 15 illustrates the development of systematic and specific risks as well as of the overall portfolio risk. While over the period from 2000 to 2015 an overall increase in portfolio risk is observable, specific risks contributed an average of 38.6% of the total portfolio risk. The development of portfolio risk can be separated into two periods of equal 8-year length. Firstly, a period of moderate risk stretching from the year 2000 to 2007 and a second phase characterised by higher volatility between 2008 and 2015. The first period from 2000 to 2007 is characterised by a steady growth in natural gas imports of about 17%, increasing from 789TWh in 2000 to 923TWh in 2007. Absolute contributions from Russia and the Netherlands during the same timeframe show only little variation while Norwegian imports increase by about 37% in absolute terms (289.1TWh in 2007). A spike in portfolio risk in 2005 can thereby be related to surges in both import- and market prices during 2005. While from January to December market prices grew by about 56%, border crossing prices show an increase of about 38% (19.5€/MWh in December 2005), leading to a rise in portfolio risk.

The second period between 2008 and 2015 is characterised by higher levels of portfolio risks and imports during this period increased by 23% to a peak of approximately 1190TWh in 2015. Three points of high volatility (2009, 2011 and 2014) can be recognised, while market price variation linked to the financial crisis and subsequently high systematic risk can be identified as the main driver of the highest observed level of portfolio risk in 2009. Whereas the average market price for importable quantities was about 35€/MWh in January 2009, prices reduced to around 16.3€/MWh in September of the same year. Showing only little variation in suppliers' contributions and reduced market price variances compared to 2009, spikes of the portfolio risk in 2011 and 2014 can to a larger extent be attributed to high specific risks. Whereas the monthly error variance in 2011 was about 1.86 it amounted to 1.57 in 2014. Thus, experiencing only minor changes in distribution of absolute imports, price variation appears to be the main driver of portfolio risk.

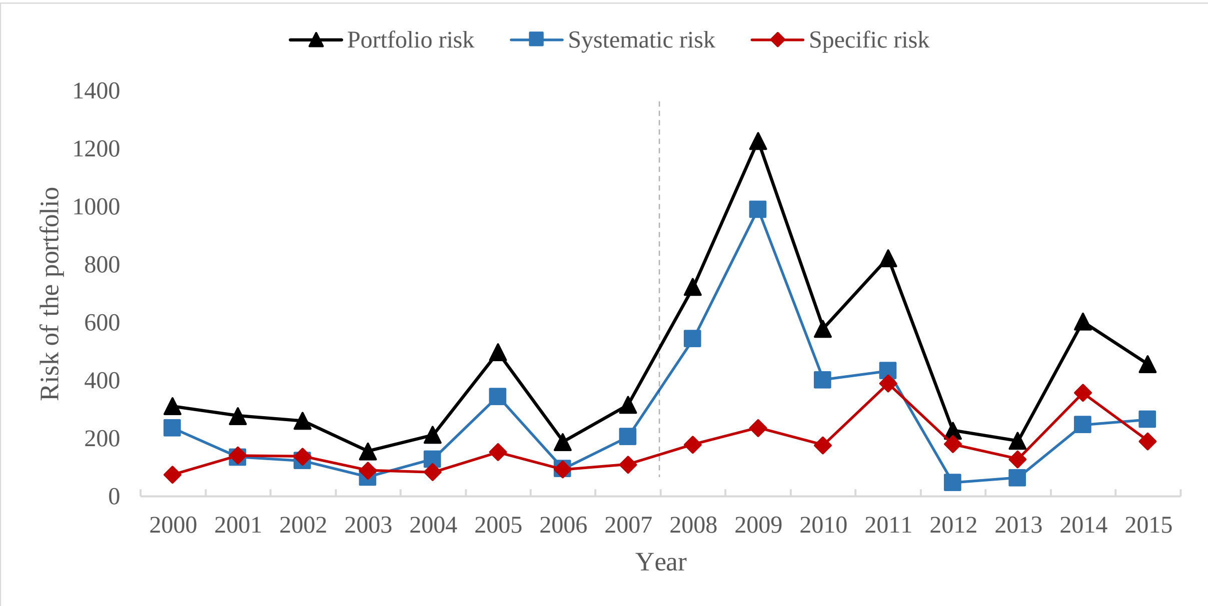

Figure 15: The systematic risk, the specific risk and the total portfolio risk

Because the equations for systematic- and specific risks (5) and (7) incorporate squared absolute import measures, increasing import quantities over the timeframe of the analysis overstate the systematic and specific risks of the portfolio. For a more precise measurement of the effect of changing import diversification and of price variation relative import terms are applied in the analysis of the systematic and specific risk index (equations (8) and (9)). Figure 16 shows the systematic and specific risk index of the portfolio. It can be noted that throughout the timeframe of the analysis the systematic risk index shows significantly higher values than the specific risk index. Over the timeframe from 2000 to 2015 no clear trend in the systematic risk index is observable, while a spike in 2005 and high values 2008 and 2009 stand out.

The systematic risk index decreases from 2000 to 2003 as a result of continuously declining oil prices brought upon by OPEC’s policy of periodic production increases (IMF, 2000). Because of oil-indexation in the pricing of natural gas, sharply-rising oil prices in 2005 consequently lead to increases in the systematic risk index of the portfolio. Linked to the price development of oil products modelled market prices for gas rose from 15.4€/MWh in January 2005 to about 24€/MWh in December the same year, equivalating an increase of around 56%. Oil prices thereby appear to be driven by production shortages as a result of hurricane Katrina in August 2005 and decreases in oil production due to the on-going war in Iraq.

High values in the systematic risk index of 2008 and 2009 indicated by Figure 16 can likewise be attributed to high variation in oil prices. While Brent crude prices peaked with an average price of 133$/barrel in July 2008, these prices – because of the lagged-character of the LTC gas formula – translate to subsequent gas price peaks in January 2009 with a price of about 35€/MWh. Lastly, the rapid price decline after 2009 driving the systematic risk index can attributed to the on-setting recession and consequently lower market demand. Relevant gas market prices for Germany here show a sharp decline of about 53% from January to September 2009 (16.3€/MWh).

It appears that high volatility of oil and gas prices in the period from 2000 to 2015 leads to high values for the systematic risk index of the German natural gas import portfolio. The demise of oil-indexation in gas pricing thereby coincides with a lower systematic risk index after 2011. Because relative supply diversification is limited over the analysis timeframe (section 3.1), market price volatility can be identified as the main driver of the systematic risk index.

