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"Assessing the Security of Natural Gas Supply in Selected European Gas Markets using Quantitative Indicators"

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Wien, November 2015

Bich Thuan Vu

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List of Abbreviations

SSI	Supply Security Index
PCA	Principal Component Analysis
PCs	Principal components
SPSS	Statistical Package for the Social Sciences (IBM)
TPEC	Total primary energy consumption
LNG	Liquefied natural gas
IEA	International Energy Agency
OECD	The Organisation for Economic Co-operation and Development

<u>Units</u>:

toe	tonne of oil equivalent
ktoe	thousand tonnes of oil equivalent
mtoe	million tonnes of oil equivalent

mcm	million cubic metres
bcm	billion cubic metres
tcm	trillion cubic metres

Zusammenfassung

Eine gesicherte Erdgasversorgung ist eines der Hauptziele der EU-Energiepolitik. In dieser Arbeit wird die Erdgasversorgungssicherheit von elf europäischen Ländern, welche bedeutende Erdgasimporteure sind, während des Zeitraumes 2001 bis 2014 bewertet. Die unterschiedlichen Dimensionen der Versorgungssicherheit werden durch ein Set von quantitativen Indikatoren, welche interne und externe Faktoren des Versorgungsrisikos reflektieren, erfasst. Durch die Bildung eines aggregierten Indexes - hergeleitet aus den vorgeschlagenen Indikatoren, nämlich dem importierten Erdgasvolumen, der Importabhängigkeit, dem Anteil des Erdgases an der Primärenergieversorgung, der Anzahl der Erdgasversorger, der Abhängigkeit vom größten Versorger und der Fragilität der Versorger, wird die Versorgungssicherheit quantifiziert. Zur Erstellung des Versorgungssicherheitsindexes (Supply Security Index, SSI) wurde die Principal Component Analysis (PCA) verwendet. Die einzelnen Indikatoren werden mittels des PCA-Verfahrens in einen zusammengesetzten Index transformiert. Die Resultate zeigen, dass das Versorgungssicherheitsrisiko der analysierten Länder unterschiedliche hoch ist. Die relativen Beiträge der einzelnen Faktoren zum Gesamtversorgungssicherheitsrisiko und die Prioritäten der abgesicherten Länder werden deutlich gemacht. Der aggregierte Index SSI dient zur Erlangung des Überblicks über die Leistungsfähigkeit des jeweiligen Landes, während die einzelnen Faktoren die Stärken und Schwächen des jeweiligen Landes aufzeigen.

Die Ergebnisse zeigen, dass die am besten abgesicherten Länder jene sind, denen es gelingt, signifikante Importmengen aus verlässlichen Quellen (Versorgungsländern) zu beziehen, welche auch eine gute Diversifizierung von Versorgungsquellen und -routen aufweisen und auch eine zu große Abhängigkeit von einem einzelnen Versorger vermeiden.

Schlagwörter: Erdgas, Versorgungssicherheit, Indikatoren, Supply Security Index (SSI), Varianz, Eigenwerte, Eigenvektoren, Principal Component Analysis (PCA).

Abstract

The security of natural gas supply is one of the main objectives of the EU energy policy. This paper assesses the security of natural gas supply of 11 major importing countries in Europe throughout the period 2001 to 2014. Different dimensions of the security of supply are captured by a set of quantitative indicators which reflect both internal and external factors of supply risks. An aggregated index is formed to quantify the security of supply based on the proposed indicators – the volume of natural gas imported, import dependency, share of gas in total primary energy consumption, number of gas suppliers, dependency on largest supplier, and fragility of supplier. The approach used to establish the supply security index (SSI) is the PCA (Principal Component Analysis). The individual indicators are transformed to a composite index by means of the PCA techniques. The results show that the countries demonstrate different levels of supply security risks. The relative contributions of the individual indicators to the countries' overall security of supply and the preferences of the secure countries are also revealed. The aggregated index SSI is useful in providing an overview of each country's performance whereas the individual indicators are used to enlighten on strengths and weaknesses of each country. The findings indicate that the most secure countries are those who are capable of maintaining significant import volumes from reliable sources (supplying countries), diversifying supply sources and routes, as well as diversifying risk by reducing over dependency on a single supplier.

Keywords: Natural gas, security of supply, indicators, Supply Security Index (SSI), variance, eigenvalues, eigenvectors, Principal Component Analysis (PCA).

Chapter 1

Introduction

1.1 Background

The need for energy sources is increasing globally. In Europe, where decarbonization is the prime objective in the EU's energy roadmap to 2050, clean energy sources such as natural gas or renewables are of high priority. The issue of security of natural gas supply is therefore of crucial importance in the European agenda. However, assessing the security of energy supply is not straightforward as it is a multi-dimensional and somewhat qualitative concept. Sophisticated models and methods are usually needed for the process of studying energy supply security.

Principal Component Analysis (PCA) is one of multivariate statistical analysis techniques which involve observation and analysis of more than two variables at a time (simultaneously). The primary idea of principal component analysis is to reduce the dimensionality of a data set which consists of a large number of correlated variables, whilst still retaining as much as possible the variation present in the data set. Dimensionality reduction means information loss. Data presentation in a lower dimensional form without losing too much information is the goal of PCA.

Applications of PCA can be found in fields such as taxonomy, biology, pharmacy, architecture, economics and finance. In recent years, PCA is utilized in the energy research literature for measuring the energy (e.g. oil, gas, coal) vulnerability index.

In this study, PCA is also applied for investigating the security of natural gas supply in selected countries. The software used to support PCA analysis is IBM SPSS Statistics (Statistical Package for the Social Sciences).

1.2 Objectives of the thesis

The aim of this thesis is to assess the security of natural gas supply in the major gas importing countries in Europe in the period 2001-2014.

First, a proposed set of quantitative indicators which measure different dimensions of the security of natural gas supply is defined. Afterwards, the overall security of supply of each country in the sample set is quantified in the form of a composite index - the security of supply index SSI - by transforming the proposed individual indicators into a single index. This process is conducted by applying PCA.

The objective of the study is twofold. First, an overview of the countries' security of gas supply is presented based on their corresponding SSI scores. The strengths and weaknesses of each country on the different dimensions of security of supply are then analysed. The variations in the relationship of the indicators over time are also revealed. Second, policy implications for each of the countries are obtained by evaluating the basis of the variations in the overall supply security index and the related factors (indicators).

In this paper, the sample set consists of 11 countries: Germany, United Kingdom, Italy, the Netherlands, Turkey, France, Spain, Belgium, Austria, Czech Republic and Poland.

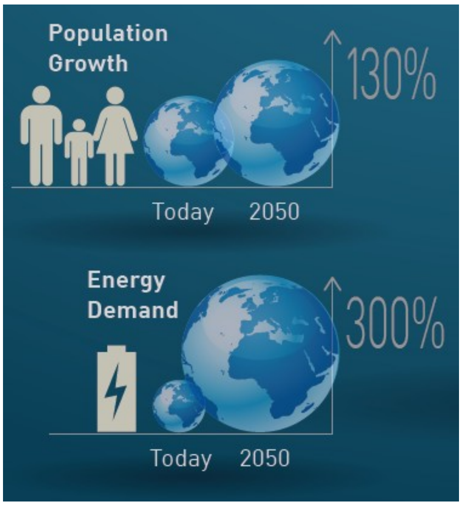
1.3 Structure of the thesis

Apart from the introductory chapter, this thesis is structured in five chapters:

- Chapter 2 provides a brief summary of global and European natural gas markets.
- In Chapter 3 a review of energy security and its indicators is presented.
- Chapter 4 provides detailed explanations of the paper's methodology.
- The empirical results and discussions, as well as the policy implications are given in Chapter 5.
- Finally, Chapter 6 includes the paper's results and recommendations for future works.

Chapter 2

Importance of energy security: the case of natural gas



Source: http://blogs.berkeley.edu

2.1 The role of natural gas in the energy mix

Natural gas is the cleanest fuel which emits the lowest carbon dioxide (CO_2) in comparison with other fossil fuels like oil, coal (see Table 1). In fact, when being burnt for heating homes or for industrial uses, gas releases 25-30% less CO_2 than oil and 40-50% less than coal per unit of energy produced. In power generation, it releases around 60% less than coal for every kWh sent out.[1]

As gas turbines can be quickly started and ramp up and down their power levels faster than coal, steam, or nuclear plants, natural gas is seen as a potential backup source for renewables.

[1] *http://www.gasnaturally.eu/facts-about-gas/a-secure-energy-source*

Building gas power plants is relatively quick (in around two years) while building nuclear power plants can take much longer. In addition, transporting natural gas can be made across the globe with no much processing required between the source (extraction point) and the end consumer, either in liquefied natural gas (LNG) form or via pipelines. Those attributes make natural gas an economically attractive option for investors.

Natural gas resources are spread over all continents and remain abundant (which is supposed to meet more than 120 years of people's demand at today's consumption [2]). Additionally, new conventional gas resources found every year as well as recent unconventional gas discoveries (such as shale gas, coal bed methane and tight gas in North America, Australia and China) do substantially contribute to the world gas supply security.

Table 1. Fossil fuel emission levels - Pounds per billion Btu of energy input

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Source: EIA – Natural Gas Issues and Trends 1998

Humanity's energy needs are substantially rising owing to economic growth and population increment worldwide. Significant rise in energy consumption however will go with an outburst of carbon dioxide (CO_2) emissions. In order to mitigate CO_2 emissions, boosting efficient use of all available energy sources and shifting to cleaner energy sources are key solutions to global climate change. Natural gas is considered a good source of energy which meets these purposes, contributing to the world's economic and environmental challenges in a secure and sustainable way.

[2] *http://www.gasnaturally.eu/facts-about-gas/a-secure-energy-source*

2.2 Global natural gas market

2.2.1 Consumption

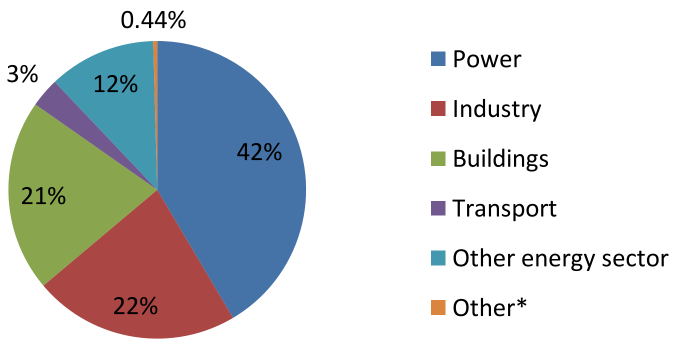
Gas presents in almost all sectors of the economy. It is mainly consumed as fuel in the power sector, where it accounts for about 42% of global gas demand. In the industrial sector, roughly 22% of total gas consumption is used as raw material. The buildings sector (includes residential, commercial and institutional buildings) consumes around 21% of gas share, mostly for heating and cooling purpose. Other energy sector includes the own use by the energy industry makes up about 12%. A small fraction of natural gas is currently consumed in the transport sector but this is viewed as a rapidly developing sector which is expected to reach 5% of total gas use by 2040 (Figure 1).

Although oil and coal are still dominant in the overall primary fuel mix (oil 31% and coal 29%), demand for these fossil fuels falls gradually through the projection period 2012-2040 as the result of energy efficiency and structural changes which tend to switch to less energy-intensive industries. The share of oil and coal is projected to reduce to 26% and 24% by 2040, respectively.

The global trend towards low-carbon fuels such as renewables and nuclear is notable, however their scale is still small. Renewables will be increasing from 14% currently to 19% by 2040, its share is still less than other fossil fuels. Gas will overtake coal and become the only fossil fuel that increases its share from 21% to 24% throughout the projection period, making up almost a quarter of world energy mix by 2040.

Growth in gas demand is quite slack in OECD countries with an average growth rate of 0.7% per year, overall. The US is the world's largest user of natural gas. US gas demand increases from 727 bcm in 2012 to 895 bcm by 2040, covering 44% of the growth of the OECD, gas becomes the largest fuel in the US energy mix. Increasing demand in natural gas is more intense in emerging economies. The main regions pushing global gas consumption are non-OECD countries, where the average annual growth rate is 2.2% over the period 2012-2040, covering almost 80% of the overall increase in global gas demand. China and the Middle East are the key drivers of growing demand in the non-OECD. The rise forecasted in these two markets alone is twice that of the rise of the entire OECD.[3]

Figure 1. World natural gas demand by sector, 2012



**Other includes agriculture and any other non-energy use.*

Source: IEA - World energy outlook 2014

2.2.2 Reserves and Production

Although global demand for natural gas is huge, remaining resources of gas (conventional and unconventional) are abundant and can satisfy the growing demand. As per data of the IEA at the end of 2013, gas proven reserves were 216 tcm which is equivalent to more than 60 years of production at current rates. Total remaining technically recoverable resources are, however, much larger than that with an estimated amount of more than 800 tcm (at the end of 2013), almost four-times larger compared to proven reserves.

The world gas reserves are not as concentrated as the world oil reserves. The regions which cover most part of proved reserves are the Middle East and Eastern Europe/Eurasia. Within the Eastern Europe/Eurasia region, Russia alone (47.8 tcm) accounts for about 65% of the entire region's proved reserves. After Eastern Europe/Eurasia, the Middle East (with 137 tcm) and Asia-Pacific (138 tcm) are the next which hold the large volumes of natural gas resources, each almost equally accounts for about 17% of the world total resources (Table 2).

[3] Most of the data in this part referred to the IEA – World Energy Outlook 2014, unless otherwise stated.

Table 2. Remaining technically recoverable natural gas resources by type and region, end-2013 (tcm)

	Conventional	Unconventional				Total	
		Tight gas	Shale gas	Coalbed methane	Sub-total	Resources	Proven reserves
E. Europe/Eurasia	143	11	15	20	46	189	73
Middle East	124	9	4	-	13	137	81
Asia-Pacific	43	21	53	21	95	138	19
OECD Americas	46	11	48	7	65	111	13
Africa	52	10	39	0	49	101	17
Latin America	31	15	40	-	55	86	8
OECD Europe	25	4	13	2	19	45	5
World	**465**	**81**	**211**	**50**	**342**	**806**	**216**

Source: IEA – World energy outlook 2014

Technology has a significant impact on natural gas production. There has been a trend towards unconventional resources in gas production thanks to new technologies in the upstream, such as 3D seismic, directional drilling, hydraulic fracturing which have been applied in tight gas, coalbed methane, shale gas exploration. Unconventional gas - largely shale gas, but also tight gas, coalbed methane – account for almost 60% of the rise in production, increasing its share in total gas output growth from 17% today to 31% by the end of 2040 (while its total resource is equivalent to about 51% of global gas resources [4]). The largest source of unconventional gas output is North America, in which the US is the world's leading unconventional gas producer. But not only in North America, unconventional gas becomes widespread globally, other countries such as China, Australia, India, Argentina are also emulating the success of the US in exploitation of unconventional gas resources.

Global gas markets are changing particularly through the growth of unconventional resources. However, development and production of those unconventional resources still rely on a number of concerns about environmental and social damages which threaten to restrain the unconventional gas development.

[4] Source: http://www.total.com

2.3 European natural gas market outlook

2.3.1 Regional trends

Decarbonization is the prime objective in the EU's energy roadmap to 2050 to fulfil its long-term commitment of reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050. Possible structural changes for the transformation aiming to a decarbonised energy system in 2050 will be made. Improving energy efficiency, switching to renewable energy sources are the main focus, however, natural gas will still play a key role in the transition of the energy system. Indeed, fossil fuels still take a large share of the global energy mix - although this share is gradually reduced owing to the reduction of energy intensity of the EU economy, the growth of renewables and improvements in energy efficiency - ranging from 81% in 2012 to 74% by 2040.[5] Therefore, substitution of coal and oil with gas is a key solution for emission reduction in the short to medium term, until at least 2030 or beyond.[6]

Figure 2 below shows the evolution of primary energy use in Europe in the past decades which reflects the trend towards a low-carbon energy system, where the shares of renewables and natural gas had been increasing a large amount while those of oil and coal had been substantially decreasing. As of 2013, the share of natural gas in primary energy consumption was 24.2%, almost a quarter of the energy mix.

2.3.2 Demand

In 2012, Europe consumed 506 bcm of natural gas, accounting for almost 15% of the world consumption. This is the second largest regional gas market after the US (723 bcm).

Gas consumption varies widely among European countries: in 2013, four big markets - Germany, the UK, Italy and Netherlands - already accounted for more than half of the continent's consumption, together with Turkey, France and Spain, these seven countries

[5] IEA - World Energy Outlook 2014

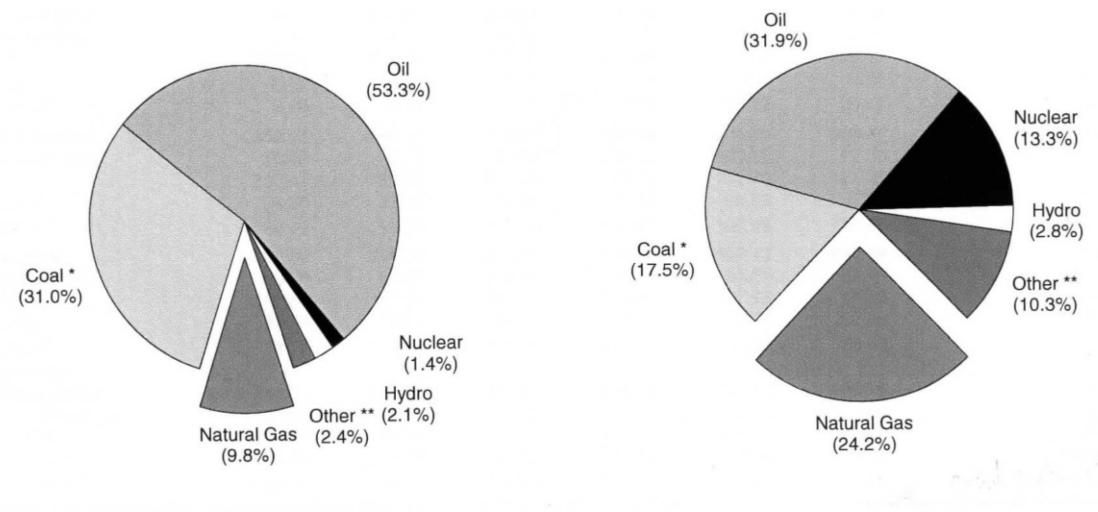
[6] Energy Roadmap 2050 - European Commission, 2012

represented up to 80% of the total demand, all the remaining European countries covered only around 20% (see Table 3).

Figure 2. Fuel shares in total primary energy supply (TPES)

1973
(TPES: 1374 Mtoe)

2013e***
(TPES: 1713 Mtoe)



* Coal includes peat and oil shale.
** Other includes geothermal, solar, wind, wave, tide, heat, biofuels & waste. Excludes electricity trade.
***2013 data are estimates

Source: Natural gas information 2014 - IEA **Europe**

Gas demand is mainly concentrated in Northwestern Europe (Germany, United Kingdom, Netherlands, France) and Italy, where gas industry started to develop around 50 years ago (Honoré A., 2014). These five countries, plus Turkey, Spain, Belgium, Austria and some countries in Eastern Europe (Poland, Czech Republic, Romania and Hungary) as a whole form a panorama of European gas market.

Table 3. Natural gas consumption in Europe in 2012-2013

	Consumption in 2012 (bcm)	Consumption in 2013* (bcm)	Share of total European consumption in 2013 (in %)	Accumulated share in 2013 (in %)
Germany	85.8	88.4	17.6	17.6
United Kingdom	78.0	77.7	15.5	33.1
Italy	74.9	70.0	13.9	47.0
Netherlands	46.0	46.4	9.2	56.3
Turkey	45.3	45.6	9.1	65.4
France	42.1	44.0	8.8	74.1
Spain	32.4	29.9	6.0	80.1
Poland	18.0	18.2	3.6	83.7
Belgium	17.9	17.7	3.5	87.2
Romania	13.6	12.5	2.5	89.7
Hungary	10.1	9.2	1.8	91.6
Remaining countries	41.9	42.4	8.4	100.0

*2013 data are estimates

Own calculations (data from IEA – Natural Gas Information 2014)

Economic performance is the main determinant of energy consumption. Since the beginning of 2011 throughout 2013, demand for all fuels in Europe has decreased due to sluggish economic recovery. Natural gas consumption fell continuously from 519.5 bcm in 2011 to 506 bcm in 2012 (-2.6%), and then slightly down again to 502 bcm in 2013 (-0.8%).[7]

2.3.3 Supply

The EU imports 53% of all the energy it consumes at a cost of more than €1 billion per day. Specifically, the EU imports:[8]

- 90% of its crude oil
- 66% of its natural gas
- 42% of its coal and other solid fuels

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[7] IEA – Natural Gas Information (2014)

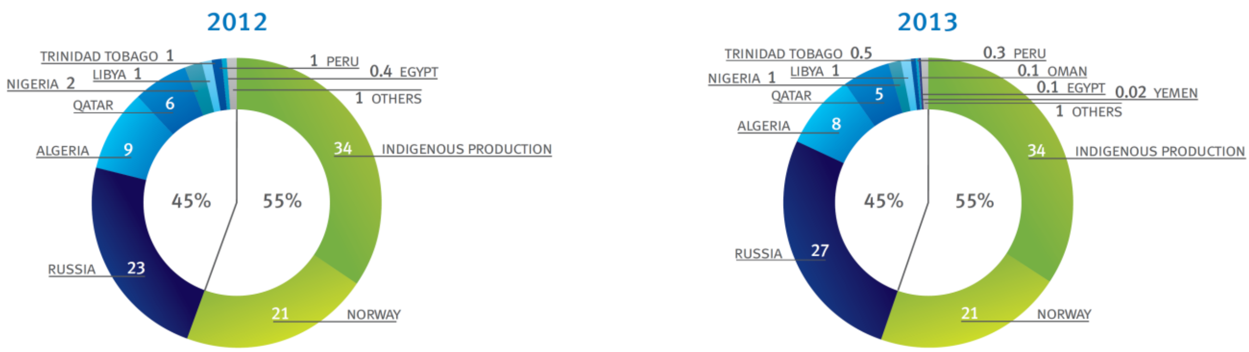
[8] European Commission: *http://ec.europa.eu/energy/en/topics/imports-and-secure-supplies*

- 40% of its uranium and other nuclear fuels

These figures indicate that the EU depends substantially on energy imports, fossil fuels in particular - in which natural gas shows the second highest import level (66%), after crude oil.