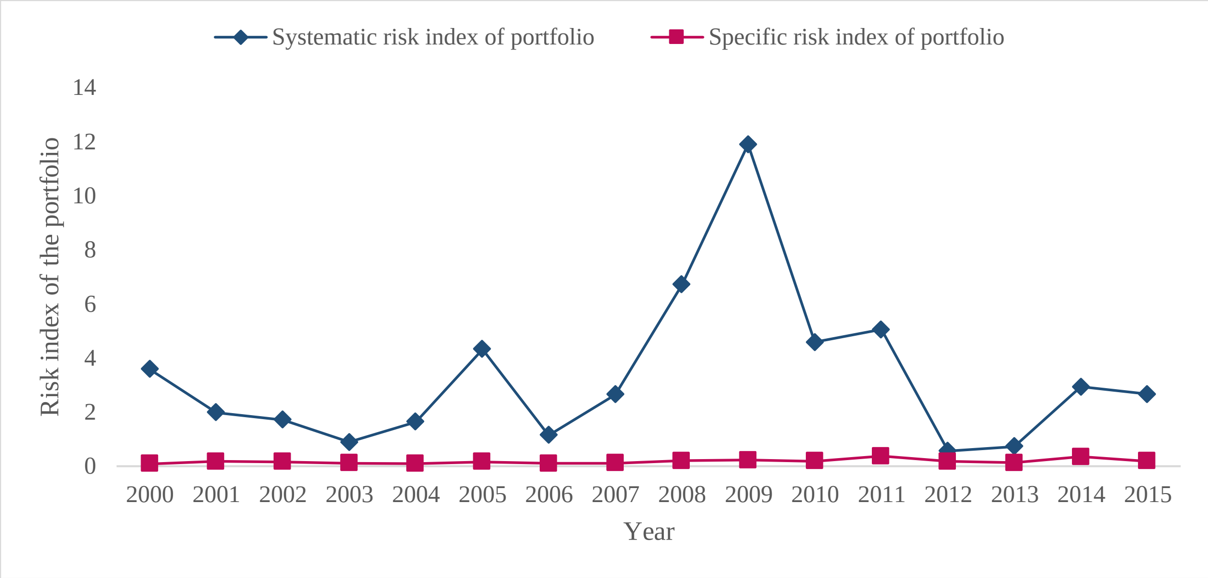

Figure 16: The systematic and specific risk index of the portfolio

The analysis of the specific risk index of the portfolio (Figure 17) indicates a moderate upward trend. Between 2000 and 2010 only little variation in the specific risk index is present, meaning that variation in import prices and thereby the risk of disruption is largely explained by variation in market prices. The third highest value of the specific risk index in 2009 represents an additional risk element unexplained by already high market price variance surrounding the financial crisis. The additional risk can thereby be linked to a gas dispute between Russia and Ukraine, when for several days in January 2009 Russian gas supplies to the EU were cut off. Although Germany entertains gas storage facilities to secure supplies for disruptions of several weeks, supply disruptions to neighbouring countries in conjunction with large dependence on Russian supplies (38% in 2009) provided for an additional risk element.

The highest point in the specific risk index (Figure 17) in 2011 can be attributed to combined effects of developments both in Germany and abroad. As a response to the Fukushima accident elven German nuclear power plants were shut-off in 2011 leading to an additional demand surge for other energy commodities such as gas. Simultaneously however, the Arab spring led to oil and gas supply disruptions from Libya to Europe affecting international markets (Rühl and Giljum, 2012). The swift shutdown of nuclear power plants appears to have led to additional risk exposure as indicated by the specific risk index.

Lastly, the magnitude of the specific risk index in 2014 marks yet another gas transit dispute between Russia and Ukraine, which not only saw cut-offs to Ukraine and Poland but also unexpectedly yet only slightly reduced quantities to some importers in Germany. Because of a large dependence on Russian imports (39% in 2014) the Russian-Ukrainian dispute led to additional risk in the German import portfolio exogenous of systematic risk.

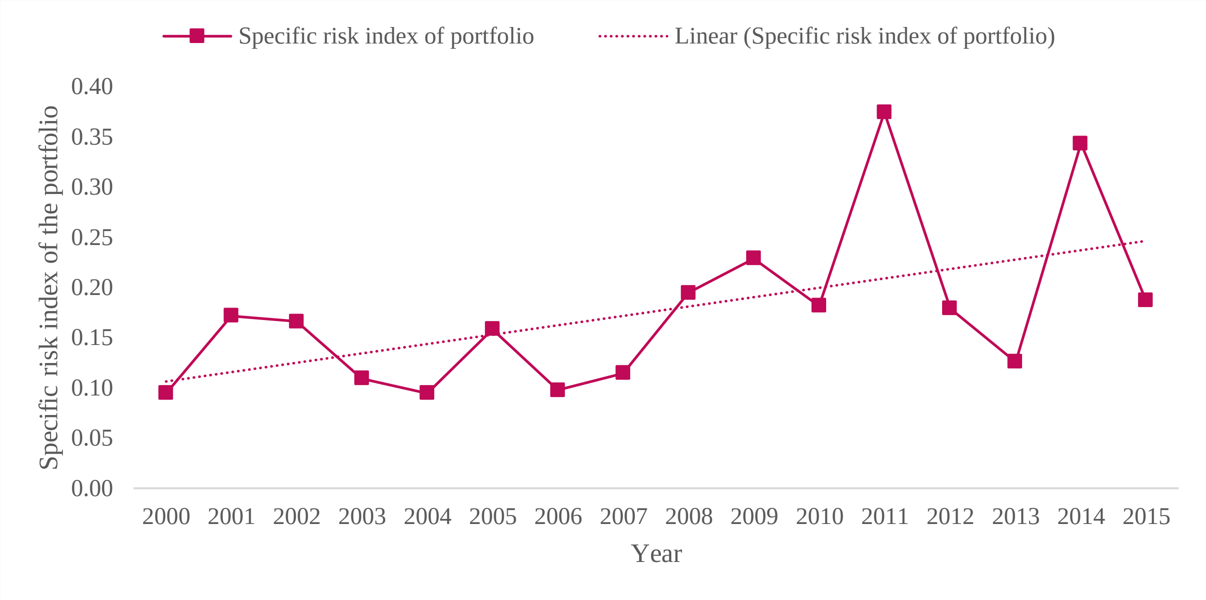

Figure 17: The specific risk index of the portfolio

Based on the results in Table 4, Figure 18 indicates no positive relationship between improved diversification and lower specific risks of the portfolio. On the contrary, the observable data provides for a relationship in which increased diversification (smaller index values) is associated with higher values for the specific risk index. Thus, while diversification has the potential of reducing risks of the import portfolio, the experienced 1.9% improvement in diversification over the period from 2000 to 2015 is insufficient in providing for an observable linkage between improved diversification and reduced risks. Therefore, by applying sensitivity analysis it is examined to which extent greater hypothetical levels of diversification can mitigate Germany's natural gas import risks.

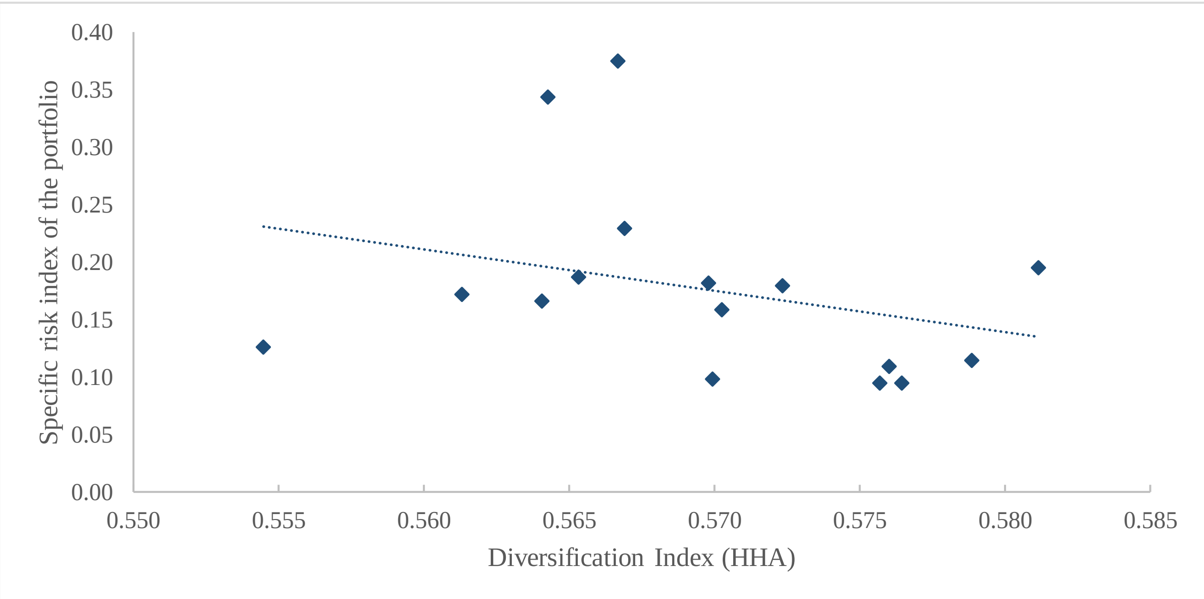

Figure 18: Relationship between diversification index (HHA) and specific risk index, yearly plots

4 Discussion

Over the period from 2000 to 2015 Russia has been the largest contributor of natural gas to Germany with contributions ranging from a minimum of 34.6% in 2015 to a maximum of 45.7% in 2000. Combining official import numbers for 2018 however with Gazprom's export statistics, suggests that Russian imports to Germany in 2018 could have amounted to a record level of about 53% (BAFA, 2019) (Gazprom Export LLC, 2019). Because policy makers are debating over the effectiveness of diversification strategies in mitigating import risks, the effect of diversification on the specific risk index is discussed by applying sensitivity analysis. Three possible scenarios are analysed:

1) **15%-point decrease in Russian supply share and proportionate substitution**
   Russian imports of a 53% share would mean an increase of approximately 15 percent points towards their average level between 2009 and 2015. Conversely, how much of a reduction in the specific risk index can be obtained, had Russian imports been 15 percent points lower in every year and distributed among existing suppliers according to their contribution weight in the original portfolio? The results indicate an average improvement in the specific risk index of about 10.2% (Table A.1). A proportionate reduction of Russian imports appears to have significant benefits for the specific risks of the portfolio.

2) **15%-point decrease in Russian supply share and substitution by one country only**
   Assuming a decrease of Russian imports by 15 percent points in every year, how would specific risks be impacted if only a single supplier compensated for the reduction?

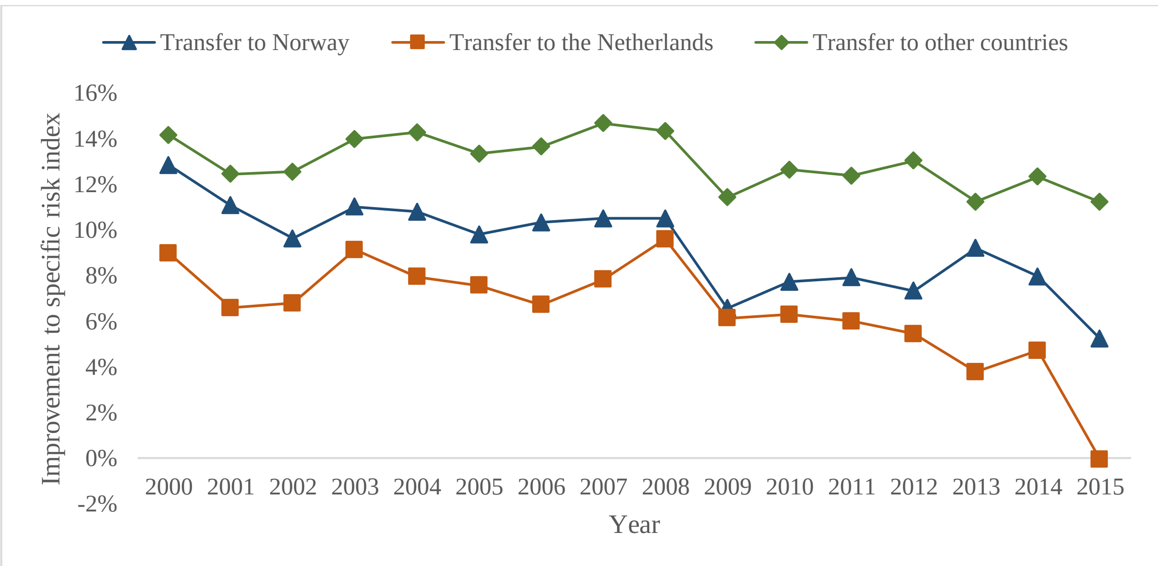

Figure 19: Compensation for a 15%-point decrease in Russian supplies by a single country: Effect on specific risk index

Table A.3 and Figure 19 show the effectiveness of this diversification strategy, whereby results vary according to every country's multiplicative assessment of risk weight (w_i) and relative supply share S_{ij}^2. The largest decrease in the specific portfolio risk can thereby be reached by import substitution from *other* countries (13%), followed by substitution from Norway (9.3%) and lastly by substitution from the Netherlands (6.5%). *Other* countries thereby denote both those suppliers already making minor yet unascertained contributions to the import portfolio, as well as likely future contributors.

It is already noteworthy that a focus on *other* supplier countries yields a greater improvement to the specific risk index (13%) than proportionate substitution in scenario 1 (10.2%). Furthermore, substitution by Norway alone would yield an only about one percent smaller contribution (9.3%) (scenario 2) than proportionate substitution by all suppliers (10.2%) (scenario 1). Although Norway is already a substantial contributor to the German gas import portfolio (average supply share of 31.6%), it appears that the country's favourable risk weight assessment (w_i) allows an even greater import share to bring reductions in specific portfolio risks. Therefore, especially if new supply routes are not available substitution should occur in those countries providing for the most favourable risk assessment.

3) **Equal 25% supply share of all existent suppliers**

By virtue of the diversification index of equation (1) a maximum level of diversification would imply an equal contribution share of all supplier countries. All else being equal, how might the specific risk index be impacted, if every supplier equally contributed 25% of total imports in every year? Figure 20 shows the result of this strategy. The result (Table A.2) indicates an average reduction in the specific risk index of about 10.7%.

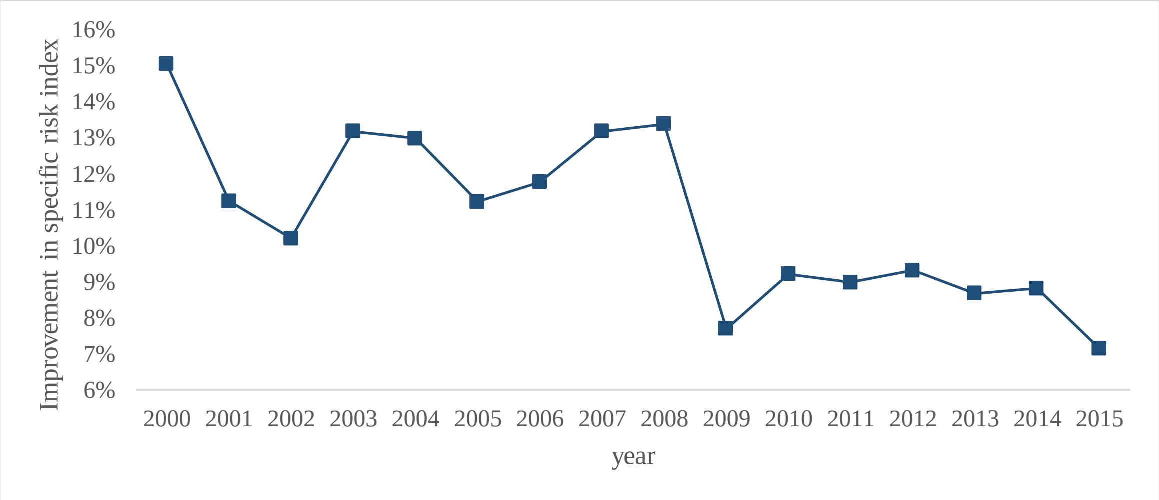

Figure 20: 25% supply share for every gas supplier: Improvement in specific risk index

Thus, of the assessed diversification strategies not equally distributed imports (10.7%) (scenario 3) yield the greatest reduction in specific risks, but rather a shift of 15 percent points of Russian contributions to *other* supplier countries (13%) (scenario 2). In other words, such strategy appears to be superior, in which only 15 percent points of Russian imports are diversified towards *other* supply sources and supplies from Norway and the Netherlands retain an original average of 31.6% and 22.8% contribution respectively as opposed to 25% each under scenario 3. Over the timeframe of the analysis the effectiveness of all analysed diversification strategies decreases due to the diminishing share of initially overrepresented Russian imports and decreasing marginal utility of diversification (Table A.1). Assuming however a return of Russian supplies beyond 50% and transferability of the historic relationship between prices and import risks to the future, the effect of diversification is likely to exceed the presented effects on the existing portfolio.

Figure 21 shows the improvement in the specific risk index assuming a decrease of Russian imports by 15 percent points and a substitution by *other* supplier countries. Whether improvements to the specific risk index beyond 13% are be attainable will depend on the availability of potential supplier routes and their individual risk assessment. Because of the significance of risk weights in assessing suppliers' potential for portfolio risk reduction, risks of new supply sources will have to be compared against existing contributors to the portfolio, while the possibility of LNG imports could require the development of new assessment criteria.