In fact, indigenous gas production within EU countries covered only 34% of the total net supplies in 2012 and 2013. Nevertheless, EU production still remained the largest source of gas for EU-customers, plus 21% import from Norway then there is approximately 55% in total coming from the fields in Europe. The remaining share is mainly filled up by Russia, Algeria, and Qatar (see Figure 3).

Figure 3. Breakdown of EU-28 supplies, 2012 and 2013



Source: Statistical Report 2014 - Eurogas

As a non-EU nation, Norway is Europe's largest natural gas producer and the world's third-largest gas exporter, after Russia and Qatar. It is also an important supplier of both oil and gas to other European markets. Within the EU countries, the Netherlands is the largest gas producer and exporter (the second-largest in Europe, following Norway). The UK's gas production takes the second position after the Netherlands, nevertheless, domestic gas production in the UK has been on a long-term declining trend, just covered 35% of the national gas supply in 2013. Major gas supplies to the UK come from Norway (38%), Qatar (12%) and the Netherlands (8%).

Russia is the world's largest gas exporter and the biggest gas supplier to European countries, 39% of total EU gas imports came from Russia (in 2013) – **only via pipelines**. Most of Russian gas exports (76%) are sent to customers in Western Europe, such as Germany, Turkey, Italy, France, and the UK.

After Russia, the second-largest gas supplier outside Europe is Algeria which accounted for 8% of the EU gas supplies in 2013. Moreover, Algeria is the largest supplier of **LNG** to the European market. Algeria's gas exports are mainly supplied to Spain, Italy, France and Turkey. Smaller volumes of the EU's natural gas imports come from Qatar (5%) and others.

Reserves

Europe holds the smallest portion of natural gas proved reserves compared with other regions in the world. The regional share accounts for only 2% of the total world reserves.

Within the region, Norway is the largest holder of natural gas reserves, provides 21% of the gas consumed on the continent. Its reserves as of 2013 is 2 tcm, however, this amount just covered a very small share of the total world reserves (1.1%). The Netherlands stays in the second position with 0.9 tcm, ahead of the UK who holds 0.2 tcm. Poland, Romania and Italy possess a smaller volume (0.1 tcm). Some of the rest countries just own a negligible portion (Table 4).

Table 4. Natural gas proved reserves in Europe, end 2013

	Trillion cubic metres	Share of total	R/P ratio
Norway	2.0	1.1%	18.8
Netherlands	0.9	0.5%	12.4
UK	0.2	0.1%	6.7
Poland	0.1	0.1%	27.5
Romania	0.1	0.1%	10.6
Italy	0.1	**	7.3
Denmark	*	**	7.0
Germany	*	**	5.9

** Less than 0.05   ** Less than 0.05%*

Total world proved reserves at end 2013: 186 tcm

Source: BP Statistical Review of World Energy, 2014

Unconventional gas resources in Europe, primarily shale gas, are estimated to be significant. According to the U.S. Energy Information Administration (EIA), technically recoverable shale gas reserves in Europe are up to 14 trillion cubic metres (tcm), as of 2013 estimates. This amount even exceeds Europe's conventional gas reserves, which is estimated at 5.2 tcm.

Poland and France have the largest unproved shale gas resources in Europe - estimated at 4.2 tcm and 3.9 tcm respectively (2013).[9] However, the contribution of unconventional gas resources to Europe's indigenous gas production is still small, so far only a few exploration wells have been drilled in Europe. The unconventional potential in this region comes with uncertainty. The industry has to struggle with a lot of potential environmental concerns, there have been expectations of whether it will come up with solutions for environmental issues and gains public and political acceptance.

Rising gas import needs - increasing reliance on external supply

Europe imports nearly half of all the natural gas it consumes. Indeed, Europe's indigenous production can only fulfil about 55% of total demand. Excluding the share from Norway (21%), the volume from the EU's (28 members) production alone covers only approximately 34% of the continental total needs, i.e. the remaining 66% need to be imported. The EU therefore will need more gas from external supply sources in order to fill the growing gap between domestic production and consumption.

So far, European market is the largest destination for internationally traded gas, ahead of "Japan and Korea". Most of the gas imports in the EU are transported via pipelines, account for 81% of total imports. Russia, Norway are the main pipeline gas supplier to the EU, make up 39% and 22% of the gas imports, respectively. Algeria is among the largest pipeline gas suppliers, after Russia and Norway.

Germany is the largest gas importer in Europe, all of its gas imports are transported through pipelines, mostly from Russia, Norway and Netherlands. Italy is the second-largest importer after Germany, most of its gas imports are from Russia and Algeria via pipeline. Following Germany and Italy are the UK and France with pipeline gas imports mainly from Russia and Norway.

LNG imports only account for 19% left (2012). This has been decreasing in recent years due to the economic crisis and the strong competition from Asian markets, LNG share of imports in the EU decreased to only 14% in 2013. Qatar is the biggest LNG supplier to the EU with

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[9] Energy Economic Developments in Europe - European Commission, January 2014, p.32

51% share of the LNG imports, other main LNG supplies come from Algeria and Nigeria (22% and 12% respectively).[10]

Spain has the biggest share of LNG imports in Europe, its main suppliers are Qatar, Algeria and Nigeria. The UK is the second largest LNG importer who buys most of its LNG from Qatar. France is the third one after Spain and the UK, its biggest suppliers are also Qatar, Algeria and Nigeria.[11]

According to the Reference Scenario 2013 (P. Capros et al., 2013), natural gas production in the EU (28 countries) within 2005-2040 will fall 50% due to the limited and depleted resources whereas gas consumption in this period falls only 11% (due to the switch to less energy-intensive industries in Europe, the growth of renewables and improvements in energy efficiency), thus gas supply in the region is more heavily dependent on imports from external supply sources (Table 5). This scenario raises the significant role of gas supply security which is becoming an important issue of the EU's and other countries energy policy in the coming years.

Table 5. The EU28 Natural Gas Baseline Scenario to 2040 (bcm)

	2005	2010	2015	2020	2025	2030	2035	2040
Production	228.81	190.23	179.27	168.88	149.41	131.53	122.30	114.45
Net Imports	309.42	331.20	343.25	319.73	341.21	348.14	358.97	369.34
Consumption	538.06	533.31	522.27	487.51	488.31	476.66	476.41	477.20
Import dependency:								
	58%	**62%**	**66%**	**66%**	**70%**	**73%**	**75%**	**77%**

Source: P. Capros et al., 2013. EU Energy, Transport and GHG Emissions - Trends To 2050, p.86. European Commission. *(Converted from ktoe to bcm).*

[10] Statistical Report 2014 - Eurogas

[11] BP Statistical Review of World Energy, June 2014

Chapter 3

A review of energy security and its indicators

Upon reviewing existing literature, this chapter provides an overview of energy security, its notions and evolution over time as well as indicators to capture different aspects and relevant factors of security of energy supply.

3.1. Definition of energy security

Increasing energy demand in general is a global issue and taking into account the fact that fossil fuel reserves are limited and depleted, energy security has become one of the primary economic and political objectives of all countries (both developed and developing ones) over the last few decades.

Notions of energy security are categorized by ECOFYS et al. as two broad groups, the first focuses on economic principles and the second is policy oriented:
"1. From an economic perspective, energy insecurity is the loss of welfare resulting from a change in the price or physical availability of energy.
2. Policy oriented definitions typically highlight basic requirements of a secure energy system. Often these stress the need for accessibly to, and affordability of energy. Other examples include availability and acceptability." (ECOFYS et al., 2009, p.6).

Energy security, mainly **security of supply**, is defined as "the uninterrupted physical availability of energy products on the market, at a price that is affordable for all consumers, while respecting environmental concerns and looking towards sustainable development"

(European Commission's green paper, 2000). This involves an extension of the IEA definition where environmental and sustainability issues (that may put forward additional constraints) are included (Labandeira X., Manzano B., 2012).

The concepts and definitions of energy security have expanded over time. Cherp Aleh et al. (Cherp et al. - GEA, 2012) indicate in their study that historically, in the first half of the 20th century, the notion of energy security arose as a concern about the secure supply of fuels (mainly coal and oil) for the military. This notion still held particularly for oil in the second half of the 20th century when oil became increasingly important not only for the military but also for industrialization and households. In later definitions, energy security is viewed as a mixture of many concerns over not only oil but also natural gas and other energy resources when the idea of globally limited resources emerged, as in the words of Daniel Yergin "in the background [of energy security concerns] – but not too far back – is the anxiety over whether there will be sufficient resources to meet the world's energy requirements in the decades ahead" (Yergin D., 2006, p.70).

Some of today definitions of energy security include four main elements which derived from a commonly cited approach – the "four A*s*" of energy security proposed by the Asia Pacific Energy Research Centre (APERC, 2007). The four elements relating to security of supply are classified into categories which are subject to a complex interplay:

- **Availability** - the first and most dominant element relates to the physical existence of energy resources (geological factors). The concern here is whether the energy available is sufficient to meet demand.
- **Accessibility** - geopolitical factors and geographical constraints due to the large spatial discrepancy between consumption and production/extraction of resources. There could be the case that even resources are available they may not be accessible.
- **Affordability** - economic factors relate to volatility in energy prices and costs of infrastructures (such as pipeline, LNG infrastructure). Energy may be available and accessible, yet its affordability may have significant economic and social impacts.
- **Acceptability** – environmental and societal concerns. Even when the above three dimensions are favourable, environmental or societal elements may also affect energy security.

(CIEP, 2004); (B. Kruyt, D.P. van Vuuren, H.J.M. de Vries and H. Groenenberg, 2009); (ECOFYS et al., 2009).

Though this approach is comprehensive, it is not well suited to a disaggregated energy system analysis because indicators often overlap in multiple dimensions. It is also assumed to be a no risk-focused approach that does not cover some key factors such as the resilience of energy systems. Additionally, environmental concerns are often treated by policy makers as constraints rather than primary goals of energy security (J. Jewell - IEA, 2011), (Kruyt et al., 2009). Thus most of scholarly discourses on energy security do not emphasize this fourth element either.

Another approach that has been recently addressed in the Global Energy Assessment (Cherp et al. - GEA, 2012) - which is further elaborated in (Cherp A. and Jewell J., 2011) - discusses three aspects of energy security:

- **Robustness**: focus on protection from disruptions caused from "predictable and objective" natural, technical, and economic factors (e.g. resource scarcity, demand growth, aging of infrastructure or energy price fluctuations).
- **Sovereignty**: energy security threats are seen in this perspective as posing from external factors, such as hostile states, unreliable or overly powerful "foreign" exporters.
- **Resilience**: disruptions in this case are originating from less or unpredictable and uncontrollable factors such as uncertain market changes, economic crisis, political instability or extreme weather events. Resilience perspective does not actually deal with quantifying or minimizing such risks but focuses on the ability to respond to and recover from those threats (spreading risks and preparing for surprises).

Energy security is affected by a large number of complex factors that are difficult to identify or quantify. Some of these factors are associated with short to medium-term energy security while others focus on long-term concerns. While the former deals with the mitigation of disruptions, the latter concerns structural aspects of the energy system and the root causes of those disruptions. There are studies of security of energy supply focusing only on the supply side, whereas others address both supply and demand aspects.

Various studies in academic literature recognize that energy security has different meaning in different contexts and its concerns vary from country to country. The focus of studies will therefore depend on the goal of the specific analysis, with relevant aspects or dimensions of energy security. It is unlikely, and probably undesirable, for researchers to agree upon one single definition and interpretation of energy security (A. Månsson, B. Johansson and Lars J. Nilsson, 2014), (Kruyt et al., 2009).

3.2. Indicators for energy supply security

An indicator is defined by OECD (OECD, 2008) as a quantitative or a qualitative measure derived from a series of observed facts that can reveal relative positions of, for example a country, in a given area. In the context of policy analysis, they can serve as useful tools for:

- Identifying trends and drawing attention to particular issues
- Setting policy priorities
- Benchmarking or monitoring performance.

There are two different groups of studies aiming to achieve an integrated understanding of energy security. One focuses on *classifying* energy security concerns into "dimensions" or "aspects" with understandable names appealing to common sense, such as the four elements or aspects in the "four A*s"* approach, or the Robustness, Sovereignty and Resilience perspectives as discussed above. The other group of studies (which may be larger than the first one) tries to achieve an integrated understanding of energy security by *quantification* rather than by classification. The studies in this group focus on developing indicators which can capture the risks of energy security and resilience capacity (Cherp A. and Jewell J., 2011).

Indicators for energy security are often distinguished between two categories: *simple* indicators and *composite* indicators. Simple or disaggregated indicators can be used to explain separate risks or single aspects of energy security, whereas composite or aggregated indicators compiling several individual indicators into a single index. The composite indicators are designed to measure multi-dimensional aspects of supply security that cannot be captured by a simple indicator (Nuclear Energy Agency, 2010).

Kruyt et al. (2009) provide a comprehensive study of the most commonly used indicators for long-term security of supply, ranging from simple to aggregated indicators. They classify indicators according to the taxonomy of the four dimensions of energy security that relate to the "four A*s*" aspects, which have been introduced earlier in Section 3.1. "*Definition of energy security"*. In this study, they also discuss the strengths and weaknesses of these indicators as well as the projections of application of some indicators up to 2050.

3.2.1. Simple indicators

Diversity indices:

Diversity is deemed to be an important factor reducing energy systems risks. Andrew Stirling (Stirling, A., 1998) identifies diversity as an overarching concept with three subordinate properties:

- **Variety**: refers to the number of categories into which the quantity in question can be partitioned. For example, the electricity mix can be partitioned into "coal", "gas", "nuclear", and "renewable". This implies that the more system categories, the greater the system diversity, *ceteris paribus*.
- **Balance**: the pattern in the apportionment (spread) of that quantity across the relevant categories (i.e. the more even the balance among categories, the greater is the diversity).
- **Disparity**: referring to the nature and degree to which the categories themselves are different from each other. The categories "coal", "gas" and "oil", for example, are less disparate than "gas", "nuclear" and "renewable". All other things being equal, the more disparate the categories of a system, the greater the system diversity.

Although all the three elements are essential in explaining diversity thoroughly, only a number of measures which capture the elements of *variety* and *balance*. Capturing *disparity*, however, is problematic. Stirling indicates that *disparity* is a fundamentally subjective and context-dependent property, and there exists no index in the literature that also captures this key property.

In the absence of an appropriate measure of *disparity*, the indices that measure only *variety* and *balance* are called indices of "dual concept diversity". Two of these indices are the

Shannon diversity index (or the Shannon-Wiener diversity index) and the Herfindhal-Hirschman Index, which are stated in mathematical forms as follows:

Shannon-Wiener diversity index (SWI) $= - \Sigma_i\, p_i \ln p_i$

Herfindhal-Hirschman Index (HHI) $= \Sigma_i\, p_i^2$

p_i in both indices denotes either:

- The share of fuel *i* in the energy mix (i.e. the diversity of fuel supply in a market/country).
- The market share of supplier *i* in the total supply market (i.e. the diversity of supply to a specific market/country).

The implications of the indices are very different. The higher the value of SWI, the more (dual property) diverse the system is, whilst for the HHI, the lower its value is, the more dual concept diverse the system is. HHI varies between 0 and 1[12], while the SWI increases with an increasing number of options. (ECOFYS et al., 2009), (Kruyt et al., 2009).

Various studies have applied the SWI, such as Jansen et al. (Jansen J.C., van Arkel W.G., Boots M.G., 2004) which will be further discussed in the next section. The Asia Pacific Energy Research Centre also utilizes a modification of the SWI when they define their energy security indicators, "since it considers both the significance of diversification in terms of abundance and equitability of sources" (APERC, 2007, p.44).

The classic Herfindhal-Hirschman measure was first applied by Thomas Neff in developing an analytic approach to quantify supply dependence across fuels - with an emphasis on nuclear fuels - for Pacific Asia region (Neff, T.L., 1997). The IEA then also adopted the HHI to construct indicators addressing the two components (i.e. the price and the physical availability) of energy security (IEA, 2007) (to be reviewed in the next section). In a later research, C. Le Coq et al. assess the short-term risks associated with the external supply of energy to the EU Member States, in which they measure the diversity of energy supplies in a similar way to the Herfindhal-Hirschman approach (C. Le Coq and E. Paltseva, 2009).

Some other widely used examples of simple indicators include:

[12] HHI: Moving from a very large amount of very small firms to a single monopolistic producer. Decreases in the HHI generally indicate a loss of pricing power and an increase in competition, whereas increases imply the opposite. (ECOFYS et al., 2009, p.268)

- ***Reserves to production ratios (R/P)***
- ***Import dependency***
- ***Energy intensity***
- ***Political stability***
- ***Market risk***
- ***Supply risk***
- ***Demand-side indicators****,* and so on.

Gnansounou employs several simple indicators such as energy intensity, oil and gas import dependency, CO2 content of primary energy supply (and some other individual indicators) to compute a composite index measuring energy vulnerability for selected industrialised countries (Gnansounou E., 2008).

Other recent studies which apply these simple indicators involve (H. Cabalu and C. Manhutu, 2009)**,** (C. Roupas, A. Flamos & J. Psarras, 2011) or (Biresselioglu M.E. ,Yelkenci T. and Oz I.O., 2014), where individual indicators are compounded to form a synthesized index that measures the vulnerability/ security of energy supply of a sample nation or region.

3.2.2. Composite (aggregated) indicators

The following are the noteworthy aggregated indicators which have been conducted in some significant researches on energy security.

Shannon index based:

One of the first research works of designing composite indicators of energy supply security in the long run is Jansen et al.'s, which is extensively based on the work of Stirling (Stirling, A., 1998). The authors develop the following four composite indices for diversity, adopting Shannon diversity index as basic indicator. These four indices allow for an increasing number of long-term supply security aspects:

- Diversification of energy sources in energy supply (I_1).
- Diversification of imports with regard to imported energy sources (I_2).

- Long-term political stability in regions of origin (I_3).
- Depletion of resources in the import regions, and in the foreign regions of origin (I_4).

These indicators are then applied to four long-term sustainability scenarios covering the period 2000-2040. The indicators prove quite well amenable to making projections of long-term development of energy supply security for a particular region (Jansen et al., 2004).