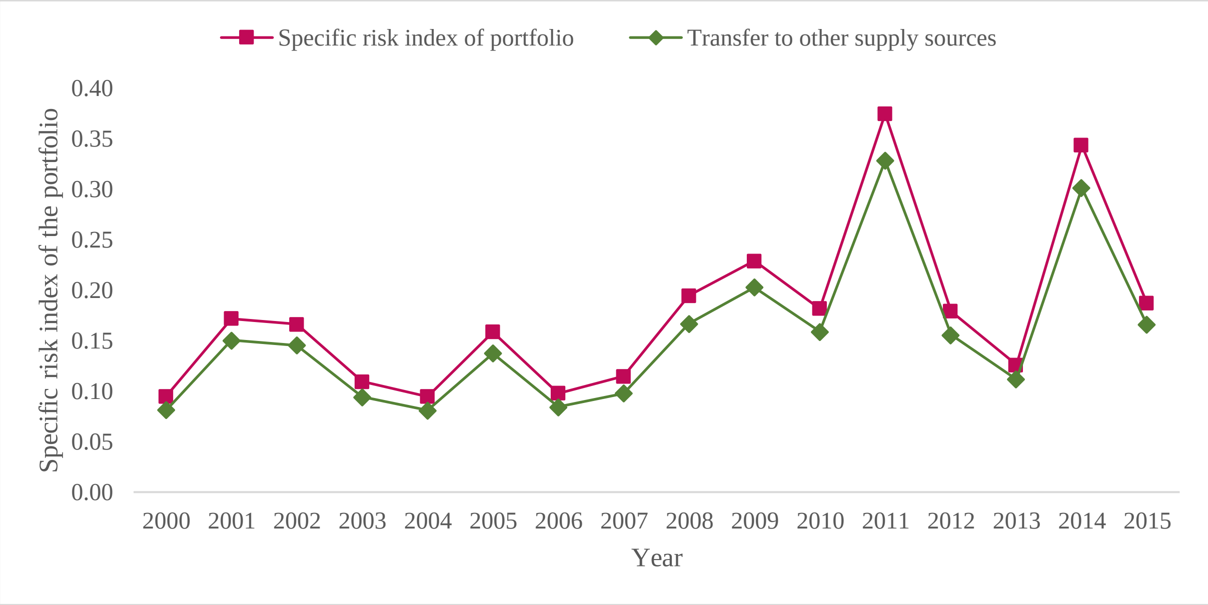

Figure 21: A 15 percent point transfer of Russian supplies to other supply sources: The impact on the systematic risk index

The degree to which diversification strategies can alter the specific risk of the portfolio is dependent on the assigned risk weights (Table 3 and appendix D). With the assigned relative risk weight for each supplier country a maximum reduction in the specific risk index of the portfolio of 15.4% is attainable. Such reduction in specific risks would hypothetically assume a constant supply share from every supplier country for every year between 2000 and 2015. This maximum reduction in specific risks would require Russian import shares to amount to 18.3%, Norwegian imports to 39.8%, Dutch supplies to 24.4% and supplies from *other* supply sources to 17.5%.

While the potential of a set of strategies for diversification of Russian imports has been identified, the need for diversification is further fuelled through the phase-out of the Groningen field and subsequently reduced supplies from the Netherlands in the future (van 't Hof, 2018). Infrastructure needs and financing requirements however serve as barriers to a swift change in supply architecture. Nevertheless, new supplier routes are identified such as the southern gas corridor which allows for gas imports from the Caspian Sea region. Today already allowing the transport of gas from Azerbaijan via the trans Adriatic pipeline (TAP), contributions from this supplier route could later be extended by the connection of gas fields in Turkmenistan and Iran (Lenzen, 2018). However, an assessment of risks inherent to new supplier routes is required to determine their potential in mitigating portfolio risk. Besides traditional imports via pipelines, the government of Germany regards LNG supplies as a step towards import diversification (BMWi, 2019). In light of projects such as Nord Stream II however, the potential of LNG will depend on a weighing of economic against political risks.

Lastly, over the timeframe of the analysis higher specific risks coincide with the demise in oil-indexation and an increasing gas spot price component in the constitution of gas market prices. Figure 22 shows yearly plots of the relationship between the degree of oil-indexation in market prices and the specific risk index. It appears that over the timeframe of the analysis lower degrees of oil-indexation and conversely higher spot price components are associated with higher specific risks. Research suggests that volatility of gas prices substantially exceeds volatility of crude oil prices by a factor of 1.5 (Alterman, 2012) and that the benefit of long-term contracts lies in the potential of supporting large scale investments and hedging against spot price volatility (Cervigni and Borbála, 2018). Without knowledge of the distinct mechanism of specific German import contracts it can hardly be assessed however, whether higher degrees of oil-indexation would have yielded a different price behaviour and thus a different risk level in years of higher observed risks.

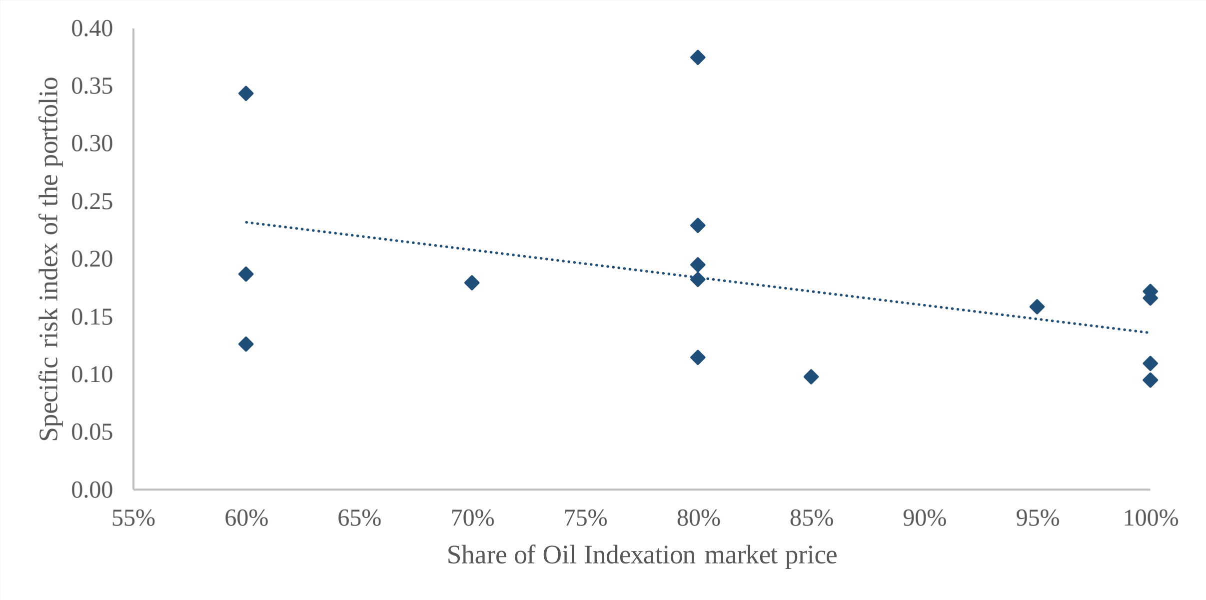

Figure 22: Relationship between oil-indexation and specific risks, yearly plots

5 Conclusion

This paper applies a portfolio model to assess the risks of Germany's natural gas imports and the effectiveness of a set of diversification strategies. By establishing the relationship between modified market prices and import prices systematic and specific risks of the import portfolio are isolated and assessed. Although changing in their composition due to the demise of oil-indexation, modified market prices are highly representative of Germany's import prices. Therefore, while systematic risks outweigh specific risks, the risk of the portfolio follows price surges representative of market disruptions. Particularly high systematic risks are observable in 2009, linked to price developments surrounding the financial crisis and the Russian-Ukraine gas dispute. Slightly increasing specific risks of the portfolio show great amplitude in 2011, when the shut-down of eleven nuclear power plants as a response to the Fukushima accident coincided with oil and gas supply disruptions to Europe as a consequence of the Arab spring and also in 2014, in connection with yet another Russian-Ukrainian gas dispute.