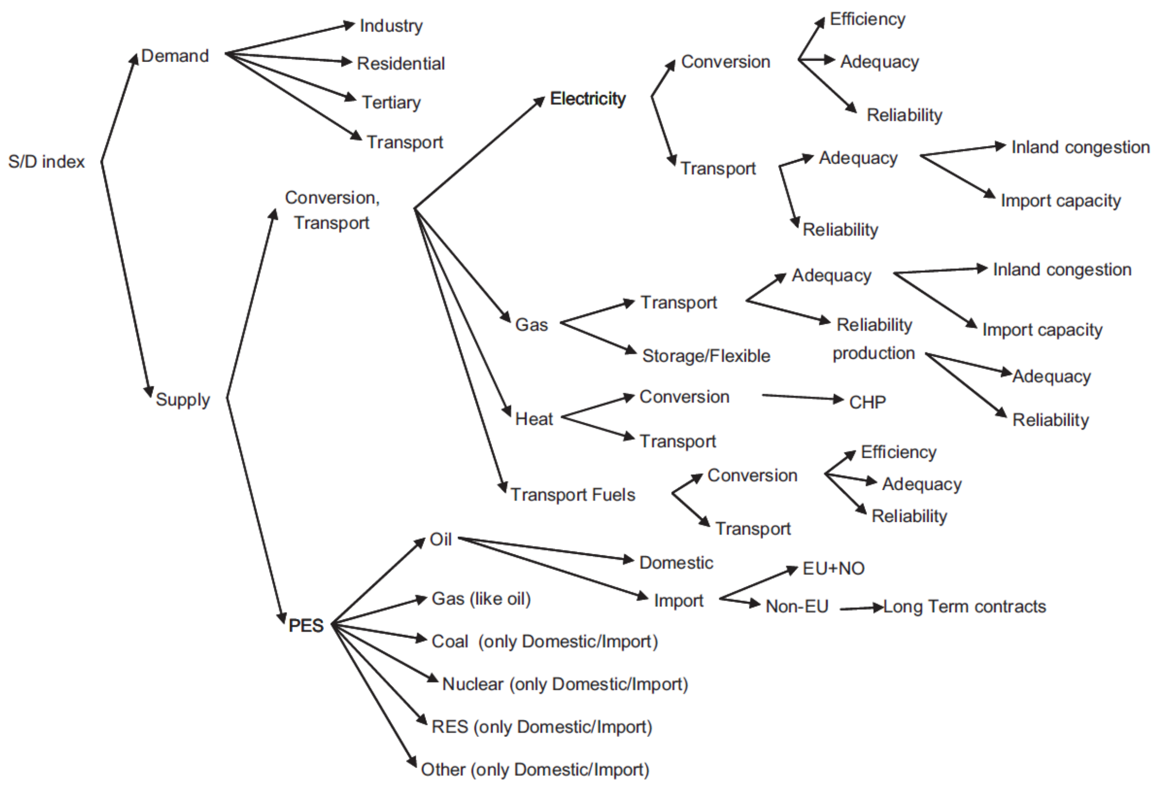
Details of designing these Shannon-based indices are also described in later studies from Kruyt et al. (2009) and Jansen et al. (Jansen J.C., Ad J. Seebregts, 2009).

Supply/Demand (S/D) Index:

Quantitative indicators being applied in energy supply security are often focusing on the energy supply side of one or several fuels. However, in order to assess energy supply security, we should also include energy demand. Increases of energy demand due to economic growth may impact energy security, while energy-saving policies may improve the energy security situation. The supply security of end users also depends on the capacity and reliability of energy conversion installations (such as power stations, refineries, etc.) and energy transmission and distribution networks (Scheepers, M.J.J., Seebregts, A.J., DeJong, J.J., Maters, J.M., 2007).
Aiming to design a model to review and assess EU's energy security, Scheepers et al. propose the S/D Index, together with the Crisis Capability Index (CC Index) and some qualitative considerations. The CC Index deals with the risk of sudden short-term supply interruptions and measures the capability of countries to manage them. The S/D Index is set to cover all possible relevant aspects of energy supply security in the medium to long term, integrating major supply-side and demand-side factors (Scheepers et al., 2007). The S/D Index Model includes all three parts of the energy system: final energy demand, energy conversion and transport, and primary energy supply (see Figure 4).

The S/D Index's design and applications are further elaborated by Kruyt et al. (2009) and Jansen et al. (2009).

Figure 4. The Supply/Demand Index model structure



Source: Scheepers et al. (2007), p.8

The IEA's energy security index:

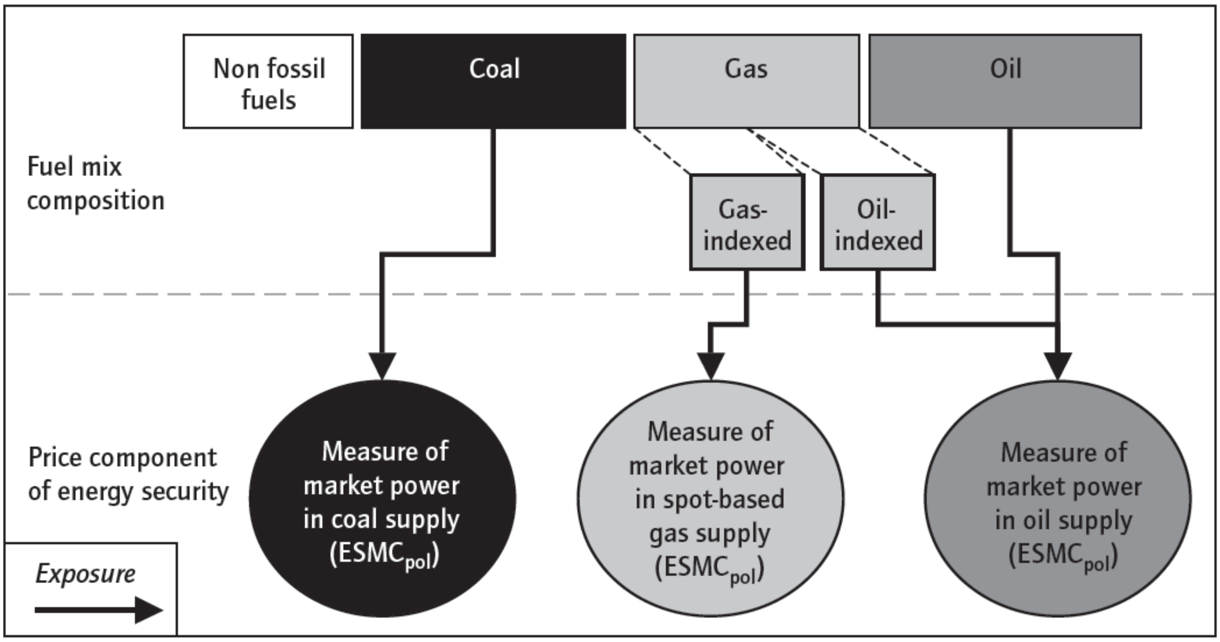
The IEA adopt the Herfindhal-Hirschman Index when they construct indicators to address the two components of energy security, i.e. the price and the physical availability of energy. The price component (Energy Security Index$_{price}$, ESI$_{price}$) is based on a modified measure of market concentration in each international fossil fuel market, referred to as the Energy Security Market Concentration (ESMC) whose basis is the HHI. This price indicator factors the risks of a given country which stem from supply market concentration (the idea here is "the more a country is exposed to high concentration markets the less it is secure"). The second component is the physical unavailability that is applied to markets where prices are regulated or indexed to oil, this indicator is called the Energy Security Index$_{volume}$ (ESI$_{volume}$) which focuses on pipe-based gas trade.

In case the fuel is natural gas, the situation is more complicated. When gas prices are set competitively, this is the same as in the case of oil and coal. However, when gas prices are indexed to oil, it is vulnerable to the energy security price risk in the oil market. In some

European markets, the gas trade is partly based on oil-indexed contracts and partly spot-based. Therefore, the share that is spot-based is exposed to gas market $ESMC_{pol}$ while the share that is oil-indexed is exposed to oil market $ESMC_{pol}$ (IEA, 2007). This process is shown in Figure 5 below.

Overall, a country who demonstrates overdependence on fossil fuels from only a small number of politically unstable supplier countries would receive a higher ESI_{price} than the situation where that country imported smaller quantities from a wider range of more politically stable suppliers (ECOFYS et al., 2009).

Figure 5. Measuring the price component of energy security



Source: (IEA, 2007, p.59)

Oil and natural gas vulnerability index:

An aggregated index of oil vulnerability is computed by Gupta (E. Gupta, 2008) when she assesses the relative oil vulnerability of 26 net oil-importing countries for the year 2004. She uses a modified Herfindhal-Hirschman Index of market concentration to calculate geopolitical oil market risk, based on the combination of three different indicators, namely, net oil import dependency, diversification of oil imports and political risks in oil-supplying countries. The statistical method *principal component analysis* (PCA) has been adopted in her approach in order to combine seven individual indicators to yield an overall index of oil vulnerability.

Gnansounou employs several simple indicators such as energy intensity, oil and gas import dependency, CO2 content of primary energy supply (and some other individual indicators) to compute a composite index using the PCA method. This composite index is defined to measure energy demand/supply weaknesses as a proxy of energy vulnerability for selected industrialised countries (Gnansounou E., 2008).

In another relevant paper, Roupas et al. (C. Roupas, A. Flamos & J. Psarras, 2009) compare the security of oil supply of the 27 countries of the European Union through the measurement of the vulnerability of their economies in the past episodes displayed to oil. The PCA has been applied to integrate six indicators into a synthetic index for the purpose of reflecting the core of vulnerability and security of supply. Afterwards, in a very similar fashion with the previous work (2009), they have another study concerning both oil and gas supply vulnerability in the EU member countries (C. Roupas et al., 2011).

Cabalu et al. (H. Cabalu and C. Manhutu, 2009) investigate the vulnerability of eight natural gas importing countries in Asia for the year 2006 using various market and supply risk indicators. In this study, the geopolitical risk indicator (among other market and supply risk indicators) is computed based on the adjusted Shannon diversity index. A composite index of gas vulnerability is then estimated by combining six individual indicators by means of the PCA techniques.

In a recent research, Biresselioglu et al. use various individual indicators and apply the PCA to create the supply security index for the purpose of assessing the natural gas supply security of 23 importing countries from different regions of the world in the 2001-2013 time frame (Biresselioglu et al., 2014).

3.2.3. Selection of indicators: advantages and drawbacks

As Kruyt et al. indicated, there is no ideal indicator as the notion of energy security is highly context dependent (Kruyt et al., 2009). Indeed, different indicators have their own strengths and weaknesses which in some cases depend on specific objective of the studies/research.

Simple indicators are deemed that cannot capture multi-dimensional concepts of energy security as composite indicators do. Composite indicators, however, also have their advantages and drawbacks. The favourable properties among other things are: "can summarise complex, multi-dimensional realities with a view to support decision-makers", "easier to interpret than a battery of many separate indicators" or "enable users to compare complex dimensions effectively". Some of the limitations of composite indicators are: "can be misused if the construction is not transparent or if it is not based on sound statistics and conceptual principles", and "the selection of indicators and weights could be the subject of debate", etc (OECD, 2008, p.13).

Nonetheless, in another case, simple indicators are supported. ECOFYS et al. suppose that: "no aggregate indicator provides an adequate measure of all the relevant root causes of energy insecurity and current attempts to do so lead to a strong trade-off in transparency" (ECOFYS et al., 2009, p.12) and "there is an inherent trade-off in the construction of more aggregated indicators, which aim to be more comprehensive in their assessment, but which can introduce subjectivity in the weighting of the different components against each other, and reduce the meaningfulness and transparency of the final results" (ECOFYS et al., 2009, p.38). Cherp et al. also point out that the limitations of quantitative and compound indices on their undercounting non-quantifiable concerns, uncertainties and non-linearities may be the reason that the policy usage of one-concern indicators (such as import dependency) is far greater than the usage of more sophisticated indicators or compound indices reflecting several concerns (Cherp et al., 2011).

Likewise, there are "pros and cons" views regarding the Shannon-Wiener diversity and the Herfindhal-Hirschman index. The SWI is mainly used for calculating diversity among fuels or generation options (Jansen et al., 2004; APERC, 2007) and the HHI is exclusively used in case of market concentration. Stirling (1998) favours the SWI for its fundamental mathematical grounds. The HHI is attractive for its transparency, elegance and mathematical tractability, its weakness shows when taking qualitative information about different supply options into account. Nevertheless, both indicators are still considered indispensable complements in any security of supply debate (Nuclear Energy Agency, 2010).

Although the Shannon index based (Jansen et al., 2004) is seen as instructive for its attempt to combine a number of energy security concerns into a single (aggregated) indicator, there is still the question of the weighting of the importance of the different factors against each other (e.g. should resource depletion be given greater importance than diversity?). The matter depends on the country's circumstances, yet this Stirling's diversity based approach may be seen as overly complex (IEA, 2007).

An advantage of the S/D Index in comparison with other alternative measures is its relative comprehensiveness for covering all elements of the energy supply chain, with the inclusion of some important demand-side aspects. Nevertheless, its drawbacks are also pointed out on its lack of transparency, less well capturing the geopolitical dimensions, and the final objectivity of the results is reduced due to the aggregation of the various components throughout the S/D Index (Jansen et al., 2009).

In sum, different indicators indicate different roles – measuring energy security with different goals, assumptions and definitions of energy security. Given the subjective and context-dependent nature of energy supply security, no single quantitative indicator can capture all aspects of energy supply security. They are therefore only valuable in a certain context. Thus, one should consider the roles of energy supply security indicators while designing and define the indicators depending on particular purposes and perspectives of the study, such as short or long term security purpose, internal or external dimension, availability or accessibility aspect; as well as circumstances of related countries/regions.

Chapter 4

Methodology

As the aim of this thesis is to assess the security of natural gas supply of the major importing countries in Europe, it is crucial to apply a methodology which will take into account the main factors that affect the supply of a primary energy fuel, specifically natural gas in this case. In order to measure the security of gas supply of selected countries, a set of various quantitative indicators which capture the main aspects of the supply security will be defined. However, by observing these individual indicators we can hardly figure out whether an importer country is secure in terms of gas supply, how the degree of security of that country changes over time, or more or less secure in comparison with other countries in the sample set. In order to solve these issues, an aggregated indicator is required to visualize and quantify relations between many different indicators. The individual indicators therefore will be transformed into a single (synthetic) index that measures the supply security of each importer country. The transformation process is conducted by means of statistical techniques of the Principal Component Analysis (PCA).

4.1. The basics of Principal Component Analysis

The method used to analyse the data set in this paper is Principal Component Analysis (PCA). There are a number of reasons that PCA method has been chosen for this study. First, this method has been commonly used in the existing literature, e.g. (E. Gupta, 2008), (Biresselioglu et al., 2014), (H. Cabalu and C. Alfonso, 2013) and other papers which have been discussed in Chapter 3 in the literature review (see the section of *"Oil and natural gas vulnerability index"*). Second, PCA allows us to produce a dependent variable as a synthetic index score by indexing through the selected indicators. PCA's techniques are useful for gaining insight into the structure of the data set.

This section provides the fundamental aspects of Principal Component Analysis. First part of the section gives a brief introduction of PCA, the other two succeeding subsections describe the key definitions and terminology used in PCA, and a mathematical background of PCA. For further details refer to the references mentioned below.

The main references used in this section are the books of "Using Multivariate Statistics" (Tabachnick, B. G., and Fidell, L. S., 2007), "Multivariate Data Analysis" (Hair Jr, J.F., Black, W.C., Babin, B.J., and Anderson, R.E., 2009), "Principal Component Analysis" (Jolliffe, T., 2002), and "Applied Multivariate Analysis" (Neil H. Timm, 2002). Some other additional references are (Y. Keho, 2012) and (OECD, 2008).

4.1.1. Introduction

Principal Component Analysis is one of multivariate analysis techniques. Multivariate analysis refers to all statistical techniques that involve observation and analysis of more than two variables at a time (simultaneously). When we have to observe a large set of variables, there may exist redundancy in those variables. Redundancy happens when some of the variables are correlated with one another, maybe because they overlap (or measure the same "thing"). In this case, we do not need to include all the variables in our analysis, but only the ones which represent the most of the variance in the original data set. However, there will be the questions of how to select or build the representative variables, which variables should be retained and which to be discarded, and so on. Principal Component Analysis answers these questions by reducing the dimensionality of the data set and transforming correlated variables into a new set of uncorrelated ones (called *principal components*).

According to Jolliffe (2002), it is generally accepted that the earliest descriptions of PCA's techniques were given by Pearson (K., Pearson, 1901) and Hotelling (H., Hotelling, 1933).

It is necessary to note Pearson's comments regarding computation, although he recognizes that the calculations become "cumbersome" for four or more variables, he states that they are still feasible and his methods "can be easily applied to numerical problems".

Hotelling suggests that there may be a smaller "fundamental set of independent variables… which determine the values" of the original p variables. He introduces the alternative term "components" for such variables, in order to avoid confusion with other uses of the word "factor" for those ones in mathematics. He calls his chosen "components", which maximize their successive contributions to the total variation of the original variables, the "principal components".

Jolliffe supposes that there seems to be very little relevant material to have been published in the 32 years between Pearson's and Hotelling's papers, and there has been a small amount of work on the development of applications of PCA after the publication of Hotelling's paper. The reason is that PCA requires large computing power. Despite Pearson's optimistic comments on the ease and feasibility of his methods, it is not really feasible to do PCA by hand (unless the number of variables, p, is around four or less). But PCA is most useful for large values of p, therefore just until after the widespread introduction of computers, the full potential of PCA's techniques could be actually utilized.

There are various statistical software packages that work well for PCA. Among others, we can list some commonly used ones, such as XLSTAT statistical software for MS Excel, SPSS Statistics (Statistical Package for the Social Sciences), SAS (Statistical Analysis System), and MATLAB.

4.1.2. Basic definitions

Before starting with the mathematics part of PCA, it is helpful to briefly review the key concepts and terms used which are important in PCA.

Indicator: single variable used in conjunction with one or more other variables to form a composite/aggregated measure.

Variance: indicates the spread of the data in a data set, it is stated as the average of the squared differences from the mean.

Correlation matrix: matrix showing the intercorrelations among all variables, the matrix is normally labelled **R**. **R** is a square and symmetrical correlation matrix.

Eigenvectors: a set of vectors u_i associated with a system of linear equations. Also known as characteristic vectors, or latent vectors.

Eigenvalues: associated with the eigenvector u_i, the eigenvalue for a given factor represents the amount of variance (in all the variables) accounted for by that factor. Also referred to as characteristic roots, or *latent roots*.

Principal components (PCs): the coordinates (linear combinations) of the original variables, represent the underlying dimensions that account for the original set of observed variables.

Orthogonal: mathematical relations of component (factor) axes to one another (at right angles, or 90 degrees), thought of as describing uncorrelated objects.

Loadings (or *component loadings*): correlation between the variables and the components (factors), indicating the degree of correspondence between them: higher loadings making the variable representative of the component. Component loadings explain the role each variable plays in determining each component.

4.1.3. The mathematics of PCA

Consider a data set consisting of p variables observed on n subjects, and correlation matrix **R** of full rank p. Variables are defined as $(x_1, x_2, \ldots, x_p)$. The data set can be seen as an $n \times p$ rectangular matrix X.

In most cases, the indicators in a data set often have different measurement units. Therefore, we assume that the data have been normalized[13] and the PCA in this case will be based on the correlation matrix **R** (and not on variance-covariance matrix[14]).

The primary idea of principal component analysis is to reduce the dimensionality of a data set which consists of a large number of correlated variables, whilst still retaining as much as possible the variation present in the data set.

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[13] Normalization procedure to be further described in Section 4.4.

[14] If the scales of measurement units are not commensurate, one should analyse correlation matrix R, otherwise variance-covariance matrix is used (Neil H. Timm, 2002).

$$x_i = \begin{pmatrix} x_{1i} \\ x_{2i} \\ \vdots \\ x_{pi} \end{pmatrix} \rightarrow \textit{reduce dimensionality} \rightarrow \quad z_i = \begin{pmatrix} z_{1i} \\ z_{2i} \\ \vdots \\ z_{qi} \end{pmatrix} \textit{ with } q < p$$

Dimensionality reduction means information loss. The question arises here is how to present the data in a lower dimensional form without losing too much information. Retaining as much information as possible is the goal of PCA.

Although there are *p* variables, $x_1, x_2, \ldots, x_p$, much of the variation in the data set can often be accounted for by a small number of variables – a new set of variables called *principal components* (PCs). The principal components are linear combinations of the original variables and can be stated as follows:

$$z_1 = \alpha_{11}x_1 + \alpha_{12}x_2 + \ldots + \alpha_{1p}x_p = u_1'X \qquad (4.1.3.1)$$

$$z_2 = \alpha_{21}x_1 + \alpha_{22}x_2 + \ldots + \alpha_{2p}x_p = u_2'X \qquad (4.1.3.2)$$

$$\vdots$$

$$z_p = \alpha_{p1}x_1 + \alpha_{p2}x_2 + \ldots + \alpha_{pp}x_p = u_p'X \qquad (4.1.3.3)$$

where the weights α_{ij} (also known as *loadings* or *component loadings*) are the elements of vectors u_i. At this point there are still *p* principal components, as many as there are original variables. The next step is to select the first $q < p$ principal components that "capture" a large amount of the cumulative variance of the original data.

To determine the first linear combination of X (equation 4.1.3.1), PCA finds a vector u_1 so that:

$$\text{var}\,(z_1) = \text{var}\,(u_1'X) \text{ is } \textbf{maximal} \qquad (4.1.3.4)$$

subject to the constraint that:

$$\textbf{s.t. } u_1'u_1 = 1 \qquad (4.1.3.5)$$

where u_1' is the transpose matrix of u_1. And u_1 is chosen to have unit length ($u_1'u_1 = 1$) then $\text{var}\,(z_1) = \lambda_1$, where var($z_1$) denotes the variance of z_1.

The vector that maximizes (4.1.3.4), s.t. the constraint that $u_1'u_1 = 1$, is the eigenvector (also called characteristic vector) associated with the largest eigenvalue (characteristic root) of the eigenequation:

$$|R - \lambda \mathrm{I}| = 0 \qquad (4.1.3.6)$$

where I is the identity matrix with the same order as **R**. λ is an eigenvalue of the correlation matrix **R** and u_i is the corresponding eigenvector. (For each λ one can solve $|R - \lambda \mathrm{I}|u_i = 0$ to find an eigenvector u_i).

Eigenvalues λ_i ($i = 1, 2, \ldots, p$) are the variance of the PCs and can be found by solving equation (4.1.3.6). The largest variance of z_1 is the largest eigenvalue λ_1 of (4.1.3.6), i.e.

$$\text{var}\,(z_1) = u_1'Ru_1 = \lambda_1 \qquad (4.1.3.7)$$

In order to find the second principal component z_2, linear combination (4.1.3.2) is constructed such that z_2 is ***orthogonal*** (uncorrelated) with the first principal component z_1 and has the largest part of the remaining variance (i.e. after the first PC has been extracted).

$$\text{var}\,(z_2) = u_2'Ru_2 = \lambda_2$$

is obtained again. So the second vector u_2 comes to be the second eigenvector of (4.1.3.6), corresponding to the second highest eigenvalue of **R**, namely λ_2, where $\lambda_2 < \lambda_1$.

Likewise, the PCA procedure is going further until the last of the principal components cover all the remaining variance which are not accounted for by the preceding components, where $\lambda_1 > \lambda_2 > \ldots > \lambda_p \geq 0$. However, since PCA's goal is to reduce dimensionality of the data set, only the first few q components ($q < p$) which are important enough for representing the data will be retained.

Eigenvalues are used to determine the meaningfulness of components. The higher eigenvalue of a component implies that the more representative the component is of the data. An exact quantitative basis or absolute threshold that states the number of components to extract (retain) has not been developed. However there are some criteria which are currently being utilized as a set of "rules of thumb". According to these criteria, only the initial components with eigenvalues greater than 1 and/or individually they contribute more than 10% of the total variance should be retained, and the computing (factoring) procedure should not be stopped until the extracted components meet a specified percent of the overall variance, usually 60% or higher (Hair et al., 2009).

The cumulative percent of variance explained by the first q principal components is calculated as follows:

$$r_q = \frac{\sum_{i=1}^{q} \lambda_i}{\sum_{i=1}^{p} \lambda_i} = \frac{\lambda_1 + \lambda_2 + \ldots + \lambda_q}{\lambda_1 + \lambda_2 + \ldots + \lambda_q + \ldots + \lambda_p} \times 100$$

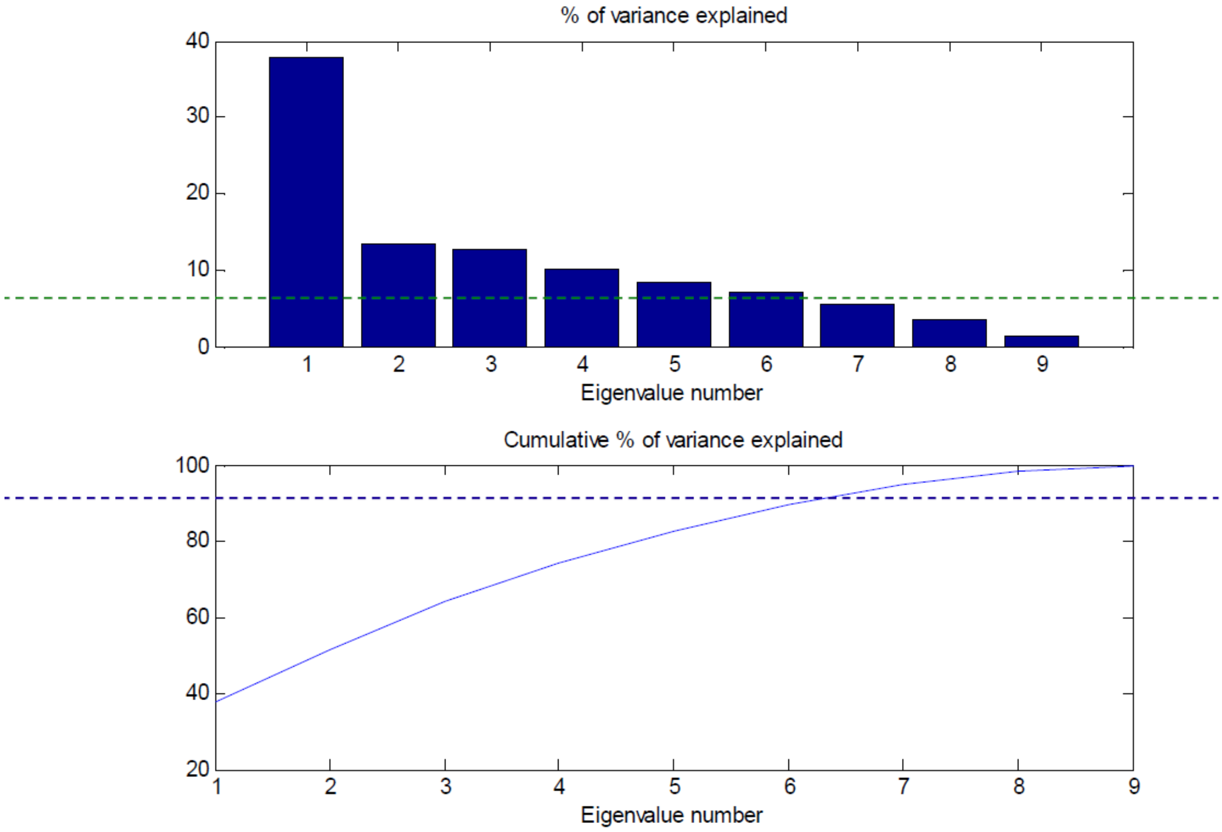
where λ_i's are sorted in descending order, and $q < p$. The criterion is graphically illustrated as shown in Figure 6.

In practice, most researchers seldom use a single criterion in determining the number of components to retain. Instead, several criteria are used at different stages of the factoring procedure to ensure the best structure; some can be used before the structure is well defined. Several proposed criteria include the Kaiser eigenvalue-one, the Cattell Scree test (Scree plot), and the cumulative percent of variance accounted for by (factors) components (see Figure 6).

Figure 6. Criteria:

1) Explained variance of a single eigenvalue below a threshold.

2) Total accounted variance above a threshold.



Source: (C.O.S. Sorzano, 2015)

4.2. Indicator selection

The selection of appropriate indicators is an essential stage for obtaining accurate results. Upon analysis of the existing literature, particularly the studies from Gupta, Biresselioglu et al.; and Cabalu & Alfonso (E. Gupta, 2008; Biresselioglu et al., 2014; H. Cabalu and C. Alfonso, 2013), six main indicators of natural gas supply security have been selected and used in this paper. The selected indicators are focusing mainly on the supply side of energy security in the medium to long-term perspectives. While short-term security of supply deals with disruptions to supply due to physical or economic factors, medium and long-term security concern structural aspects of the energy system and the root causes of those disruptions (such as inadequate investments in production and infrastructure, lack of supply diversity and risks associated with import dependency).

The formation of indicators involves the factors that specifically measure the *accessibility* dimension (such as the level of import dependency, the diversity of supply, political stability) and the *availability* dimension of security of supply (e.g. the overall level of demand for energy). The following subsections will elaborate on these indicators.

4.2.1. Volume of natural gas imported (X_1)

The volume of the natural gas imported for each selected country is measured in actual volume (in this case is *billion cubic metres, bcm*), as the indicator of import dependency will be shown in percentage and this percentage figure alone does not really reflect the actual scales when we compare countries' import dependency by percentage.

This indicator is calculated by subtracting natural gas production (NGP) volume from the total gas consumption (NGC) for each country "*j*" in the sample set. A negative value for natural gas import indicates that the country is a net exporter (as the case of the Netherlands).

$$X_{1j} = NGC_j - NGP_j$$

The effect of X_{1j} on the (aggregated) index is positive, as higher gas imports will increase the risk of gas supply security for importer country.

In fact, the volume of natural gas imported represented by X_1 is the necessary minimum import to meet country *j*'s consumption. Thus, it does not always match the quantity of natural gas that the country imported in reality. In some cases there exist considerable differences between the two figures, "calculated" volume (which is the difference of subtracting production volume from total gas consumption) and "actual" import amount. The reason is that some countries do not only import natural gas for meeting their domestic demand but also for re-export, such as in the case of Germany or the United Kingdom. Therefore, the "volume of natural gas imported" indicator is created taking the "calculated" volume in order to reflect the country's "real" extent of dependence on natural gas import, i.e. the import for its domestic demand satisfaction. (Detailed figures presenting the differences are provided in Appendix A).

4.2.2. Import dependency (X_2)

Import dependency is viewed as a widely used measure when discussing the energy security implications of resource concentration, in case a distinction between domestic and foreign resources can be made. Import dependency indicates the extent to which a country depends on imports of primary energy. This indicator and the volume of natural gas imported indicator (X_1) are regarded as a proxy for the vulnerability of the energy system to physical unavailability risks of imported energy sources (ECOFYS et al., 2009).

Import dependency is calculated by dividing natural gas production by the total gas consumption, then subtracting the result from 1.

$$X_{2j} = 1 - \frac{NGP_j}{NGC_j}$$

This indicator covers another similar measure in its formula, i.e. the ratio of domestic production to consumption, but import dependency reflects an external rather than domestic perspective. Similar to X_1 above, indicator X_2 is also positive related to the supply security index.

Reserves to production ratio (R/P) is a commonly used indicator but it is not included in this paper because this measure does not actually give a clear picture in all cases. Most of the countries in the sample set possess very small reserves along with negligible domestic production, which will result in very high R/P ratio.

Another alternative indicator is natural gas reserves to total energy consumption ratio. This was however rejected as it failed to fit with the remaining dataset (Biresselioglu et al., 2014).

4.2.3. Share of natural gas in total primary energy consumption (X_3)

Share of natural gas in total primary energy consumption states the rate of natural gas consumption in total primary energy consumption (TPEC).

$$X_{3j} = \frac{NGC_j}{TPEC_j}$$

This rate reflects the role of natural gas in the energy mix of each country. However, its effect on the composite index is positive, as increasing consumption also increases dependency on imports and on suppliers, and therefore raising the risk of security of supply to the importer country.

4.2.4. Number of natural gas suppliers (X_4)

The total number of natural gas suppliers is one of important factors indicating a key concept in the security of supply discussion – namely diversity. Importing countries with a larger number of suppliers have a higher level of diversification of gas import sources and therefore they are more secure.

X_{4j} = number of gas suppliers for country *"j"*

It is important to include the supply level of LNG in the assessment of supply security for importer countries. However, the total number of natural gas suppliers is included instead of simply taking into account LNG as a percentage of overall imports. It is likely that the countries with a larger number of gas suppliers will tend to include higher amounts of LNG in their overall gas imports (Biresselioglu et al., 2014).

This is the only indicator in the set that has negative effect on the supply security index, because a higher number of suppliers will decrease the supplier security risk to the importing country.

4.2.5. Dependency on largest supplier (X_5)

Whether the importing country exposes a diversified supply strategy or it heavily depends on a major supplier, the dependency on largest supplier indicator will capture this fact. It is computed by dividing the maximum volume of natural gas imported from the related supplier by the total natural gas imports (NGI).

$$X_{5j} = \frac{Max(m_{ij})}{NGI_j}$$

This indicator is made positively related to the security index, as a country who displays a high volume of natural gas import from only one supplying country will be facing greater supplier security risk.

4.2.6. Supplier fragility (X_6)

Geopolitical elements are captured by the last three indicators (i.e. X_4, X_5 and X_6). In the case of X_6, namely the supplier fragility indicator, it is specifically designed to enhance the essence of the geopolitical factors by determining a range of risks presented by supplier country, including both security and political risks.

This indicator is defined by employing the State Fragility Index which is developed by Marshall and Cole - Center for Systemic Peace. The State Fragility Index provides scores on both effectiveness and legitimacy in four different performance dimensions: security, political, economic and social for 167 countries in the world in which the total country population is greater than 500,000. The State Fragility Index ranges from 0 (i.e. "no fragility") to 25 ("extreme fragility") (Marshall, M. G., Cole, B. R., 2001-2013). Therefore, applying fragility index scores enable us to calculate the fragility of supplier countries.

The supplier fragility is defined by multiplying the state fragility index of the natural gas supplier (f_i) by the share of gas imported from the relevant supplying country (m_{ij}/NGI_j), the supplier fragility indicator is then obtained by adding up all of these products. This indicator is created in a similar fashion to the Shannon-Wiener diversity index.

$$X_{6j} = \sum_i f_i \left(\frac{m_{ij}}{NGI_j} \right)$$

The effect of X_6 on the security index is positive, as a high level of fragility of the supplying country increases the supplier security risk to the importer country.

4.3. Data

The sample consists of 11 countries: Germany, United Kingdom, Italy, the Netherlands, Turkey, France, Spain, Belgium, Austria, Czech Republic and Poland.

The first eight countries are chosen because they are the major gas consumers and importers in Europe, these countries account for 80% of total natural gas consumption in Europe in 2013. The Netherlands is an exception among this group, as the country imported a large volume of gas (about 26 bcm in 2012, 29 bcm in 2014[15]) but is a net gas exporter (Honoré A., 2014; IEA, 2014c). Although Austria, Czech Republic and Poland are not the major natural gas importers in the region, they are included in this paper because their heavy import dependence on only one large gas supplier (namely Russia) could complete the picture when assessing security of supply in major gas consuming countries in Europe.

In the case of Turkey, it is in fact not a member of the European Union and not considered a European country either. Turkey is included in this study because of its geographical and geopolitical importance: a major market for energy supplies (as a net importer, the country imported 90% of its oil and almost 100% of its natural gas in 2012 – *EIA, U.S. Energy Information Administration database*), holding a strategic role as an oil and gas transit hub between Russia, the Caspian region, and the Middle East to continental Europe. Turkey is also a member of OECD Europe.

The data of this study cover the period of 2001-2014 for 11 selected countries. "*Volume of natural gas imported*" and "*Import dependency*" indicators are calculated using data from U.S. Energy Information Administration's database (EIA). EIA data were collected because they provide sufficient information on the small production and consumption volumes, which were not available in BP's annual reports as they rounded down to zero for the small volumes less than 0.05 bcm. The indicators of "*Share of natural gas in total primary energy consumption*", "*Number of natural gas suppliers*" and "*Dependency on largest supplier*" are calculated based on the data from BP's annual reports (BP Statistical Review of World Energy) for each of related years. The "*Supplier fragility*" indicator is obtained by employing

[15] EIA, U.S. Energy Information Administration database.

the State Fragility Index which is developed by Marshall and Cole - Center for Systemic Peace (Marshall, M. G., Cole, B. R., 2001-2013).

In some cases data were not always available, assumptions therefore were sometimes needed for a few countries, for example those concerning the origins of natural gas imports, or the State Fragility Index for supplier countries (e.g. where data of early 2007 were assumed applicable to the year 2005, and data of 2013 were applied to 2014). However, in these cases, the most favourable values were assumed thus it would create almost no effect on the final analysis results.

4.4. Research model

The method applied to assess the natural gas supply security of selected importing countries in this paper is the PCA (principal component analysis). The central idea of the PCA here is to calculate natural gas supply security as an unobserved or latent variable which cannot be measured or observed directly but is measured indirectly through some observed variables. This latent variable is the dependent variable, being computed as a synthetic index by assuming that it is linearly related with the independent variables, i.e. the six indicators described above. The (natural gas) supply security index (SSI) is constructed as follows:

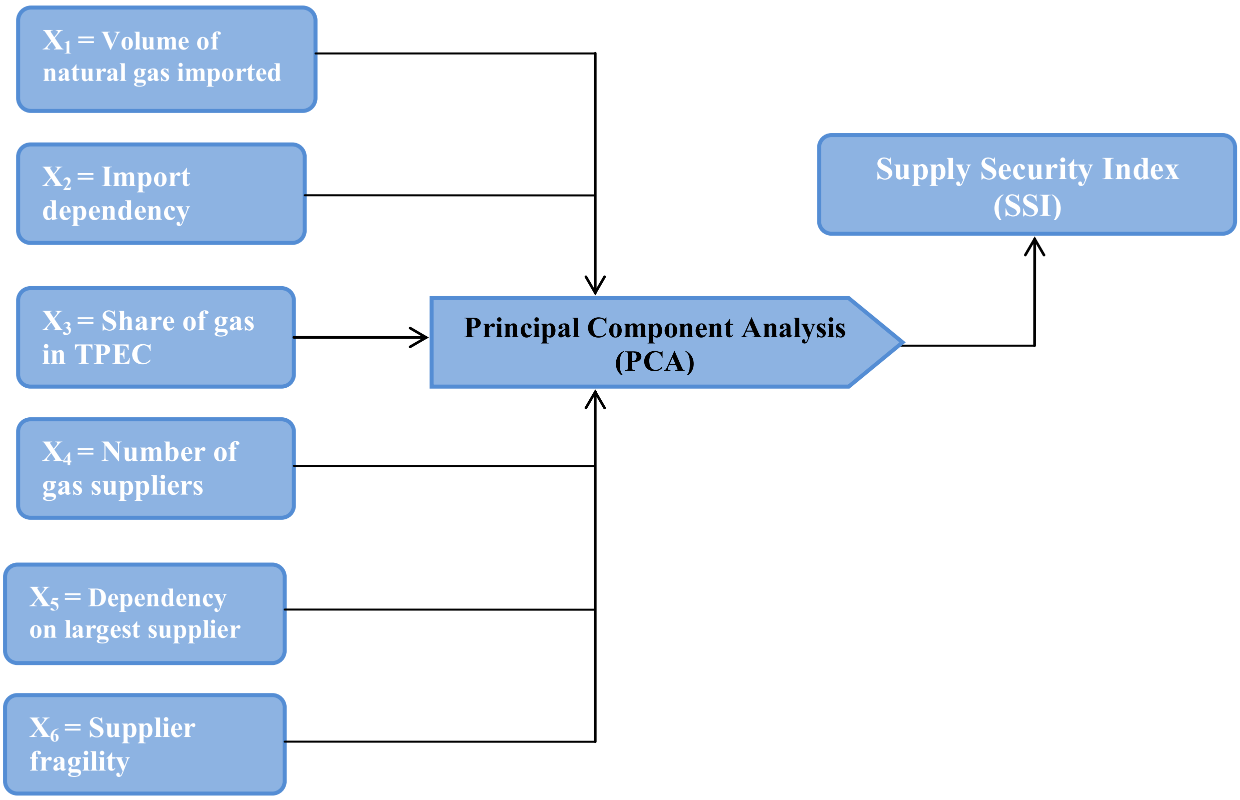
$$SSI_j = \beta_1 X_{1j} + \beta_2 X_{2j} + \beta_3 X_{3j} + \beta_4 X_{4j} + \beta_5 X_{5j} + \beta_6 X_{6j} + \varepsilon \quad (4.4.1)$$

where:

- SSI_j is the supply security index of country "j",
- X_{1j}...X_{6j} denote the set of proposed indicators corresponding to country "j", these indicators were used for capturing the main elements of supply security, i.e. market risk and supply risk,
- β_1...β_6 are the corresponding vectors of parameters in each domain,
- and "ε" is the error term.

The total variation in the index for natural gas supply security is composed of the variation due to sets of selected indicators, and the variation due to error[16]. The model is illustrated in Figure 7 below.

Figure 7. Formulation of the synthetic index SSI consisting of six indicators.



Author's illustration

The indicators in the data set have different measurement units. In order to "avoid adding up apples and oranges" (OECD, 2008, p.27), normalization is required prior to computing the principal components (PCs). The selected indicators are transformed by using one of the normalization methods, i.e. Min-Max method, thereby having the indicators in an identical interval [0, 1]. The original indicators are rescaled in the following manner:

$$\gamma_{ij} = \frac{X_{ij} - Min(X_i)}{Max(X_i) - Min(X_i)}$$

for i = 1, 2, 3, 5, 6 (*positively* related to the supply security risk)

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[16] The variation in the error term is caused by the factors that could impact natural gas supply security but have not been considered in the study (E. Gupta, 2008).

$$\gamma_{ij} = \frac{Max(X_i) - X_{ij}}{Max(X_i) - Min(X_i)}$$ for i = 4 (*negatively* related to the supply security risk)

$\gamma_{1j} \ldots \gamma_{6j}$ are the relative indicators related to the original indicators $X_{1j} \ldots X_{6j}$. Indicators X_1, X_2, X_3, X_5, X_6 are made positively, whilst X_4 is made negatively related to the SSI.

A low value of γ_{ij} means that the country *j* has a low value of the supply security indicator, with "0" represents the lowest value, whereas "1" is assigned to the highest value of the selected supply security indicator for that country. Table 6 represents calculations for the relative indicators which are scaled (normalized) values of the six original supply security indicators, data 2001. (Calculation of the year 2014 is provided in Appendix B).