While supplier diversification can reduce the risk of supply disruptions, historical improvements in diversification of only 1.9% between 2000 and 2015 are not linked to lower specific risks of the import portfolio. Through sensitivity analysis hypothetical changes to suppliers' import shares are applied in order to assess the contribution potential of higher diversification levels in the reduction of import risks. The study finds that a reduction of Russian natural gas imports by 15 percent points in every between 2000 and 2015 and substitution by *other* countries yields a reduction in specific risks of about 13%. Furthermore, a 15 percent point substitution of Russian imports solely by Norwegian imports yields a reduction of about 9.3%, pointing towards the significance of identifying secure supply routes in case of limited diversification availability. The potential of diversification in import risk mitigation depends on risk weights assigned to supplier countries and a weighing of the assessment criteria. With the assigned weights a maximum reduction in specific risks of 15.4% is attainable, which in every year between 2000 and 20015 assumes the supply share from Russia to amount to 18.3%, Norwegian imports to 39.8%, Dutch supplies to 24.4% and supplies from *other* supply sources to 17.5%.

Although import contracts between exporters and importers of natural gas are substance of private business operations, national legislation has the potential of steering the diversification process by offering companies suitable financial incentives. These could be directed at investment financing of pipeline projects which are in accordance with national diversification goals. Because of a decreasing marginal utility of diversification close attention is to be paid to the risks of potential supplier countries. Further research may be pointed at the inclusion of new supplier prospects and LNG imports, while the analysis of this study focuses on diversification among the existing supplier set. Supplier countries could thereby be evaluated by other than the applied criteria of the 4A of energy security but rather by a narrower focus of accessibility and transit risk.

Because this work indicates an association between higher specific risks and lower levels of oil-indexation, further analysis of the relationship between natural gas pricing and import risk is suggested. Thereby pricing formulas different from the applied 6-3-1 indexation formula can be tested in the modelling of historical market prices. Presuming data availability, a focus on the developments after 2015 however should incorporate the price development of the increasingly-important German hubs Gaspool and NetConnect. Lastly, taking into account growing interconnectivity in the European gas market, a broader scope can be used to assess gas import security on a European level.

Acknowledgements

I would like to thank my supervisor Terje Andreas Mathisen for his guidance and support in the process of this work. I would also like to express my gratitude for the education I was able to receive at Nord University and MGIMO, for which I am especially thankful to Elena Dybtsyna, Petter Nore and many other professors at both institutions.

Appendix A: Discussion tables and figures

Table A.1: Proportionate distribution of 15 percent points of Russian imports in every year: The impact on specific risks

Year	Original I_{SG_t}	Improved $I_{SG_t}*$	% Change
2000	0.095	0.082	13.2%
2001	0.172	0.152	11.3%
2002	0.166	0.148	10.7%
2003	0.109	0.096	12.3%
2004	0.095	0.084	11.6%
2005	0.158	0.141	11.0%
2006	0.098	0.087	10.8%
2007	0.115	0.102	11.3%
2008	0.195	0.171	12.1%
2009	0.229	0.209	8.6%
2010	0.182	0.165	9.3%
2011	0.374	0.340	9.3%
2012	0.179	0.164	8.6%
2013	0.126	0.115	9.0%
2014	0.343	0.313	8.7%
2015	0.187	0.178	4.8%
Average Contribution			10.2%

Table A.2: Distribution of 15 percent points of Russian imports in every year to one particular supplier country: The impact on specific risks

Year	Original I_{SG_t}	Transfer to *Other* $I_{SG_t}*$	Transfer to Norway $I_{SG_t}*$	Transfer to Netherlands $I_{SG_t}*$	% *Other*	% Norway	% Nether-lands
2000	0.095	0.081	0.083	0.086	14.1%	12.8%	9.0%
2001	0.172	0.150	0.153	0.160	12.4%	11.1%	6.6%
2002	0.166	0.145	0.150	0.155	12.5%	9.6%	6.8%
2003	0.109	0.094	0.097	0.099	14.0%	11.0%	9.1%
2004	0.095	0.081	0.084	0.087	14.3%	10.8%	7.9%
2005	0.158	0.137	0.143	0.146	13.3%	9.8%	7.6%
2006	0.098	0.084	0.088	0.091	13.6%	10.3%	6.7%
2007	0.115	0.098	0.102	0.106	14.7%	10.5%	7.8%
2008	0.195	0.167	0.174	0.176	14.3%	10.5%	9.6%
2009	0.229	0.203	0.214	0.215	11.4%	6.6%	6.1%
2010	0.182	0.159	0.168	0.170	12.6%	7.7%	6.3%
2011	0.374	0.328	0.345	0.352	12.4%	7.9%	6.0%
2012	0.179	0.156	0.166	0.169	13.0%	7.3%	5.4%
2013	0.126	0.112	0.114	0.121	11.2%	9.2%	3.8%
2014	0.343	0.301	0.316	0.327	12.3%	8.0%	4.7%
2015	0.187	0.166	0.177	0.187	11.2%	5.2%	-0.1%
Average Contribution					13.0%	9.3%	6.5%

Table A.3: 25% contribution of every supplier country to the import portfolio: The impact on the specific risk index

Year	Original I_{SG_t}	Improved $I_{SG_t}*$	% Change
2000	0.095	0.081	15.0%
2001	0.172	0.152	11.2%
2002	0.166	0.149	10.2%
2003	0.109	0.095	13.2%
2004	0.095	0.082	13.0%
2005	0.158	0.141	11.2%
2006	0.098	0.086	11.8%
2007	0.115	0.099	13.2%
2008	0.195	0.169	13.4%
2009	0.229	0.211	7.7%
2010	0.182	0.165	9.2%
2011	0.374	0.341	9.0%
2012	0.179	0.162	9.3%
2013	0.126	0.115	8.7%
2014	0.343	0.313	8.8%
2015	0.187	0.174	7.2%
Average Contribution			10.7%

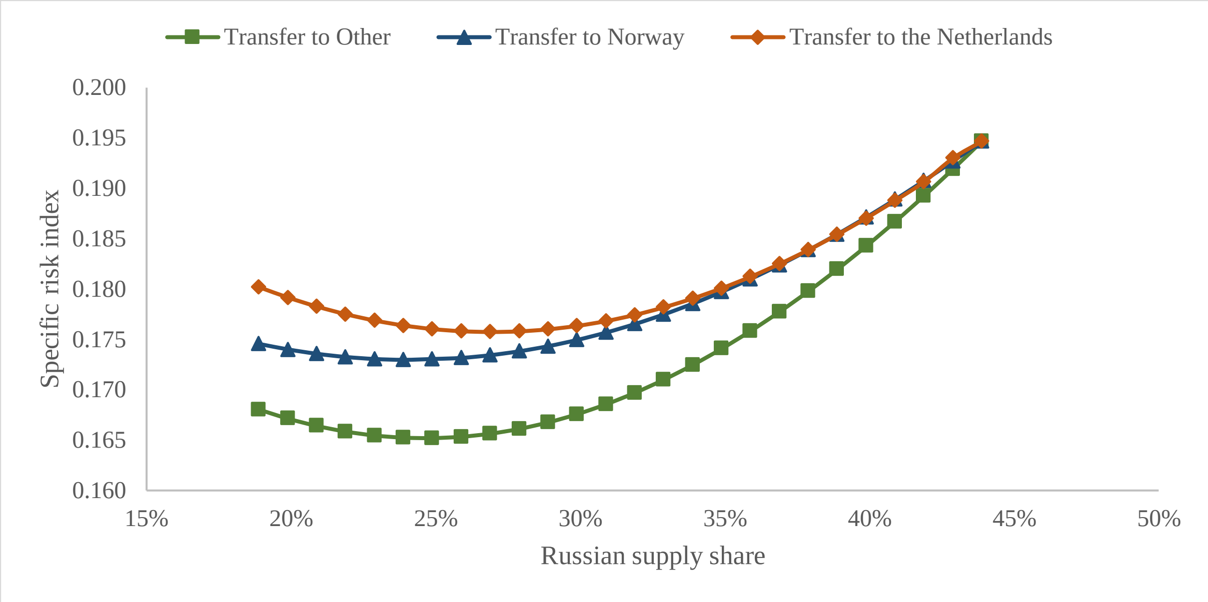

Figure A.1: Decreasing marginal utility of a step-by-step 1 percent point transfer from Russia solely to one supplier: 2008