Table 6. Relative (scaled) and original indicators (2001)

	X_1	γ_1	X_2	γ_2	X_3	γ_3	X_4	γ_4	X_5	γ_5	X_6	γ_6
Austria	6.42	0.35	0.79	0.86	0.21	0.33	3	0.83	0.86	0.95	7.94	0.49
Belgium	15.48	0.44	1.00	1.00	0.21	0.32	6	0.33	0.49	0.30	3.32	0.13
Czech Republic	9.74	0.39	0.98	0.99	0.19	0.27	2	1.00	0.82	0.87	7.71	0.47
France	39.74	0.69	0.95	0.97	0.14	0.09	7	0.17	0.31	0.00	7.37	0.45
Germany	69.50	1.00	0.76	0.84	0.22	0.38	5	0.50	0.42	0.19	4.38	0.21
Italy	55.70	0.86	0.79	0.86	0.33	0.75	5	0.50	0.44	0.22	11.81	0.79
Netherlands	-27.70	0.00	-0.55	0.00	0.40	1.00	3	0.83	0.57	0.45	2.07	0.03
Poland	8.17	0.37	0.60	0.74	0.12	0.00	3	0.83	0.89	1.00	8.13	0.51
Spain	17.44	0.46	0.97	0.98	0.12	0.02	8	0.00	0.67	0.61	14.47	1.00
Turkey	15.63	0.45	0.98	0.99	0.20	0.29	4	0.67	0.69	0.65	11.71	0.78
United Kingdom	-9.95	0.18	-0.11	0.29	0.38	0.95	2	1.00	0.81	0.87	1.63	0.00

Note: Variable X_1 = Volume of natural gas imported, X_2 = Import dependency, X_3 = Share of gas in total primary energy consumption, X_4 = Number of gas suppliers, X_5 = Dependency on largest supplier, X_6 = Supplier fragility. $\gamma_1 \ldots \gamma_6$ are the scaled values of the corresponding indicators $X_1 \ldots X_6$.

Source: Author's computation[17]

The software used to support PCA analysis in this paper is **IBM SPSS Statistics** Version 22 - Statistical Package for the Social Sciences.

[17] Other figures and tables added later on are the author's illustrations/computations; unless otherwise stated.

First, 6x6 correlation matrix R of the normalized indicators was calculated in order to test if we have appropriate correlations to carry out the PCA. No correlation between any of the variables means that there is a set of uncorrelated axes, which would make the use of PCA inappropriate (Biresselioglu et al., 2014). PCA requires that there should be some correlations greater than 0.30 between variables in the analysis. Here we have 12 correlations in the matrix (for data of the year 2001) greater than 0.30, which satisfy this requirement (Table 7). Data analyses for other years (2005, 2010 and 2014) also meet the requirement.

Table 7. Correlation matrix (2001)

Indicator	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6
γ_1	1					
γ_2	0.617	1				
γ_3	-0.319	-0.786	1			
γ_4	-0.511	-0.496	0.460	1		
γ_5	-0.609	-0.149	-0.075	0.666	1	
γ_6	0.339	0.627	-0.541	-0.434	0.062	1

Note: $\gamma_1 \ldots \gamma_6$ are the relative indicators or scaled values of the original indicators $X_1 \ldots X_6$

Besides looking at the correlation matrix we can also consider some other methods for testing the factorability of the data. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy provides an index ranges from 0 to 1. KMO values must exceed 0.50. Values closer to 1 are better, above 0.80 is considered "*meritorious*" and below 0.50 "*unacceptable*". The Bartlett's Test of Sphericity compares the correlation matrix with an identity matrix (a matrix of zero correlations). The null hypothesis is rejected when the level of significance exceeds 0.05; i.e. sig < 0.05 is acceptable (Hair et al., 2009, see "Rules of Thumb 2"). The Bartlett's Test of Sphericity is, however, referred to as less reliable for small sample sizes.

Table 8 shows the results of KMO and Bartlett's Test (data 2001) that satisfy the requirements. Although the overall KMO of 0.544 is not among the "*meritorious*" values, it meets the requirement (> 0.5).

Table 8. Results of KMO and Bartlett's Test (data 2001)

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.544
Bartlett's Test of Sphericity	Approx. Chi-Square	31.222
	df	15
	Sig.	.008

After the data was deemed to be appropriate for principal component analysis, eigenvalues and eigenvectors will be computed so as to obtain principal components.

Table 9 displays the eigenvalues, percent of variance, and cumulative percent of variance from the observed data 2001. The table shows the importance of each of the six components. According to the Kaiser method (eigenvalue-one criterion), at first glance the first and the second component should be extracted as they account for a meaningful amount of variance (79.36%) and have eigenvalues greater than 1. Other subsequent components with eigenvalues less than one, or each contributes less than 10% of the overall variance, are of little use and will not be retained. An illustration is shown in the scree plot in Figure 8.

Table 9. Eigenvalues and total variance explained (data 2001)

Eigenvalues	Value	Proportion of Variance (%)	Cumulative (%)
λ_1	3.220	53.67	53.67
λ_2	1.541	25.69	79.36
λ_3	0.551	9.19	88.55
λ_4	0.482	8.03	96.59
λ_5	0.130	2.17	98.75
λ_6	0.075	1.25	100

The eigenvalues λ are arranged in descending order, $\lambda_1 > \lambda_2 > \lambda_3 > \lambda_4 > \lambda_5 > \lambda_6$. Eigenvectors and eigenvalues always come in pairs, thus corresponding to each λ is a 1 x 6 eigenvector F. Here we have six eigenvectors $F_1, F_2, F_3, F_4, F_5, F_6$ which correspond to $\lambda_1 > \lambda_2 > \lambda_3 > \lambda_4 > \lambda_5 > \lambda_6$ (Table 10). While eigenvector indicates its orientation (direction) in space, eigenvalue represents the amount of variation regarding that direction. The eigenvector with the largest eigenvalue is the one that points to the direction which has greatest variation. It specifies the most important relationship between the data dimensions.

Figure 8. Scree Plot (2001)

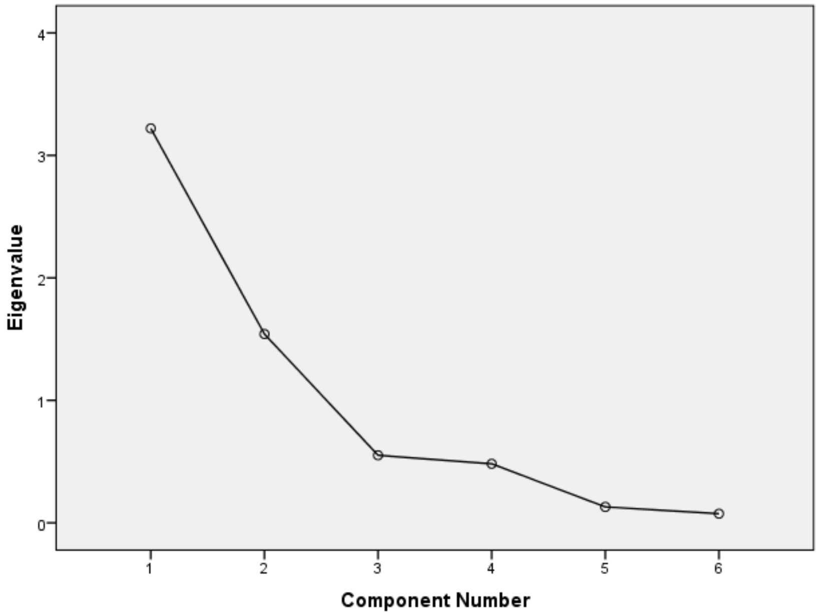


Table 10. Eigenvectors (2001)

Indicators	F_1	F_2	F_3	F_4	F_5	F_6
γ_1	0.4263	-0.2934	0.6353	0.2375	-0.4671	0.2325
γ_2	0.4885	0.2411	0.3260	-0.1394	0.7440	0.1548
γ_3	-0.4109	-0.4075	0.0353	0.5872	0.4172	0.3807
γ_4	-0.4445	0.2710	0.6258	0.1481	0.0735	-0.5567
γ_5	-0.2583	0.6949	0.0889	0.0435	-0.2169	0.6273
γ_6	0.3827	0.3653	-0.2989	0.7453	-0.0426	-0.2711

The principal components (PCs), P_{ij}, are then computed in the following manner:

$$P_{1j} = \gamma_{1j} F_1'$$
$$\vdots$$
$$P_{6j} = \gamma_{6j} F_6'$$

where:

$F_i = [f_1, f_2, ..., f_6]$ is a 1 x 6 eigenvector corresponding to eigenvalues $\lambda_1 > \lambda_2 > \lambda_3 > ... > \lambda_6 \geq 0$, subject to the condition that $F_i' F_i = 1$;

γ_{ij} is a vector of normalized indicators for country j.

Alternative way to compute principal components is taking *component loadings* in the component matrix obtaining from SPSS output by analysing the normalized variables, where loadings are the correlation of each variable and the component. Loadings are described as the *weights* (coefficients) in the linear combinations in Eqs. (4.1.3.1) - (4.1.3.3), Section 4.1.3. We can briefly indicate a simplified formulation of loadings as below:

$$Loadings = Eigenvectors * \sqrt{Eigenvalues}$$

It is known that one of the motivations for principal components analysis is to reduce the dimensionality of a data set by extracting the first ($q < p$) principal components that "capture" a large amount of the cumulative variance of the original data. However, where there is no clear-cut best solution in a case like this, we should follow the rule of thumb which is usually applied in the natural science to extract the components which account for at least 95% of the variance, or until the last component accounts for only a small portion, i.e. less than 5% (Hair et al., 2009, *"Percentage of variance criterion", p.109*). Therefore, in this case we will retain the first four components, not just the first two as seen earlier at first glance. The first and second components are obvious to be extracted for the reasons explained above. The third component has an eigenvalue of 0.551 but accounts for 9.19% of the overall variance, which is not too far from the 10% criterion. The fourth component accounts for 8.03% which is very close to 9.19% from the third component, we may consider retaining this component as well[18]. The situation is also illustrated in the involved scree test (Figure 8) where the plot does not really show a sharp break, it just begins to level off after the fifth component. Other remaining components after the "leveling-off point" (i.e. 5 and 6) are regarded as insignificant.

Table 11 compares the component matrices when three and four components are extracted (Component Matrix **a** and **b**). Note that the first three components are exactly the same in both cases, and each will still be the same as when we extract all the six components. The reason is that each component's portion of variability is extracted sequentially, so that later extracted components are not affected by the previous ones (Daniel T. Larose , 2006).

[18] The resulting differences from extracting two, three and four components are shown later in the country rankings which are based on the SSI scores.

Table 11. Component Matrix (2001)

Component Matrix[a]

Variables	Component		
	1	2	3
X_1	.765	-.364	.472
X_2	.877	.299	.242
X_3	-.737	-.506	.026
X_4	-.798	.336	.465
X_5	-.464	.863	.066
X_6	.687	.453	-.222

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

Component Matrix[b]

Variables	Component			
	1	2	3	4
X_1	.765	-.364	.472	.165
X_2	.877	.299	.242	-.097
X_3	-.737	-.506	.026	.408
X_4	-.798	.336	.465	.103
X_5	-.464	.863	.066	.030
X_6	.687	.453	-.222	.517

Extraction Method: Principal Component Analysis.

b. 4 components extracted.

Note: X_1 Volume of natural gas imported, X_2 Import dependency, X_3 Share of natural gas in total primary energy consumption, X_4 Number of gas suppliers, X_5 Dependency on largest supplier, X_6 Supplier fragility.

The component scores for principal components for each country are then calculated by multiplying normalized value on each variable (from Table 6) by the corresponding loading of the variable for the given principal component, and summing these products.

Taking the data from "component matrix b" (Table 11) and the normalized indicators (Table 6), we obtain the principal components for each subject (country) in this fashion:

$$PC_1 = 0.765*\gamma_1 + 0.877*\gamma_2 - 0.737*\gamma_3 - 0.798*\gamma_4 - 0.464*\gamma_5 + 0.687*\gamma_6$$

Other remaining PCs are computed in a similar fashion. The first PC accounts for the maximal amount of variance of the original indicators (eigenvalue of 3.220 in Table 9). The second PC is orthogonal with the first PC and accounts for the maximum amount of the remaining variance (with a variance of 1.541) after that associated with the first PC has been extracted; and so on. Each successive PC is orthogonal with all of the prior PCs. The resulting PCs are shown in Table 12.

Table 12. Principal components (2001)

	Austria	Belgium	Czech Republic	France	Germany	Italy	Netherlands	Poland	Spain	Turkey	U.K
PC_1	0.0153	0.6646	0.0889	1.4864	0.8864	0.9024	-1.5866	0.1521	1.6039	0.6952	-1.5051
PC_2	1.2883	0.4095	1.3186	0.2491	0.1291	0.2876	0.1770	1.4604	1.0971	1.1252	0.6244
PC_3	0.7240	0.6057	0.8452	0.5430	0.8833	0.7041	0.4355	0.6946	0.2757	0.6355	0.7027
PC_4	0.4769	0.2186	0.4514	0.3070	0.4049	0.8315	0.5247	0.3668	0.5255	0.5924	0.5173

Finally, the supply security index SSI for each country is computed as a weighted sum of six[19] principal components P_{ij}, in which weights are the corresponding proportion of total variance accounted for by that P_{ij} (E. Gupta, 2008).

$$SSI_j = \frac{\lambda_1 P_{1j} + \lambda_2 P_{2j} + \lambda_3 P_{3j} + \lambda_4 P_{4j} + \lambda_5 P_{5j} + \lambda_6 P_{6j}}{\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6} \quad (4.4.2)$$

It is essential to note that $\lambda_i = var\ (P_i)$, as indicated earlier in equation (4.1.3.7), Section 4.1.3, thus the total variation in the SSI equals the summation of $\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6$. The proportion of total variance accounted for by a PC, P_{ij}, is therefore equal to $\lambda_i/\Sigma\lambda_i$.

Consider the case when four components are extracted as shown in Table 12. The four components explained 96.59% of the total variation, with the first, second, third, and fourth components explaining 53.67%, 25.69%, 9.19% and 8.03% respectively. Using the proportion of these percentages as weights on the principal component coefficients, an SSI is developed for each country *j* as follows:

$SSI_j = (53.67/96.59)*PC_1 + (25.69/96.59)*PC_2 + (9.19/96.59)*PC_3 + (8.03/96.59)*PC_4$

Note that these proportions also equal the proportions of eigenvalues $\lambda_i/(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)$, e.g. 3.220/5.795, 1.541/5.795, and so on (see Table 9 for eigenvalues).

The value of the index can be positive and negative which makes it difficult to interpret. Therefore, a standardized index will be created using the formula:

$$Score_i = \frac{NSS_i - NSS_{\min}}{NSS_{\max} - NSS_{\min}}$$

where *NSS* denotes "*non-standardized score*", NSS_{min} and NSS_{max} are the minimum and maximum values of the non-standardized scores.

[19] In fact, all the six PCs are retained during implementing the principal component analysis using SPSS. The purpose is to ensure 100% of the variables' variation being explained by the components, because we are not focusing on just the total amount of variance but also work out the degree of explanation for the individual indicators in determining the SSI score in subsequent analyses; and to ensure consistency in comparisons of the SSI scores throughout the period 2001-2014.

Table 13 shows both the original and standardized scores. Using the standardized SSI scores, countries are sorted in ascending order. The *lower* scores represent *higher* level of security of supply.

Table 13. Index scores with 4 components extracted (2001)

	Country	Scores	Standardized scores
1	Netherlands	-0.750	0.000
2	United Kingdom	-0.560	0.094
3	Austria	0.460	0.604
4	Czech Republic	0.518	0.633
5	Belgium	0.554	0.651
6	Poland	0.570	0.659
7	Germany	0.645	0.696
8	Italy	0.714	0.731
9	Turkey	0.795	0.771
10	France	0.969	0.858
11	Spain	1.253	1.000

The scores in the case when three components are extracted are quite similar to those in the case when four components are extracted. And the country rankings in both cases are exactly the same. However, the result is slightly different from that for the case when only two components are retained. This is shown in Table 14, where the scores and ranking of Belgium and Poland are changing.

The difference in the results indicates that for this case we should extract the first three or four components, which account for up to 88.55% to 96.59% of the total variance of the six variables, and that 9.19% of the variance (which is very close to the 10% criterion) explained by the third component may contribute to a more accurate result.

Table 14. Index scores* (2001), 3 versus 2 PCs

3 components extracted			**2 components extracted**		
	Country	Scores		Country	Scores
1	Netherlands	0.000	1	Netherlands	0.000
2	United Kingdom	0.095	2	United Kingdom	0.081
3	Austria	0.606	3	Austria	0.588
4	Czech Republic	0.636	4	Czech Republic	0.612
5	*Belgium*	0.664	**5**	*Poland*	0.648
6	*Poland*	0.665	**6**	*Belgium*	0.651
7	Germany	0.701	7	Germany	0.675
8	Italy	0.718	8	Italy	0.700
9	Turkey	0.769	9	Turkey	0.753
10	France	0.867	10	France	0.856
11	Spain	1.000	11	Spain	1.000

*Scores are standardized; higher values correspond to higher risk of supply security.

Chapter 5

Empirical Results and Discussions

The intention of the study is to analyse the security of natural gas supply of the selected importing countries in the period 2000-2015, represented by the four 5-year intervals 2000, 2005, 2010 and 2015. However, data for 2000 and 2015 are not available, thus analyses will be made for 2001, 2005, 2010 and 2014. The results will be shown for the year 2014 and other remaining years in order to demonstrate the effects of a country's natural gas import policies to its position in the ranking. A detailed analysis will be focused on the year 2014, the most recent year, and therefore would be the most useful to reveal the preferences of the secure countries as well as the important factors and their relevant effects on the security of supply.

5.1. Discussing SSI values

We start the analysis with the final values of the aggregated indicator SSI for all the countries, as shown in Table 15. The results present the overall performance of the selected countries throughout the examined period 2001-2014. The countries are displayed in ascending rank order, with higher scores representing higher risk of supply security.

As shown in the results, there is not much difference in the rankings of the countries from the year 2001 to 2010.

The Netherlands and the United Kingdom are on top as the two best performers whereas Turkey, France, Italy and Spain appear to be the least secure countries on the list. It is not surprising that the Netherlands always ranks as the most secure country in the sample. As discussed in the earlier sections, although the Netherlands imported a considerable amount of natural gas (around 25.74 and 29.11 bcm in 2010 and 2014 respectively[20]) and its share of gas in total primary energy consumption amounts to 36%-40%, the country is a natural gas net exporter. Obviously, the Netherlands does not depend on gas import or other factors which are related to import dependency and supply uncertainty. The United Kingdom is also one of the most secure countries owing to its large indigenous production which covered 110.53%, 92.36% and 59.6% of the country's consumption in 2001, 2005 and 2010 respectively[21].

Table 15. SSI scores from 2001 to 2014

	2001		2005		2010		2014	
1	Netherlands	0.000	Netherlands	0.000	Netherlands	0.000	Netherlands	0.000
2	United Kingdom	0.095	United Kingdom	0.293	United Kingdom	0.470	United Kingdom	0.508
3	Austria	0.604	Austria	0.649	Austria	0.490	Belgium	0.546
4	Czech Republic	0.633	Belgium	0.680	Poland	0.510	Austria	0.624
5	Belgium	0.652	Czech Republic	0.754	Czech Republic	0.537	Italy	0.715
6	Poland	0.658	Poland	0.755	Belgium	0.604	Germany	0.738
7	Germany	0.696	Germany	0.766	Germany	0.670	Czech Republic	0.790
8	Italy	0.731	Italy	0.814	Turkey	0.844	France	0.832
9	Turkey	0.772	Turkey	0.829	France	0.853	Turkey	0.874
10	France	0.858	France	0.910	Italy	0.860	Poland	0.881
11	Spain	1.000	Spain	1.000	Spain	1.000	Spain	1.000
	Average	*0.609*	*Average*	*0.677*	*Average*	*0.622*	*Average*	*0.683*

The group of countries with medium-level security of supply in this period includes Austria, Belgium, Czech Republic, Poland and Germany. These countries have lower volume of imported natural gas (except Germany) and/or mostly stable origins of imports (their imports are from politically stable supplier countries[22]).

The remaining countries, Italy, Turkey, France and Spain have high index scores due to their larger volume of imported natural gas (and therefore more reliance on gas imports) and their politically unstable supplier countries (such as Algeria, Nigeria and some other suppliers from the Middle East) which resulted in higher levels of supplier fragility.

[20, 21] EIA, U.S. Energy Information Administration database.

[22] Actually, as explained in Chapter 4, the State Fragility Index used to develop X_6 (supplier fragility) is based not only on political stability but on four different performace dimensions: security, political, economic and social. However, we use the term "*politically stable*" repeatedly in this paper for brevity.

Afterwards, between 2010 and 2014, there is a notable change where Poland and Italy almost switched their positions. Poland fell from the fourth position in 2010 to close to the bottom of the list in 2014 (just above Spain), ranked as the second least secure country in this year. Poland's abrupt change in position is explained by the country's weaknesses in both dimensions, diversification of supply sources and dependency on a single supplier, indicated by the lowest number of gas suppliers and the highest degree of dependency on a single supplier. Apart from that, in 2014 Poland's gas consumption increased, while other remaining countries in the sample, except Turkey, are decreasing their gas use (see Table 16). In this year the country's performances on the other indicators are not good either.

Italy considerably improved its ranking between 2010 and 2014 mainly because the country performed well on the volume of gas imported and the fragility of supplier. In fact, Italy had substantially reduced its gas consumption, giving in turn a slight improvement on the import dependency as well. The country had moved a large volume of gas import from Algeria in 2010 to Russia in 2014, creating a better figure on the supplier fragility, as the "State Fragility Index" for Russia is better than that of Algeria. Additionally, Italy's performance on the number of gas suppliers and dependency on largest supplier is relatively good compared to the other countries.

Spain ranked constantly as the least secure country throughout the period 2001-2014. Although Spain has the greatest extent of diversity of the origins of imports compared to other countries in the sample, the country faces the problem of having the highest level of the fragility of supplier. Most of the gas imports in Spain came from the countries where political stability is low, such as Algeria, Nigeria, Egypt and Qatar. Further, Spain's indigenous gas production is very small (3% in 2001) and even declining, thus the country's import dependency amounts to 100% from 2005 onwards, in spite of its decreasing consumption.

Table 16. Natural gas consumption (bcm)[23]

	2001	2005	2010	2014	% of change (2010-2014)
Austria	8.15	10.01	10.01	7.76	-22.41
Belgium	15.48	17.03	19.81	15.80	-20.25
Czech Republic	9.90	9.49	9.28	7.51	-19.09
France	41.65	49.28	47.99	35.77	-25.47
Germany	91.73	90.69	94.25	77.48	-17.79
Italy	70.94	86.27	83.10	61.91	-25.49
Netherlands	50.09	49.30	54.85	39.98	-27.10
Poland	13.64	16.23	17.16	17.86	**4.12**
Spain	17.96	33.63	35.82	27.16	-24.18
Turkey	15.94	27.38	38.13	48.46	**27.09**
United Kingdom	94.52	95.59	94.48	70.25	-25.65

5.2. Relative importance of the individual indicators in the SSI

The analysis which has been done so far is based on the aggregated SSI. However, it is important to figure out relative positions of the countries in the overall SSI by analysing the selected individual indicators. By that way we will be able to clarify some primary concerns, such as at which dimensions of security of supply each country performs well/poorly, where their strengths and weaknesses are, or which individual indicator contributes most to the overall performance.

Table 17 presents estimates of the six supply security indicators for the selected 11 natural gas importing countries in Europe from 2001 to 2014. We will go into detail by examining the individual indicators associated with the countries' performance of the security of supply.

[23] Data from EIA - U.S. Energy Information Administration.

Table 17. Individual gas supply security indicators 2001-2014

Country	Years	Score	X_1	X_2	X_3	X_4	X_5	X_6
Netherlands	2001	0.000	-27.70	-0.55	0.40	3	0.57	2.07
	2005	0.000	-29.22	-0.59	0.37	5	0.35	1.88
	2010	0.000	-33.80	-0.62	0.39	5	0.48	2.62
	2014	0.000	-30.27	-0.76	0.36	4	0.41	1.87
United Kingdom	2001	0.095	-9.95	-0.11	0.38	2	0.81	1.63
	2005	0.293	7.30	0.08	0.37	6	0.76	2.10
	2010	0.470	38.18	0.40	0.40	10	0.50	3.31
	2014	0.508	31.73	0.45	0.32	6	0.59	2.31
Austria	2001	0.604	6.42	0.79	0.21	3	0.86	7.94
	2005	0.649	8.28	0.83	0.26	3	0.78	5.66
	2010	0.490	8.20	0.82	0.27	3	0.78	5.75
	2014	0.624	6.52	0.84	0.22	2	0.50	4.50
Belgium	2001	0.652	15.48	1.00	0.21	6	0.49	3.32
	2005	0.680	17.03	1.00	0.21	7	0.39	2.87
	2010	0.604	19.81	1.00	0.25	10	0.28	2.22
	2014	0.546	15.80	1.00	0.23	5	0.33	3.20
Czech Republic	2001	0.633	9.74	0.98	0.19	2	0.82	7.71
	2005	0.754	9.29	0.98	0.17	2	0.75	5.76
	2010	0.537	9.08	0.98	0.20	2	0.77	5.66
	2014	0.790	7.26	0.97	0.17	2	0.64	5.22
Poland	2001	0.658	8.17	0.60	0.12	3	0.89	8.13
	2005	0.755	10.17	0.63	0.13	5	0.63	7.31
	2010	0.510	11.08	0.65	0.13	2	0.89	6.26
	2014	0.881	11.78	0.66	0.15	2	0.84	5.88
Germany	2001	0.696	69.50	0.76	0.22	5	0.42	4.38
	2005	0.766	71.18	0.78	0.24	6	0.40	3.47
	2010	0.670	79.35	0.84	0.23	5	0.37	3.25
	2014	0.738	67.42	0.87	0.21	4	0.45	3.82
France	2001	0.858	39.74	0.95	0.14	7	0.31	7.37
	2005	0.910	48.13	0.98	0.15	10	0.29	6.43
	2010	0.853	47.24	0.98	0.17	13	0.29	5.51
	2014	0.832	35.75	1.00	0.14	10	0.46	4.89
Italy	2001	0.731	55.70	0.79	0.33	5	0.44	11.81
	2005	0.814	74.19	0.86	0.39	7	0.38	8.56
	2010	0.860	74.69	0.90	0.40	11	0.37	8.48
	2014	0.715	54.76	0.88	0.34	9	0.41	6.55
Turkey	2001	0.772	15.63	0.98	0.20	4	0.69	11.71
	2005	0.829	26.48	0.97	0.27	4	0.66	9.72
	2010	0.844	37.45	0.98	0.32	10	0.45	9.76
	2014	0.874	47.98	0.99	0.35	9	0.56	8.84
Spain	2001	1.000	17.44	0.97	0.12	8	0.67	14.47
	2005	1.000	33.47	1.00	0.20	11	0.44	11.95
	2010	1.000	35.77	1.00	0.21	13	0.33	11.32
	2014	1.000	27.14	1.00	0.18	9	0.52	10.01
Average		*0.65*	*24.53*	*0.69*	*0.25*	*5.91*	*0.55*	*6.08*

Note: X_1 Volume of natural gas imported, X_2 Import dependency, X_3 Share of gas in total primary energy consumption, X_4 Number of gas suppliers, X_5 Dependency on largest supplier, and X_6 Supplier fragility.

As mentioned above, the Netherlands is an exception in the sample set because this country is a net gas exporter, though it also imports a large volume of gas every year. The negative figures of "volume of gas imported" (and resulting negative "import dependency" figures) shown in Table 17 imply that the country's production volumes far exceed domestic consumptions. Being the largest gas producer within the European Union and holding substantial natural gas reserves, the Netherlands will remain a net gas exporter for the coming decade. However, experts anticipated that the country would become a net gas importer in the period between 2020 and 2025 due to its continuous decline in indigenous production (IEA, 2014c).

The United Kingdom consistently registered the second lowest SSI, which means the second most secure country. Its major strengths are at indicators X_1, X_2 and X_6. UK production peaked in 2000, therefore the indicator "volume of gas imported" in 2001 is shown in negative number. It implies that country's consumed domestically less gas than it produced. After that, UK production declined about 6% per year, thus the figures since 2005 indicate that the country slightly depends on gas import in 2005 where X_2 import dependency is equal to 8%. This percentage (X_2) is rising to 40% in 2010 and 45% in 2014, where the country's productions cover just more than half of its consumptions. Nevertheless, the United Kingdom still has a high level of security of supply owing to its relatively large production compared with other remaining countries in the region (just behind the Netherlands). That returns in lower import dependency figures. In addition, the UK has performed well in diversification of supply sources, backed up by its sound transport infrastructure for natural gas with 5 pipelines and 4 LNG import terminals. This is indicated by X_4 (number of gas suppliers) with relatively good figures from 2005 onwards – above the average value of all the selected eleven countries (see Table 17). In addition, UK gas imports are mainly from Norway, partly from the Netherlands and Qatar, therefore stable origins of imports also support the country's security of supply, explained by the low "supplier fragility" values (X_6).

Austria's volume of gas consumed and imported is low compared with other countries in the sample. However, the country highly relies on gas imports, especially on Russian gas. This is reflected by the poor performance on X_5 "dependency on largest supplier", which shows relatively high numbers (86% in 2001 and 78% in both 2005 and 2010). In 2014 the country has reduced the strong dependence on Russian gas by splitting its imports between Norway and Russia, diminishing the dependency on largest supplier to 50%. Therefore the country's record on the "supplier fragility" is also improved, as Norway is more politically stable than Russia.

Austria's infrastructure system gives the country an advantage to strengthen diversification of sources of gas supply. The reversible pipelines directly connecting Austria to the neighbouring countries (e.g. Germany, Italy and Hungary) make it an important gas transit hub in Central Europe. In addition to the sound gas transport system, the Austrian government is making efforts towards a diversity of supply routes as well as reducing dependency on a single supplier. Hence, the security of gas supply in Austria could be maintained in the long term, ranking in between a "relatively high" and "medium" level.

Similar to the neighbouring country Austria, the Czech Republic's performance on X_1 is poor. The country's gas production covers only a small fraction of total domestic demand (roughly 2%), that explains the Czech Republic's high levels of import dependency throughout the examined period (97-98%). Another weakness of the country is in "number of gas suppliers" (X_3), there are only 2, which is far below the average value of the entire sample (i.e. 5.91, see Table 17). As compensation for the weak performance on X_1 and X_2, the scores on other indicators are better. Czech Republic gas use shares a relatively small amount (from 17% to 20%) in total primary energy consumption. In an effort to reduce dependency on largest supplier, the Czech government has increased gas import from Norway, reducing the dependency on Russian gas from 82% in 2001 to 64% in 2014 (historically, all of the country's gas imports came from Russia). The performance on supplier fragility is therefore improved as well. Gazelle pipeline, the extension of Nord Stream's branch for transporting Russian gas from Nord Stream via Germany to France, was brought into operation in January 2013. The transit gas pipeline running through the Czech Republic has considerably improved the country's energy security.

Compared with Austria and the Czech Republic, Poland is less reliant on gas import as its production covers about 35% of the country's gas demand. That is why Poland has a better performance on "import dependency" in comparison with the other countries (just behind the Netherlands and the United Kingdom). Poland also performs well on X_3, as share of gas in total primary energy consumption accounts for only 12% to 15% (while the average value is

25%). However, Poland shows its weaknesses on the heavy dependency on a single supplier and undiversified supply sources. Most of Poland's gas imports come from Russia, resulting in a high score on X_5 "dependency on largest supplier" (89% and 84% in 2010 and 2014 respectively). The number of suppliers is small with only two supplying countries. These are the main causes that made Poland's ranking drop in 2014.

Nevertheless, there are advantages which support Poland's gas security policy, such as development of natural gas infrastructure for diversification of supply sources (including pipelines and an LNG terminal), increasing indigenous production, existing considerable proven reserves (100 bcm at the end of 2012). Furthermore, unconventional gas might offer a potential to Poland. The shale gas resources are estimated at 1.4 to 3 trillion cubic meters. If these resources are confirmed, Poland may turn into a net gas exporter country (IEA, 2014c).

Although Belgium relies 100% on gas imports as it has no indigenous gas production, the country ranks among the medium-level secure group. Except the highest extent of import dependency, the remaining indicators show relatively well performance. Belgium's gas imports are diversified with various stable origins and types, mainly through pipelines from Norway, the Netherlands and Russia, and partly in the form of LNG from Qatar. Figures on the number of gas suppliers, dependency on largest supplier and supplier fragility indicate Belgium's security on those dimensions. In fact, the country possesses a sound transmission system with pipelines and LNG terminal. The Zeebrugge port serves as a crossroads of two major axes in European natural gas flows, which are from Russia to the United Kingdom and from Norway to Southern Europe. This international trade attracting hub is the key factor to enhance Belgium's security of gas supply.

Germany has highest imported volumes compared to the remaining countries. The country's production in 2001 accounted for 24% of total demand. Unfortunately, domestic production is continuously decreasing in recent years by an annual average of 8% (estimated from 2010 to 2014), resulting in an increase in import dependency (87% in 2014 compared to 76% in 2001). Germany's imports are however relatively diversified, with 45% from Russia, 33% from Norway and 21% from the Netherlands (2014). This helps to keep the "dependency on largest supplier" and "fragility of supplier" at stable levels below the average values of the sample set. Those factors retain Germany among the countries of medium-level security of supply. Germany's advantages of having a comprehensive cross-border pipeline system and geopolitical location in central Europe make the country an important natural gas transit hub in the region. Some efforts are also being made by the German government in order to reduce the country's reliance on Russian gas, such as increasing renewables, pursuing LNG or unconventional gas to boost up domestic production. An LNG terminal project (Wilhelmshaven) was proposed in 2010 but has not been started yet. However, there is a possibility for the future as a permitted site for an LNG terminal in Germany is available in reality (IEA, 2014c).

France is insecure due to its weaknesses in the imported volume, import dependency and fragility of supplier. France's volume of gas imported is large, only behind its neighbouring countries Germany and Italy. The country is almost 100% dependent on gas imports because of its minimal domestic production (2% and less than 0.5% in 2010 and 2014 respectively). France's import sources are diversified but many of the suppliers are not politically stable, for example Russia, Algeria, Nigeria. However, increasing share of gas import from Norway from 29% (in both 2005 and 2010) to 46% (2014) has improved the fragility of supplier. France's good performance is on X_3 with relatively small share of gas in total primary energy consumption. France's security of supply still needs further improvements. Despite a good system of numerous pipelines and LNG terminals, the country's gas infrastructure should be developed to reduce internal congestion and increase cross-border flows with other north-western European countries.

Italy is the second largest gas importer in Europe, after Germany. Indigenous production covered 21% of Italy's natural gas demand in 2001 but reduced afterwards to only 12% in 2014. Italy's import dependency is therefore relatively high (88% in 2014) and expected to slowly increase to 90% in 2018. Share of gas in total primary energy consumption in Italy is quite large, ranging from 33% to 40% (above the average value of 25%). Italy's supply sources are diversified, but most of its major supplier countries are politically unstable, such as Algeria, Libya, Russia and Qatar. This explains Italy's poor performance on the fragility of supplier. However, switching the gas supply from Algeria to Russia had considerably improved Italy's performance on the fragility of supplier. Thereby 37% of total import which came from Algeria in 2010 is moved to Russia in 2014, reducing Algerian gas import to only 12% in 2014 and increasing Russian share from 19% to 41%.

Italy's gas transport infrastructure consists of a system of both pipelines and LNG terminals, which can further the country's security of supply. Improvements, however, still need to be made so as to protect Italy from disruptions of gas supplies, such as the disruption occurred over the winter of 2005-2006 or the gas crisis in the winter of 2011-2012 which severely affected the country (IEA, 2014c).

Turkey ranks among the least secure countries. The country is highly dependent on natural gas imports as its domestic production is minimal (1% in 2014) while consumption is increasing each year. Gas demand in Turkey is significantly increasing, in contrast to the situation in the other countries where gas consumption is continuously decreasing. Turkey's gas consumption increases 27% within four years, from 38.13 bcm in 2010 to 48.46 bcm in 2014 (Table 16). Share of gas in the energy mix in Turkey also rises from 20% in 2001 to 35% in 2014. Turkey has improved import diversification by adding more gas suppliers to its import portfolio, increasing number of suppliers from 4 in 2005 to 10 in 2010 and 9 in 2014. Dependency on largest supplier is however still high, as Turkey imported 56% of its gas from Russia in 2014 (this was 69% in 2001). Another 18.4% came from Iran, 11% from Azerbaijan, and the rest from Algeria, Qatar and Nigeria (2014). All of these supplier countries are politically unstable, resulting in Turkey's high levels of supplier fragility.

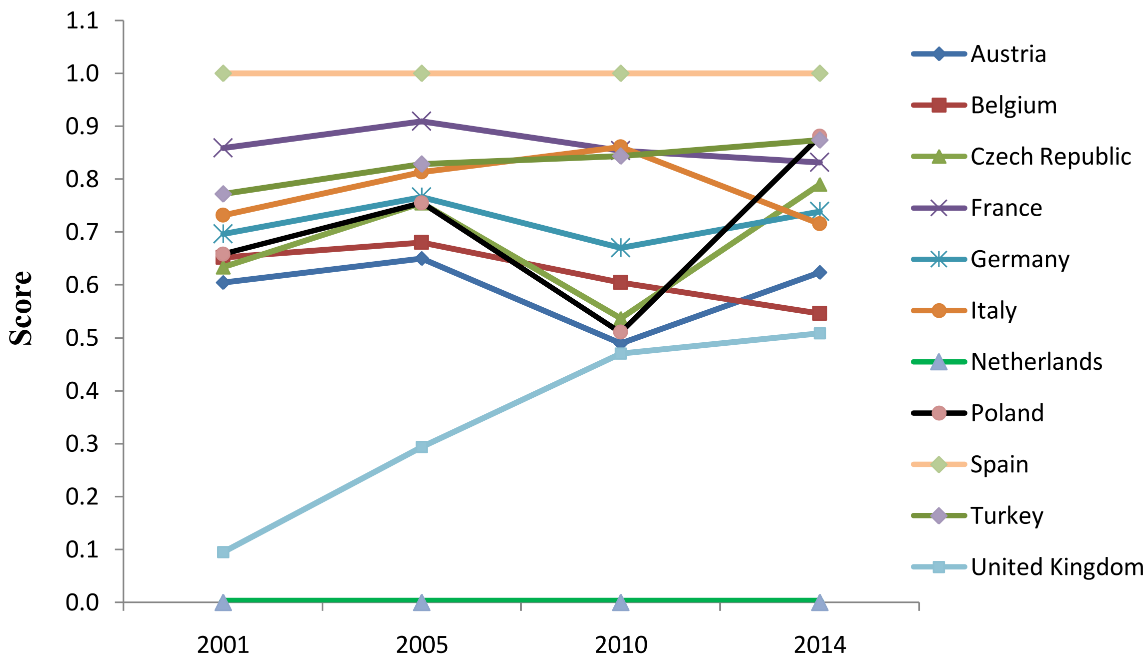
Most natural gas in Turkey is imported through pipelines from Russia, Iran, Azerbaijan, and only about 16% of LNG deliveries from Algeria, Nigeria and Qatar. Despite the fact that Turkey holds a strategic role as an oil and gas transit hub between Russia, the Caspian region, and the Middle East to continental Europe, the country is extremely vulnerable to supply disruptions and its pipeline capacity may be insufficient to keep pace with rising domestic demand. Turkey needs to improve its diversity of supply routes, particularly through pipeline network. A number of pipeline projects have been proposed, in which Turkey plays an important role in natural gas transit. Yet none of these projects has been started, many European net gas importer countries are interested in realizing at least some of them.

Spain is the least secure country in the sample. All of the country's gas demand is met by imports, reflected by the highest import dependency through the period 2001-2014. Similar to France and Italy, Spain's noteworthy strong point is on the import diversification with a large number of suppliers, giving in turn good performances on X_4. Most of the gas imports in Spain are LNG deliveries from Algeria, Nigeria, Egypt and Qatar, where political stability is low. Therefore Spain's performance on the fragility of supplier is constantly worst compared to the other countries, which shows an estimate of 11.94, almost double the average value (6.08) of all the selected countries. In 2005, 65% of Spain's gas imports were in the form of LNG and this portion increased up to 76% in 2010. Until 2014, Spain imported more gas through pipelines than LNG due to a drop in demand and high LNG prices, thus LNG imports shrank to only 52%. Spain also presents relatively high dependency on largest supplier. In 2001 there was 67% of total gas import from a single supplier, i.e. Algeria, this proportion reduced to 52% in 2014. Although Spain's natural gas supply system is well diversified and flexible (LNG diversification, etc.), it shows no significant improvements in the six dimensions in the period studied. The country's poor overall performance made it remain the weakest performer on the list of all the selected eleven countries.

Figure 9 plots the countries' scoring performance throughout the period 2001-2014, illustrating how their security of gas supply "improved" or "degraded". Overall, most of the countries showed stable performance from 2001 to 2005 and insignificant improvements in the interval 2005-2010. The noteworthy changes within 2010 and 2014 are from Poland and Italy where they switched their positions. Italy's improvements have earned the country a better level of security of supply, while Poland dropped its ranking from the fourth of the medium-level security group to the second least secure country.