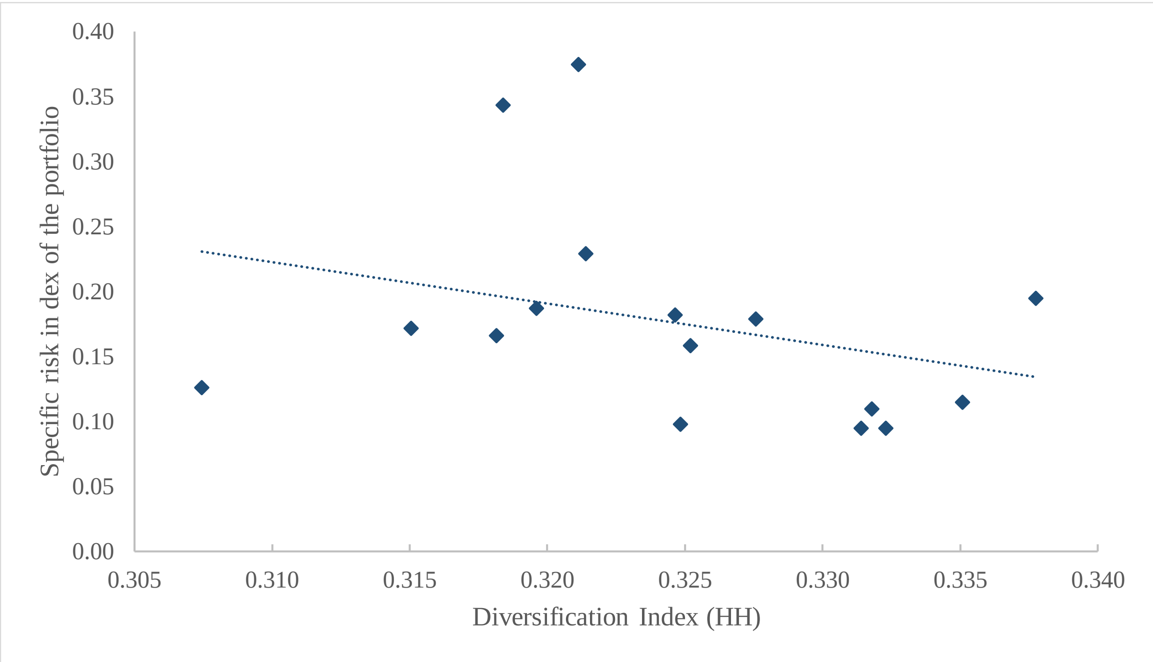

Figure A.2: Relationship between diversification index (HH) and specific risk index, yearly plots

Appendix B: Figures on Germany's natural gas imports

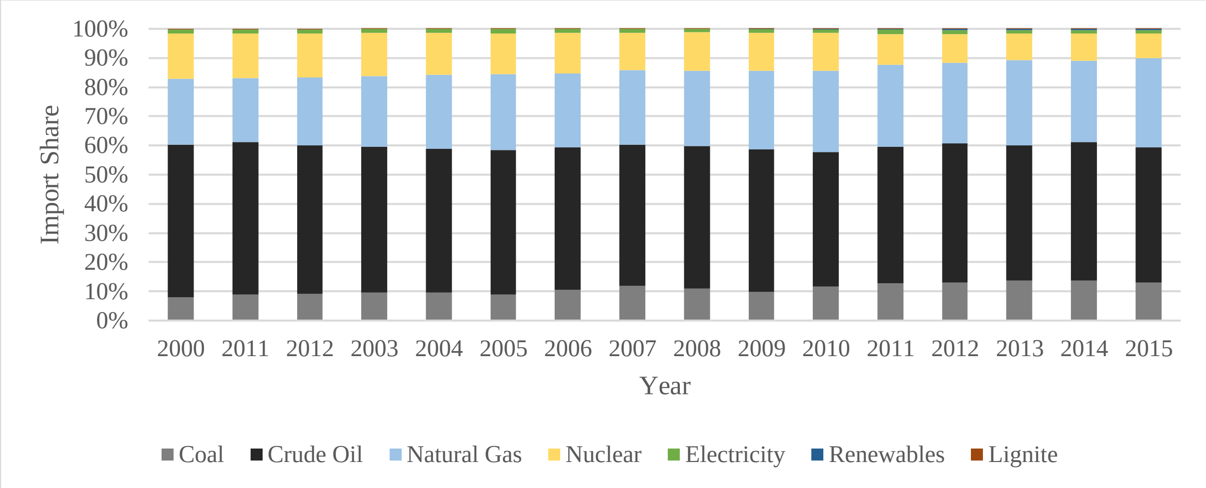

Figure B.1: Gross imports of energy sources to Germany: 2000 – 2015 (AGEB, 2018)

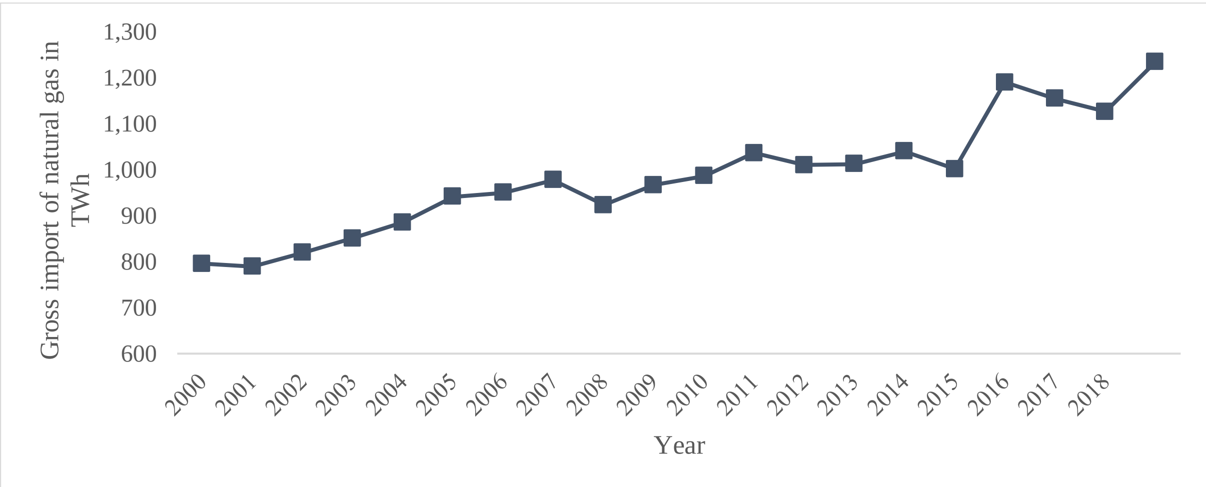

Figure B.2: Annual gas imports to Germany in million TJ: 2000 – 2018 (BAFA, 2019)