In the entire period 2001-2014, UK's scores gradually get higher but it still remains the second most secure country, after the net gas exporter the Netherlands. Meanwhile, Spain consistently stays as the weakest performer, without any significant improvements.

Figure 9. Performance of selected countries from 2001 to 2014 based on the SSI scores



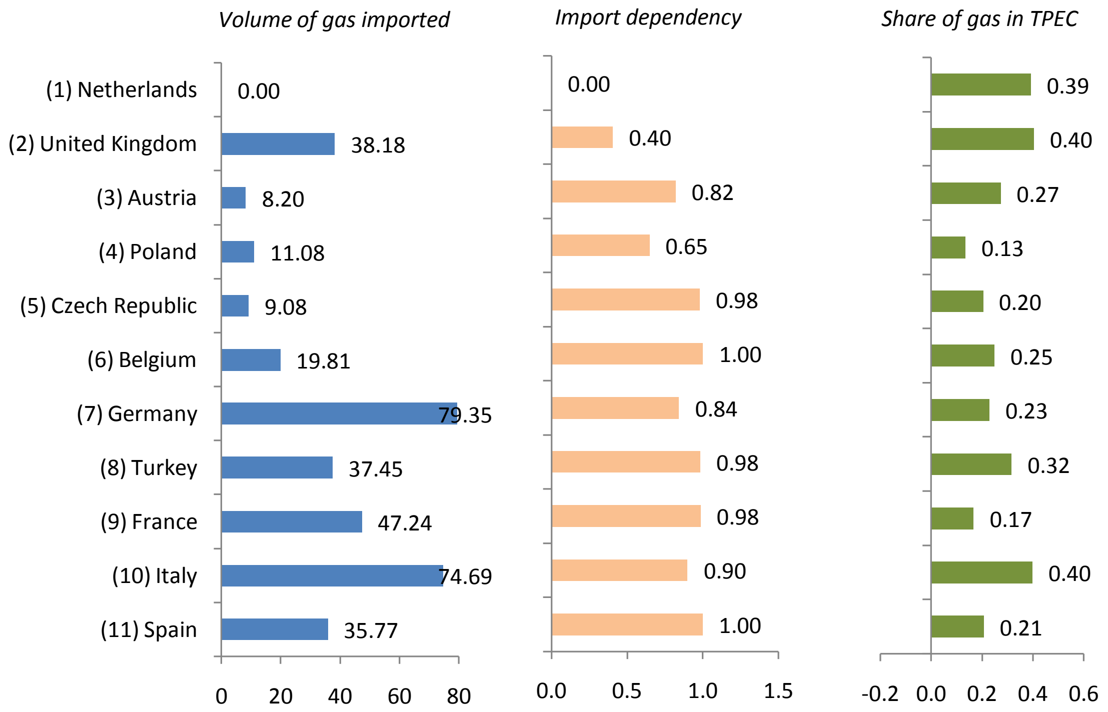
The findings that we have obtained so far indicate that most of the greatest consumers and importers of gas by volume, and those with the highest dependence on gas imports are the most exposed to supply security threats. The results also show that the countries with a large number of suppliers are not necessarily those most secure. In fact, it is possible that these are very insecure countries, if their gas imports came from the supplying countries those who have low political stability, as in the case of Spain, Italy and Turkey. There also exists the case that the greatest importer of gas with relatively high dependence on imports must not certainly be the least secure country. This case belongs to Germany - despite the largest imported volume of gas and high import dependency, Germany stands in the group of medium-level security countries as the country's import sources are relatively diversified, and the major supplying countries are those politically stable (i.e. the Netherlands and Norway, only Russia is not very stable). Figure 10 demonstrates the countries' performance on each of the individual indicators for the year 2010. The countries are placed in ascending rank order, with higher rankings corresponding to higher risk of supply security.

It is seen from Figure 10 that the two indicators "volume of natural gas imported" and "fragility of supplier" significantly contribute to the overall SSI index. Indeed, most of the countries with greatest imported volume (which are usually associated with higher import dependency) and high fragility of supplier are those with highest SSI scores, and therefore the least secure countries. In addition, the figure displays the negative correlation between the number of gas suppliers and the dependency on largest supplier. Most of the countries with lower degree of diversification of supply sources, indicated by a smaller number of suppliers, have greater dependency on a single supplier.

The links between the composite indicator SSI and other individual measures with significant importance are also illustrated in this paper. First, the strong correlation between the SSI and one of the indicators which represents internal risks of supply security, namely the volume of natural gas imported, is shown. Higher gas imported volume will most likely result in higher risk of supply security, Figure 11 shows this link. Most of the countries in the sample are close to the trend line. Germany appears to be an outlier when it lies out of the trend. As pointed out earlier, although Germany has the largest imported volume of gas, the country is relatively secure because it gives better performance on the other dimensions, for instance diversification of supply sources and major suppliers' political stability.

Second, the close correlation between the SSI and the indicator representing external risks of supply security, the fragility of supplier, is plotted in Figure 12. Data of the year 2010 are used as they show a more visible trend line, where the importer countries with higher records of supplier fragility lie on the top end of the line, specifying greater SSI scores or higher risk of supply security.

Figure 10. Individual indicator performances for the selected countries (2010)



Note: Negative number of volume of gas imported and import dependency for the Netherlands have been converted to zero.

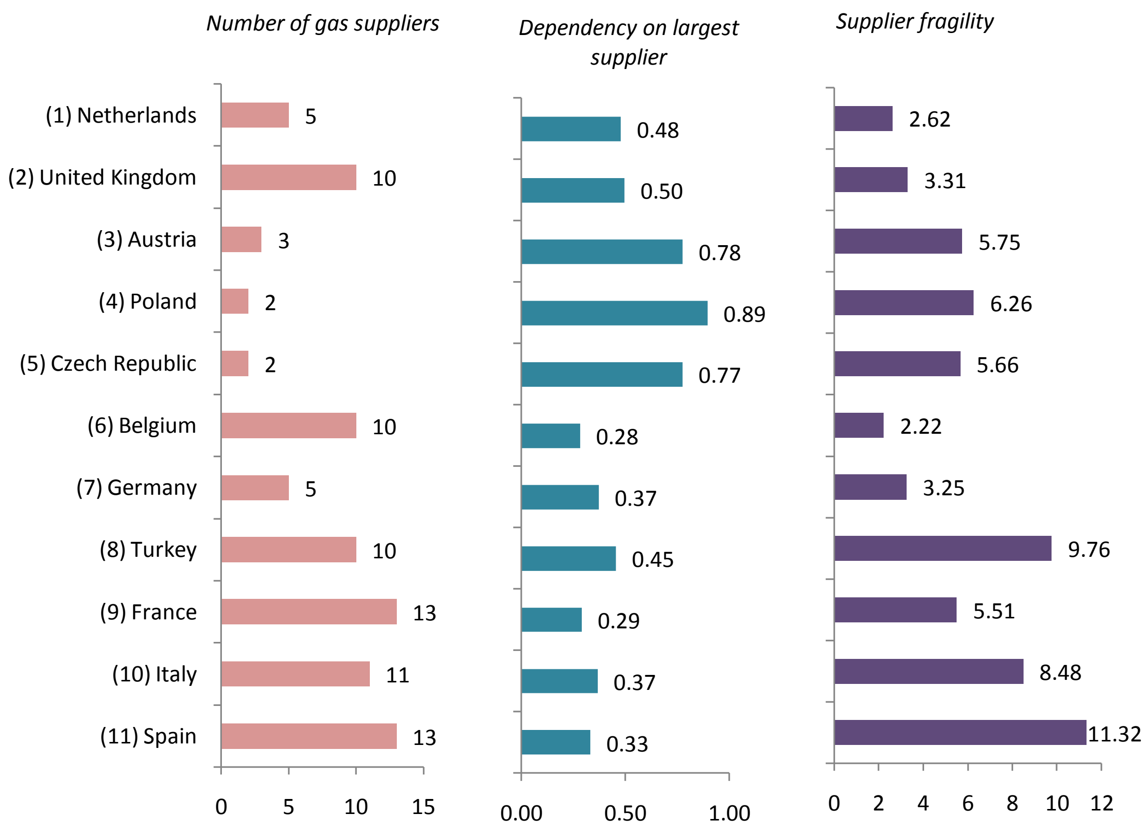
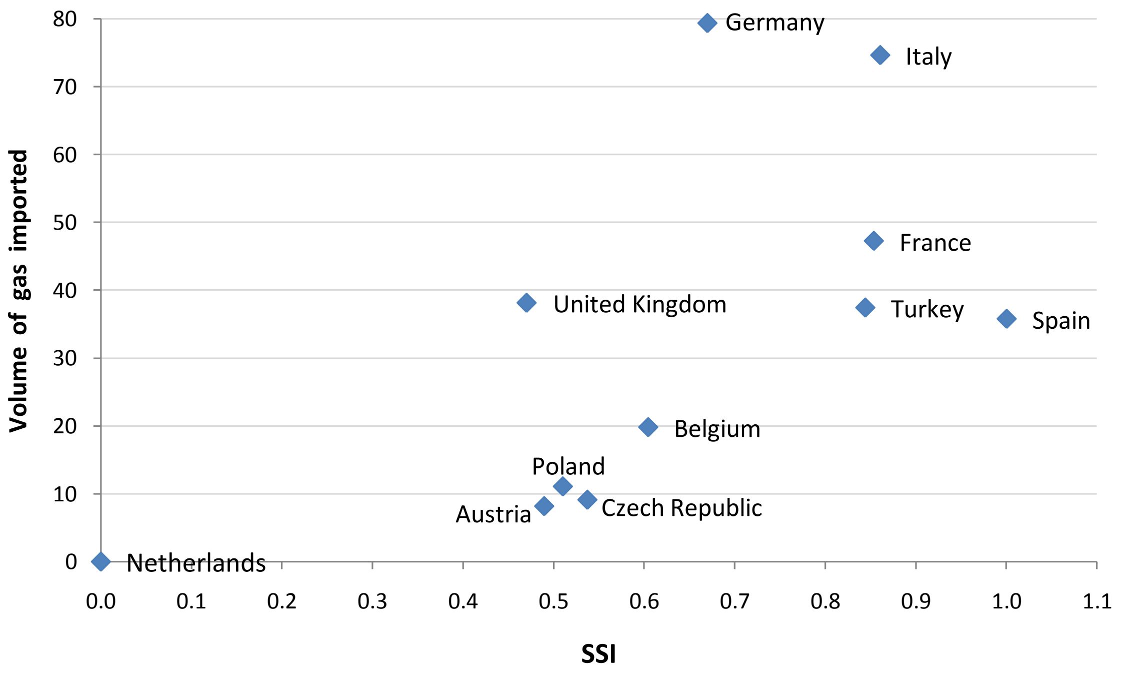
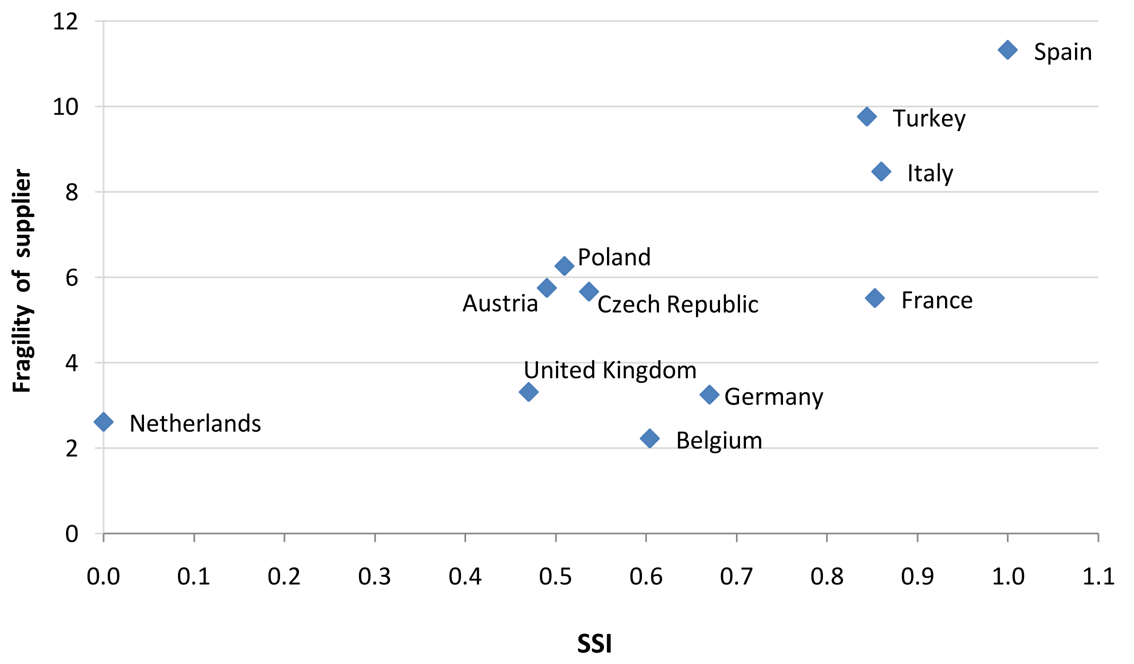


Figure 11. Link between "volume of gas imported" and Supply Security Index SSI (2010)



Note: Negative number of volume of gas imported for the Netherlands (-33.80) has been converted to zero.

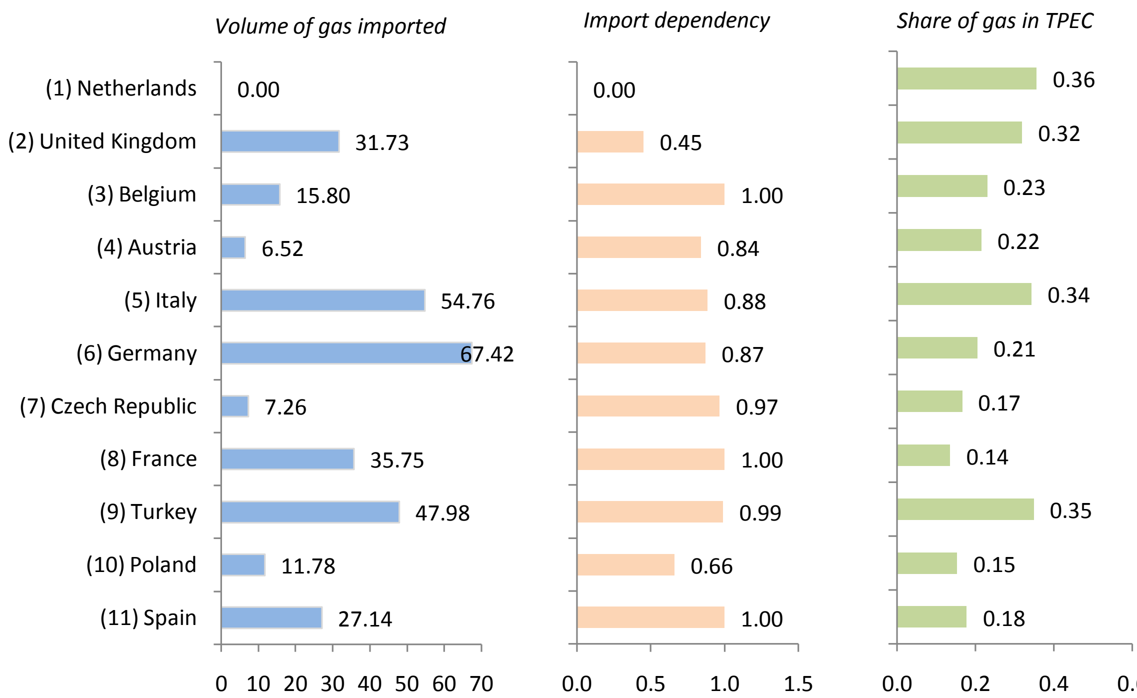
Figure 12. Link between "fragility of supplier" and Supply Security Index SSI (2010)



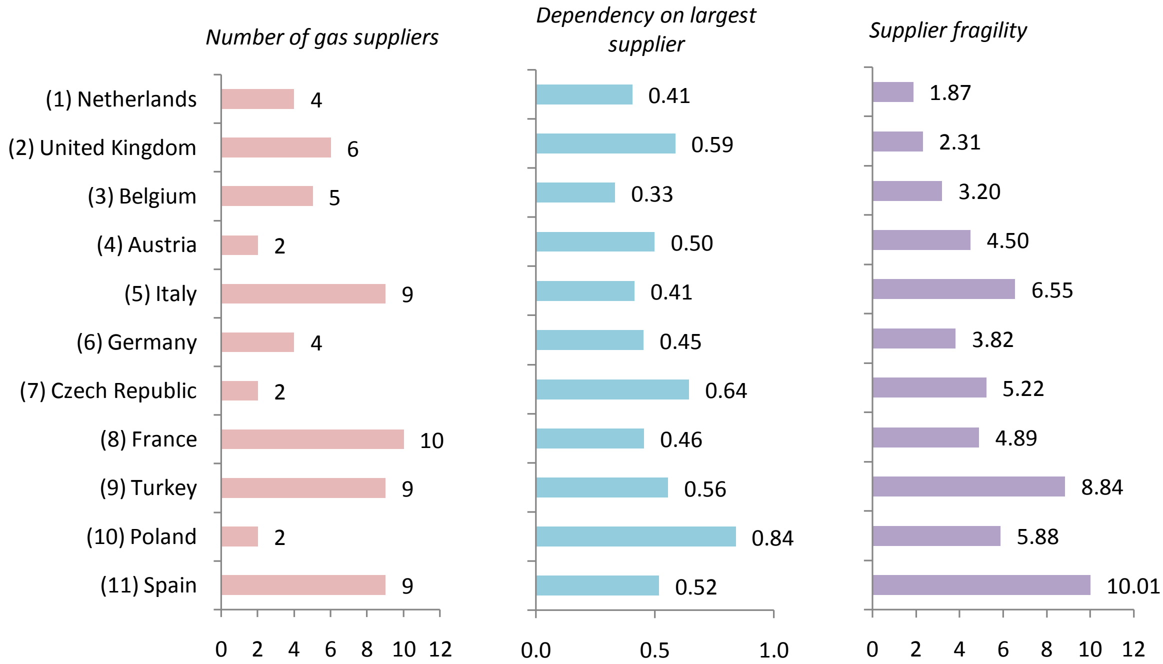
The correlation between the SSI and the fragility of supplier exists consistently throughout the period 2001-2014. However, the connection between the SSI and the indicator volume of gas imported is clear on the figures of the year 2001, 2005 and 2010, but no more clear for 2014, as displayed in Figure 13 (see the first small chart for "volume of gas imported"). The reason is that in 2014 Italy - the second largest gas importer in Europe - moved from the near bottom up to the 5th position on the list, whereas Poland - a relatively small gas importer - fell sharply to the bottom at the 10th position (just above the worst performer Spain).

This "phenomenon" explains the fact that even though the indicator's contribution to the aggregated index SSI is considerable, it would probably not be the only driver for determining the overall performance of the countries' security of supply. Therefore, the construction of the aggregated composite index should be based on various dimensions/indicators in order to capture as many aspects of the security of supply as possible.

Figure 13. Individual indicator performances for the selected countries (2014)



Note: Negative number of volume of gas imported and import dependency for the Netherlands have been converted to zero.



5.3. Policy implications

The analysis presented in the previous sections shows that there are significant differences in individual performances among the countries in terms of their security of natural gas supply. By evaluating the basis of the variation in the overall supply security index SSI for different countries, policy-makers can identify the problems and thus can protect or mitigate nations from the threats of natural gas supply disruptions.

As we have observed, it is unlikely that a good performer must necessarily have best performance on all of the dimensions. That performer may have the best performance on several dimensions and not that good on the other dimensions. However, when a country shows the worst performance on several dimensions at the same time, then it would be very likely the case that the country is facing the risk of being highly insecure. The least secure countries in the sample are the clear examples, such as Spain, Turkey, or Poland in 2014. In the light of these facts, we can identify the trade-offs between the indicators. A surplus in one dimension can be offset by a decrease in another. In terms of policy, a country with high score on one indicator will therefore need a much lower score on the others in order to obtain a low SSI score, which means a high level of security of supply.

Thus, isolating the factors that caused supply security performance would be emphasized. The results indicate that the SSI has a different sensitivity to the changes in values of the individual indicators. On an average, the indicators volume of gas imported, import dependency, and fragility of supplier appear to be more significant than the other remaining indicators in determining the overall security of supply of the selected countries. This presumably implies that the policies aiming at these indicators may be more effective than the policies which focus on dealing with the other dimensions. However, the revealed relationships between the indicators are also important for characterizing the nature of the security of supply facing the gas importer countries. Furthermore, each country requires a specific policy design, as each of the countries' SSI has a different sensitivity to the individual indicators.