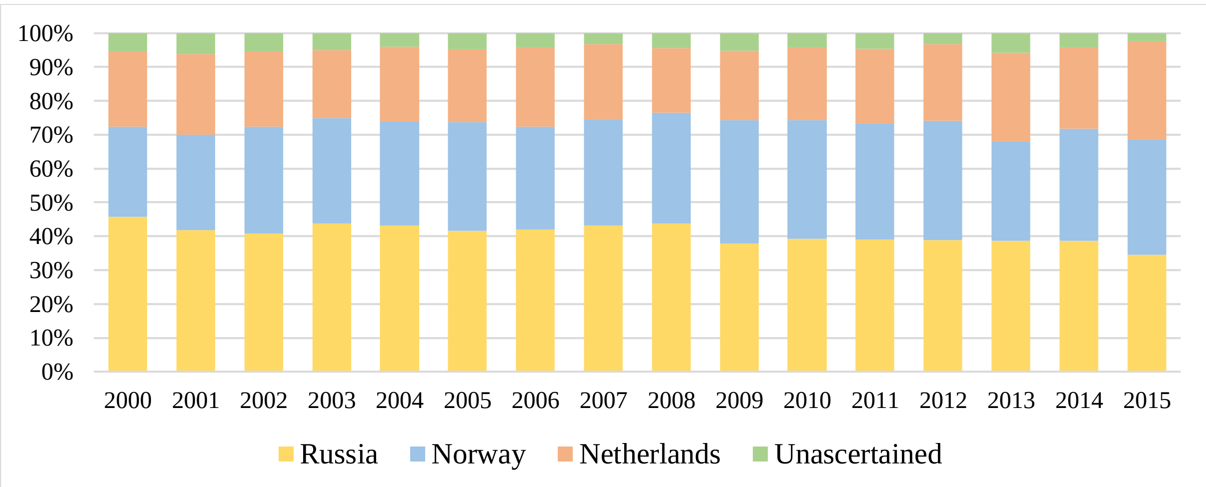

Figure B.3: Share of Imports in Germany's natural gas import portfolio: 2000 – 2015 (BAFA, 2019)

Appendix C: Figures on the computation of market price basket

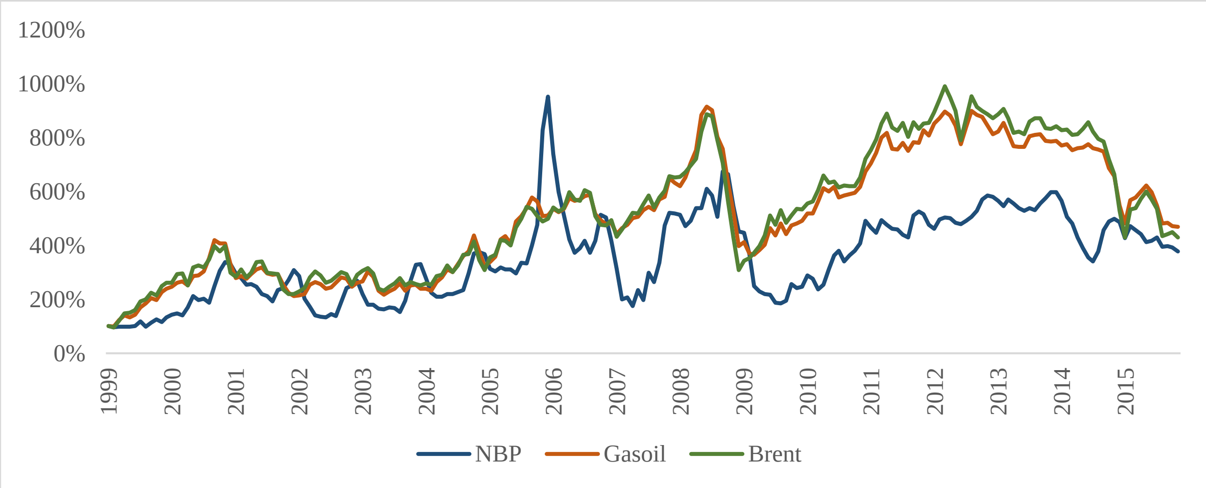

Figure C.1: Price development of continuous future contracts relative to respective January 1999 average prices

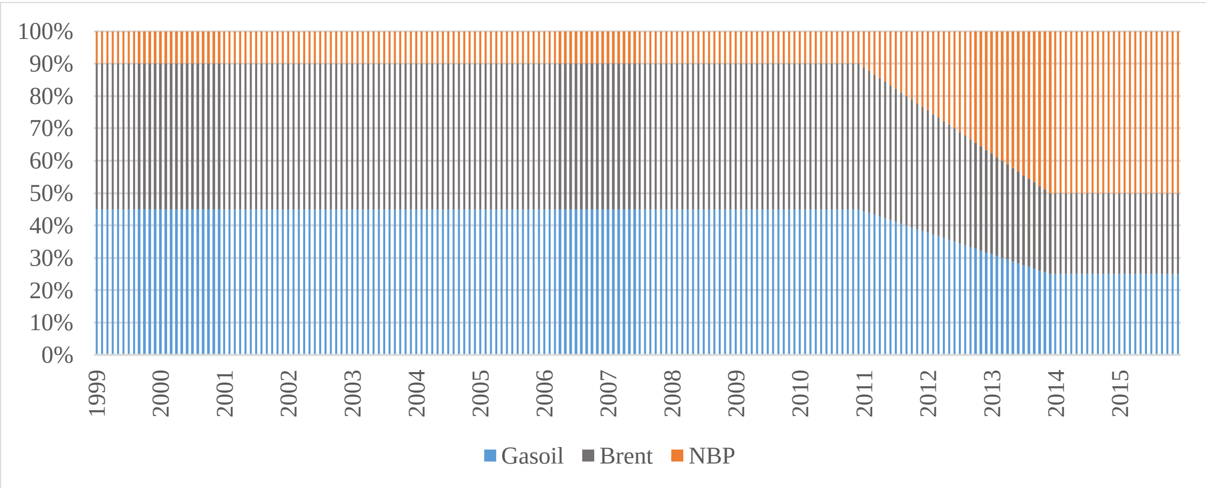

Figure C.2: Future contracts applied in the composition of the indexed price component

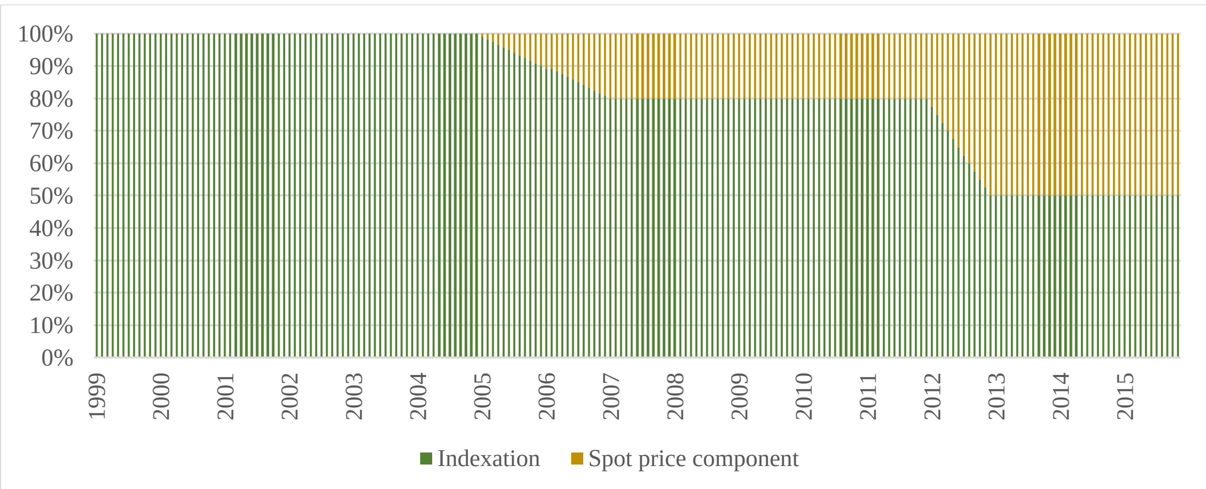

Figure C.3: Indexed price component and spot component in final market price

Appendix D: The analytical hierarchical process (AHP)

Following the example of Wabiri and Amusa (2010) risk weights are assigned to every supplier country based on a series of comparative judgements applying an analytical hirarcical process (AHP, Saaty, 1980) displayed in Figure D.1. The AHP structures the assessment process into the three levels of focus, criteria and alternatives. Focus of Germany's import diversification is improved energy security. Attaining this goal is possible by making a choice between supplier alternatives. Criteria of this selection are the four elements of the 4A concept of energy security (Availability, Accessibility, Affordibility and Acceptibility) (Kruyt, van Vuuren, H.J.M., & Groenenberg, 2009). In order to assess supplier countries's importance for decision makers in Germany, the meaning of each element of the 4A criteria is formed around the specific scenario from a German import perspective.

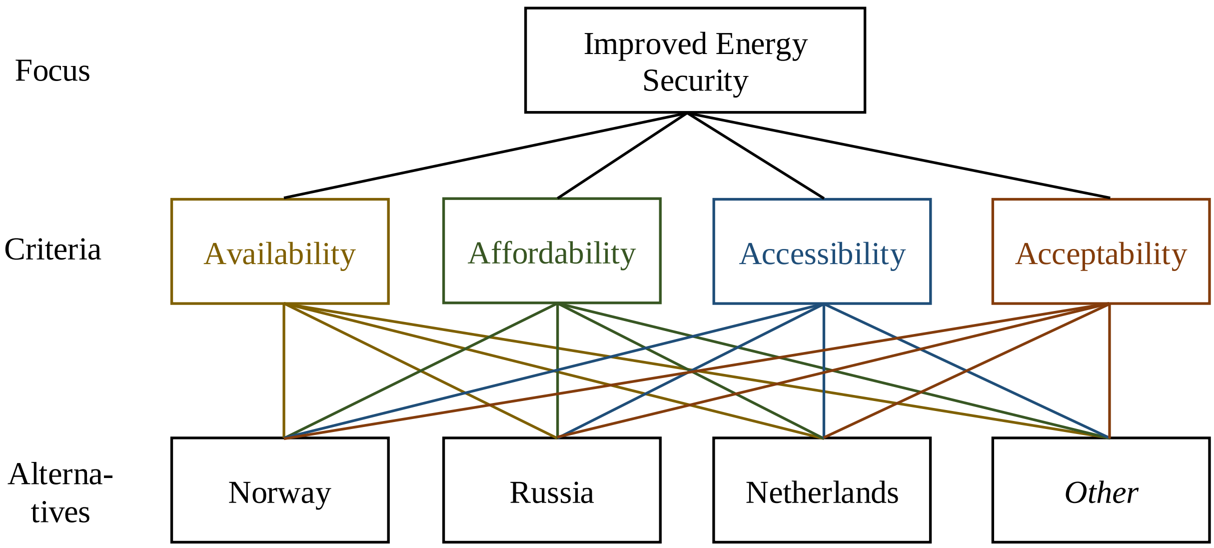

Figure D.1: The decision hierarchy model for assessing supplier countries according to a judgement along the 4A of energy security

Availability provides a judgment of a country's relative endowment with natural gas recourses compared to the other supplier countries in the portfolio. *Accessibility* is an estimation of countries' proneness towards the risk of disruption, whereby supply distances are evaluated. *Affordability* evaluates whether business operations could suffer from economic risks such as a potential loss of assets due to sanctions. Lastly, *Acceptability* is descriptive of regulatory, environmental and ethical risks. Each country is evaluated against all other supplier countries in all four assessment criteria, whereby higher values denote higher importance to decision makers and therefore higher risks. Similarly, the judgment criteria itself is evaluated against each other according to the importance of each criterion relative to other criteria. Table D.1 shows the assignable scale of values allowing for a quantification of qualitative judgement criteria (Saaty, 1980). Values in between (e.g. 2) thereby denote a settlement between the listed definition items.

Table D.1: Comparative judgements and numerical equivalent (Saaty, 1980)

Definition	Intensity
Absolutely the most important	9
Much more important	7
More important	5
Slightly more important	3
Equal importance	1
Slightly less important	1/3
Less important	1/5
Much less important	1/7
Absolutely less important	1/9

With these value scales, a pair wise comparison is generated first for the judgment criteria itself (Table D.2). A value of 3 for *Accessibility* for instance means that for the goal of improved energy security *Accessibility* factors are slightly more important than *Affordability* factors, and with a value of 5 also more important than factors concerning *Acceptability*. Secondly, for each criterion a pair wise comparison among supplier countries is undertaken, whereby Table D.3 denotes the results for such comparison for the *Affordability* criterion. As expressed before, this judgement criterion here describes risk factors from an economic standpoint, such as the risk of a loss of assets as a consequence of economic sanctions. A value of 5 (Table D.3) thereby indicates that economic risk factors (e.g. sanctions) are regarded more important with regards to Russia, than for Norway and the Netherlands, and slightly more important than for *Other*.

Table D.2: Pair wise comparison matrix (A) for the judgement criteria

	Availability	Affordability	Accessibility	Acceptability
Availability (av)	1	1	1	3
Affordability (af)	1	1	1/3	5
Accessibility (as)	1	3	1	5
Acceptability (ap)	1/3	1/5	1/5	1

Table D.3: Pair wise comparison matrix of supplier countries according to importance of Affordability factors

	Norway	Netherlands	Russia	*Other*
Norway (af_{No})	1	1	1/5	1/2
Netherlands (af_{Ne})	1	1	1/5	1/2
Russia (af_R)	5	5	1	3
Other (af_O)	2	2	1/3	1

Starting with the comparison of judgement criteria, weights for each criterion are generated using the Eigen vector method ($Aw = \lambda w$), in which A represents the comparison matrix for the judgement criteria (Table D.2), w is the vector for criteria weights (av, af, as, ap) normalised to 1 and λ is the Eigen value approximating 4. Likewise, for every criterion the same method is applied, such as for the *Affordability* criterion ($Aaf = \lambda af$), in which A represents the comparison matrix with regards to this criterion (Table D.3), af is the vector of assigned weights ($af_{No}, af_{Ne}, af_R, af_O$) and λ is the Eigen value approximately equal to 4. The same procedure is applied for the remaining three criteria to derive the weights for *Availability* av ($av_{No}, av_{Ne}, av_R, av_O$), *Accessibility* as ($as_{No}, as_{Ne}, as_R, as_O$) and Acceptability ap ($ap_{No}, ap_{Ne}, ap_R, ap_O$). The final risk weight for every supplier country is then calculated as a sum of the weighted measure of all applied criteria (Table D.7). For Norway for example, the final risk weight is equal to ($av_{No} \times av$) + ($af_{No} \times af$) + ($as_{No} \times as$) + ($ap_{No} \times ap$).

Table D.4: Calculation of risk weight coefficients for supplier countries

	Availability (av)	Affordability (af)	Accessibility (as)	Acceptability (ap)	Risk weight (w_i)
Norway	av_{No}	af_{No}	as_{No}	ap_{No}	($av_{No} \times av$) + ($af_{No} \times af$) + ($as_{No} \times as$) + ($ap_{No} \times ap$)
Netherlands	av_{Ne}	af_{Ne}	as_{Ne}	ap_{Ne}	($av_{Ne} \times av$) + ($af_{Ne} \times af$) + ($as_{Ne} \times as$) + ($ap_{Ne} \times ap$)

Russia	av_R	af_R	as_R	ap_R	$(av_R \times av) +$ $(af_R \times af) +$ $(as_R \times as) +$ $(ap_R \times ap)$
Other	av_O	af_O	as_O	ap_O	$(av_O \times av) +$ $(af_O \times af) +$ $(as_O \times as) +$ $(ap_O \times ap)$

Appendix E: Unit conversion table

Table E.1: Unit conversion table (Norwegian Petroleum Directorate, n.d.)

1 Sm^3	=	35.315 SCF (scf)	SCF - Standard Cubic Feet
1 SCF	=	0.028317 Sm^3	
1 Sm^3	≈	40 MJ = 11.111 kWh	Energy content varies; 40 MJ is used as standard
1 Sm^3	≈	37913 BTU	BTU - British Thermal Unit

		MJ	kWh	BTU
MJ	Megajoule	1	0.2778	947.81
kWh	Kilowatt hour	3.6	1	3412.13
BTU	British Thermal Unit	0.001055	0.0002931	1

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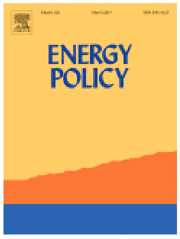

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