Among the selected 11 countries, we can easily recognize that the ranking based on SSI index moves Italy, Turkey, France and Spain down on the list, placing them among the biggest contributors to supply risk exposure. The reason is that they have high levels of gas consumption and therefore gas imports. But smaller countries like Austria, Czech Republic and Poland with much lower gas import levels relative to the rest are not always secure either, as they rely heavily on the non-EU gas supplier, Russia.

Given the depletion of gas reserves/resources in most of the big gas consuming countries like the Netherlands, the United Kingdom or Italy, and the negligible reserves of the remaining countries, the potential of a growth in gas production is not likely feasible. Consequently, a reduction in volume of gas imported for the countries in the long term, in connection with a reduction in import dependency, is difficult. Nevertheless, improving gas use efficiency to cut down consumption, increasing substitutes for natural gas such as renewable energy (e.g. biofuels, solar, wind, tidal power) are still some of the goals that the governments of the EU countries are striving for so as to reduce dependency on gas imports.

Diversification is often assumed to be a key factor when dealing with security of supply in a long-term perspective. Of all the selected 11 countries, Spain's gas supply source is the most diversified but it ranked as the least secure country throughout the period studied. In fact, Spain imports small amounts of gas from various supplying countries such as Nigeria, Egypt, Oman, Qatar, Trinidad and Tobago, etc. but its largest supplier through pipelines and LNG is Algeria (67% and 52% of Spain's total imports in 2001 and 2014 respectively). In this case the country's gas imports are diversified only in terms of geographical origins but not in quantities of imports, which means that without applying risk diversification. This issue has been addressed in a study in which they investigated the impact of a natural gas supply disruption from Algeria, the EU's third largest supplier, on the European natural gas security, in terms of gas demand satisfaction. The result of the pilot application (applying a Monte Carlo simulation) turns out that in case of a gas disruption from Algeria, Spain would most likely have almost 50% probability not to cover its natural gas demand, whereas that probability for France is only 20%, even though France is also directly affected by a supply interruption from Algeria like Spain. The result difference is because apart from Algeria, France imports natural gas from various EU countries such as Norway, the Netherlands, Germany, the UK, with sufficiently large amounts (Flouri M., Karakosta C., Kladouchou C., and Psarras J, 2015).

Thus, policymakers who deal with supply diversification should take both geographical origins and quantities of imports into account. Spain would be able to move up to the middle of the list – the group of medium-level security. One possible option for Spain's gas supply security planners is to give priority to reducing Algerian gas share of imports and increasing the share of other European supplier countries (for instance Norway), in addition to reducing domestic gas consumption. France implemented the same action and an improvement on the SSI score and ranking can be recognized when the country reduced the gas import from Algeria and Nigeria, and moved part of that to Norway. France has slightly improved its performance by adjusting its diversification policy, moving its gas import to a more reliable and stable supplier. This implies that apart from the other factors, reliable and (politically) stable sources of supply should necessarily be considered as well.

Different transport options (or the modes of transportation) should also be included in the diversification of supply sources, in addition to the quantities and origins of imports. An overall security of gas supply should be determined by both pipeline gas and LNG imports. In case of a supply disruption, the ease of switching between suppliers can have significant impact on the security of supply. An LNG supply is considered more substitutable in the short run than a gas supplied via pipeline. However, while LNG is usually seen as less risky than pipeline gas owing to lower transport risks and its substitutability, it is not necessarily associated with a very low risk index. Within the countries with largest amounts of LNG import in our sample (Spain, France, UK, Italy and Turkey), only the UK has very low SSI scores, while the other four show either highest or very high values of the SSI. That could be explained by their (i.e. Spain, France, Italy, Turkey) insufficient diversification LNG portfolio. And another important reason is that LNG imports just account for relatively small portions of most of these countries' total imports (except for Spain with 76% in 2010 and 50% in 2014 of LNG share of total imports, that share at the remaining three countries ranges from only 10% to maximum 30%).

The impact of LNG import on the European security of gas supply has thus far not been significant as its proportion is still small compared to that of pipeline gas import. The EU imported only 19% and 14% of LNG in their total gas imports (in 2012 and 2013 respectively)[24]. Nonetheless, gas transports both by pipelines and by LNG carriers (tankers) should be considered as complements and well-time investments in LNG installations are still necessary to heighten supply flexibility in the long term.

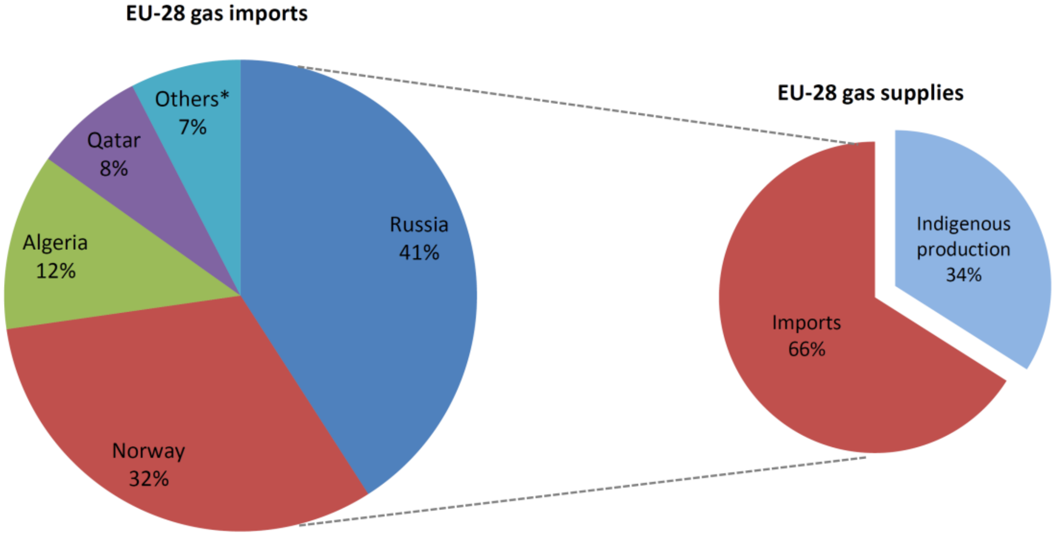
Apart from what we have mentioned above, investments in the technologies which further domestic exploration and production activities should be included in the policy tool set that aims to reduce overall supply risk. It is possible that new gas resources such as unconventional gas can change national, even regional gas flow. The "shale revolution" in North America, particularly in the U.S., could have given EU countries incentives to take a harder look at this opportunity. Among the countries in the sample, Poland and France are deemed to have the largest estimated shale gas resources in the EU which amount to 14 tcm (trillion cubic metres), exceeding Europe's conventional natural gas reserves - estimated at 5.2 tcm (Erbach G., 2014). In case Poland and France could exploit those shale gas resources, their overall performances of security of supply on all the selected dimensions could be substantially improved. An investment in the upstream sector is therefore essential to enhancing indigenous production for these two countries. However, unlike the shale revolution in the U.S., shale gas development in Europe is currently considered more evolution than revolution, given the uncertainty of resources and the persistence of

[24] Eurogas Statistical Report 2014.

environmental concerns/public non-acceptances of shale gas exploration techniques such as hydraulic fracturing (fracking) and horizontal drilling. Thus investments in the upstream supply stages are usually considered on the basis of long-term trends.

Finally, it is worth noting that a common policy on security of gas supply for all the countries is not likely possible. Different countries face different situations. Some have substantial domestic production (as in the case of the Netherlands and the United Kingdom), some import most of their gas from EU suppliers or Norway (such as Belgium, France, the UK), and some others get most of their gas imports from non-European suppliers (for instance Czech Republic, Poland, Turkey, Spain). Among those various supplying countries, Russia, Norway and Algeria are the three largest gas suppliers to Europe, in which Russia accounts for the largest share of the EU's total gas imports (41% compared with 32% from Norway and 12% from Algeria, in 2013), as shown in Figure 14. In the short and medium term, diversity and security of natural gas supply in Europe appear to primarily concern Russia, irrespective of experts' anticipation which argues that Europe will benefit from recent changes in global natural gas development, specifically from the potential of US shale gas exports (in LNG form). Indeed, Norway has been a reliable and stable gas provider for Europe for decades, while Algeria just accounts for a small portion relative to the other two, the main concern now is thus over Russian gas supply. However, the degree of dependency on Russian gas varies between the countries. For example, Germany, France, Italy can be clustered in a group of high volumes of gas imported from Russia, but are less dependent on Russia, whereas those in Central-Eastern Europe are much more dependent on Russian gas, yet with small volumes, such as Austria, Czech Republic and Poland. Hence, policy instruments for security of supply should be differently treated by the countries, based upon each own situation.

Figure 14. Breakdown of EU-28 total gas imports, 2013



*Others include Nigeria, Libya, Trinidad & Tobago, Peru, Oman, Egypt and some others

Own graphic (data from Eurogas Statistical Report 2014)

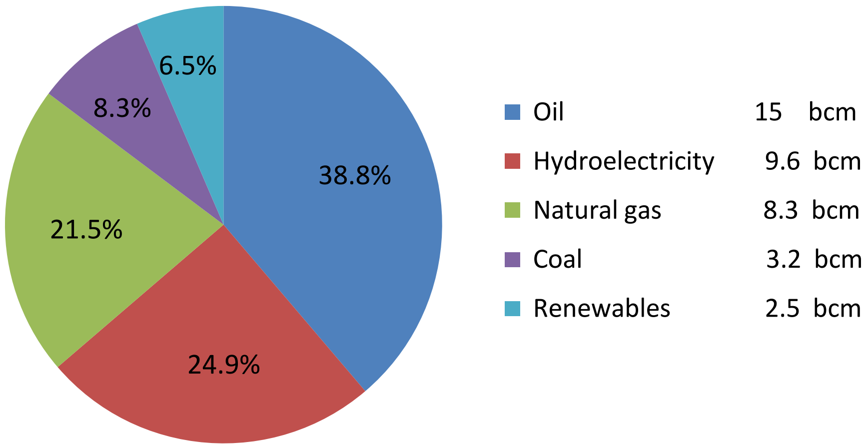
5.4 News in brief - a look at Austria's security of gas supply

In the primary energy mix of the country, natural gas share accounts for only around one-fifth (21.5% in 2014), stands behind oil and hydroelectricity. Austrian gas is mainly used for electricity generation and industry. Oil still remains Austria's major energy source, accounting for 38.8% while hydroelectricity, the country's second largest energy source, accounts for 24.9% (see Figure 15). Although natural gas plays an important role, it does not have extremely high impact on the country's energy security.

Being a small country in terms of area and population, Austria consumes and imports much less natural gas compared with other countries in the sample. However, the country highly relies on gas imports, specifically on Russian gas. Throughout the period studied, Austria shows its weakness on the high records of import dependency and dependence on a single supplier. The country's gas production covers only 16% of total domestic demand (2014), while its proven reserves are moderate, which were estimated at 20.6 bcm as of January 2013

(IEA, 2014c). A growth in domestic gas production in the long run is not possible for Austria. The country's policies for supply security should primarily concern import issues (for instance reducing the strong reliance on Russia by increasing gas imports from Norway or EU suppliers), diversification of supply sources and routes, promoting gas use efficiency and increasing substitutes as renewables in the energy mix.

Figure 15. Share of natural gas in total primary energy consumption (2014)



Own graphic (data from BP Statistical Review of World Energy, 2015)

As a landlocked country, Austria - which is in the same situation as some of its neighbouring countries such as Czech Republic, Hungary or Slovakia - has no prospects of directly benefiting from LNG trade. The main strength that enables Austria to enhance diversification of sources and routes of gas supply is on the country's available infrastructure, specifically, on its reversible pipeline network which is considered the country's "gas highway network", with around 2,000 km of pipelines. Austria's Baumgarten gas hub (where a number of pipelines converge) directly connects it to the neighbouring countries (e.g. Germany, Italy, Hungary and Slovakia). This gas hub makes Austria an important transit point for approximately one third of the gas exports from Russia to Europe, and as a result strongly supports the country's security of supply.

In addition to the pipeline network, another key element of Austria's gas security policy is its sufficient storage capacity with large gas commercial stocks (which are currently estimated at 7.4 bcm - around 78% of yearly consumption). This presents a strong infrastructure resilience which can protect Austrian gas supply from sudden disruptions in the short term, as in the case when the cut-off from Russian gas supply occurred during the Russian-Ukrainian gas dispute in January 2009.

Further, Austria also focuses on the network development in order to be closely coordinated with neighbouring countries, and particularly on the infrastructure development of new gas sources from the Caspian region.

Overall, given the country's "state-of-the-art" infrastructure, geopolitical strength, and its efforts towards a diversity of supply sources and routes as well as reducing dependency on a single supplier, Austria will be able to remain as one of the secure countries in Europe in terms of natural gas supply in the long term.

Chapter 6

Conclusions

Capturing a broad notion as security of energy supply is in general not straightforward as it is a multi-dimensional and somewhat qualitative concept. In this paper, a set of quantitative indicators is proposed to measure different dimensions of the security of natural gas supply in the selected gas importer countries in Europe. The overall security of supply of each country is afterwards quantified in the form of a composite index - the security of supply index SSI - which is obtained by transforming the selected individual indicators into a single synthetic index. The transformation is implemented by applying one of multivariate analysis techniques, the Principal Component Analysis (PCA).

The aggregated index SSI is useful as a starting point for analysis, providing an overview of each country's performance and identifying best practices within the countries in the sample. The individual indicators are then used to shed light on strengths and weaknesses of each country, extending the analysis of the countries' overall performance.

The individual indicators take into account the factors that are associated with both internal and external risks of supply security. The indicator volume of natural gas imported and the share of gas in TPEC are represented for internal risks, while the factors associated with external risks involve the import dependency, number of gas supplier, dependency on largest supplier, and fragility of supplier.

The final results show no much improvement in the individual country's performance over the four intervals of the period studied 2001-2014. The major findings, however, have been obtained through the changes in the relationships of the indicators, corresponding to the changes in the overall security of supply index for each country. It is obvious that countries which have sufficient domestic gas production are considered to be risk free. But it must not necessarily be true that a country with high volume of gas imported has also a high level of risk. Most of the countries being studied are either large-scale importers or small-scale importers but with high import dependency. If they are secure or insecure from supply risks, the outcome depends on how they implement their policies for security of supply. Diversification is the key factor for the countries to improve their security of gas supply.

However, diversity is an "overarching concept", it should be implemented thoroughly, involving as many of its properties as possible. The supply sources of some of the selected countries are diversified with a large number of suppliers, their overall performances on security of supply are still far from the other best/good performers. Those countries' gas imports are diversified only in terms of geographical origins but not quantities of imports, as they still place the major part of their gas imports on a single supplier. That way of diversifying supply sources does not correspond to the common-sense rule of risk diversification - "*don't put all your eggs in one basket*". In order to reinforce the diversification of import sources and routes (also taking quantities of imports into consideration), the modes of transport are important to back up the diversification of supply sources and routes. In addition to the available pipeline networks (which currently dominate in European gas transport system), development of LNG transport is of great importance for European countries to improve the gas supply flexibility and diversification.

It is observed from the results that even though diversification is the primary tool, political stability of the supplying countries reflected by the supplier fragility also contributes to the natural gas supply security of the importing countries.

In line with the findings of this study, policy making for the security of natural gas supply should aim at maintaining significant import volumes from reliable suppliers, diversification of supply sources and routes, as well as risk diversification by reducing over dependence on a single supplier.

Sources of insecurity can be dynamic and changing over time. The highlight of this paper is that we followed the changes in the relationship of the six indicators contributing to the developed security of supply index SSI over a relatively long period, starting from 2001 to the most updated year 2014. Empirical tests of the relations between factors are also demonstrated, presenting useful statistical evidence.

While the study has provided in-depth analyses and interesting insights into the nature of the security of energy supply facing importer countries, it has some limitations.

First, the analysis can be improved by the inclusion of more indicators. For example, the economic impacts on the supply security are not covered in this paper. We might include an indicator measuring gas price volatility within the countries studied (but it should also be noted that energy research models if aimed at a long-term focus might be unfit for assessment of price volatility). Further, this paper does not capture different transport modes (gas supply via pipelines and LNG). The ease of switching between suppliers in case of gas supply interruptions also has an impact on the security of supply. Another interesting factor is the distance measure from the supplier country to its destination. The distance can be considered as a useful measure of the ease of energy delivery between supplier and buyer countries, as the probability of transport failure is expected to increase with the length of transport. This dimension is, however, not included in the paper due to lack of data sources.

Second, the relatively small sample size in this study may be somewhat less sufficient for the Principal Component Analysis. Some other works on the security of energy supply where a wide range of countries are chosen can show wider views by splitting the countries studied into different clusters. Unlike those other works, this study just focuses on the major gas consuming and importing countries in Europe, who almost stay in a similar situation (relatively high homogeneity). Therefore, distinction between the "best" and "worst" performer might not always be clear as in the cases where the samples are larger and more heterogeneous.

Nonetheless, this study provides a better understanding of intercountry variations in energy supply security and corresponding factors. Further studies can take the above described limitations into consideration, such that the proposed model can be refined and applied for different countries as a decision-making instrument with regard to national and international security of fuels supply.

Appendix

Appendix A

Actual total gas import (bcm)

	2010	2014
Austria	12.43	10.17
Belgium	22.91	16.85
Czech Republic	8.52	7.25
France	48.76	41.17
Germany	94.04	86.85
Italy	75.35	55.76
Netherlands	25.74	29.11
Poland	10.90	11.81
Spain	36.73	36.39
Turkey	38.03	48.90
United Kingdom	53.83	42.84

Source:
U.S. Energy Information Administration database

Volume of gas imported* (bcm)

	2010	2014
Austria	8.20	6.52
Belgium	19.81	15.80
Czech Republic	9.08	7.26
France	47.24	35.75
Germany	79.35	67.42
Italy	74.69	54.76
Netherlands	-33.80	-30.27
Poland	11.08	11.78
Spain	35.77	27.14
Turkey	37.45	47.98
United Kingdom	38.18	31.73

*Based on author's calculations of indicator "volume of gas imported"

Appendix B

Relative (scaled) and original indicators (2014)

	X_1	γ_1	X_2	γ_2	X_3	γ_3	X_4	γ_4	X_5	γ_5	X_6	γ_6
Austria	6.520	0.377	0.840	0.909	0.215	0.360	2	1.000	0.500	0.329	4.500	0.323
Belgium	15.802	0.472	1.000	1.000	0.231	0.429	5	0.625	0.333	0.000	3.202	0.164
Czech Republic	7.263	0.384	0.967	0.981	0.166	0.137	2	1.000	0.644	0.613	5.219	0.412
France	35.748	0.676	0.999	1.000	0.136	0.000	10	0.000	0.455	0.240	4.893	0.372
Germany	67.420	1.000	0.870	0.926	0.205	0.314	4	0.750	0.453	0.236	3.822	0.240
Italy	54.763	0.870	0.885	0.934	0.343	0.940	9	0.125	0.414	0.160	6.551	0.575
Netherlands	-30.270	0.000	-0.757	0.000	0.356	1.000	4	0.750	0.405	0.142	1.866	0.000
Poland	11.782	0.430	0.660	0.806	0.154	0.080	2	1.000	0.840	1.000	5.877	0.493
Spain	27.136	0.588	0.999	0.999	0.178	0.191	9	0.125	0.518	0.364	10.010	1.000
Turkey	47.980	0.801	0.990	0.994	0.349	0.966	9	0.125	0.556	0.439	8.841	0.856
United Kingdom	31.728	0.635	0.452	0.688	0.319	0.832	6	0.500	0.586	0.499	2.308	0.054

Note: Variable X_1 = Volume of natural gas imported, X_2 = Import dependency, X_3 = Share of gas in total primary energy consumption, X_4 = Number of gas suppliers, X_5 = Dependency on largest supplier, X_6 = Supplier fragility. $\gamma_1 \ldots \gamma_6$ are the scaled values of the corresponding indicators $X_1 \ldots X_6$.

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Curriculum vitae

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01/2011 - 03/2011 BEST Training, Vienna, Austria
Accounting

01/1999 - 12/1999 Ho Chi Minh City University of Education, Vietnam
Advanced English

1994 - 1998 Ho Chi Minh City University of Economics, Vietnam
Bachelor of Economics - Business Administration

Professional Experience

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Administrative Assistant (part time)

02/2004 - 10/2007 William E. Connor & Associates Ltd.
(American global trading group - Resident Representative Office in Vietnam)
Senior Market Representative

12/2002 - 01/2004	Rochdale Spears Company, Vietnam *(British owned furniture manufacturer)* Customer Service Manager
06/2001- 11/2002	Li & Fung Group *(Hongkong based global trading group, Representative Office in Vietnam)* Merchandiser
06/1996 - 05/2001	Han Kyung Corporation, Ho Chi Minh City – Vietnam (*Korean owned automotive spare parts trading company)* Assistant Sales Manager

Language Skills

English	Professional proficiency
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Computer Skills

MS Office, Internal database systems, SAP for supply chain (basics), SPSS Statistics, C++, Xpress-Optimizer (mathematical modeling and optimization)