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# Shale Gas and Germany's Energiewende:
## *A Cost-Benefit Analysis for the Power Generation Sector*

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## Abstract

This paper analyzes the question of shale gas production in Germany aimed at aiding the power generation sector in its compliance with the country's greenhouse emissions reduction goal, one of the pillars of the nation's energy transition (*Energiewende*). After discussing the key characteristics of natural gas markets and unconventional gas, and the chief constraints faced by the country as it attempts to increase the share of renewables in its electricity mix, we begin our analysis of the costs and benefits of shale gas production in Germany.

We begin our analysis by defining how much natural gas will be needed in future decades for electricity generation under different scenarios of energy efficiency and renewables penetration in the electricity mix, and project the amounts that can be produced domestically using existing conventional reserves. We find that in all cases, a significant amount of natural gas will be imported during the 2020s and 2030s, and that demand for natural gas will increase in following decades in scenarios with low to medium renewables penetration.

Through an analysis of potential shale gas reserves, we determine that, given the relatively small quantities that can be extracted, German shale gas alone cannot significantly shift the supply curve outwards and lower prices, and that the primary benefits will be strategic.

By projecting the possible evolution of natural gas import prices, we calculate the degree to which shale gas production could aid Germany in maintaining its trade surplus. We find that, while shale gas could reduce imports by up to € 10.76 billion per year, electricity-related gas imports alone are unlikely to tilt the country's trade balance into a long-standing trade deficit.

On the issue of energy security, we find shale gas to be helpful in reducing the country's exposure to foreign sources – by up to 40.3% over the studied period. However, we also identify a number of alternative solutions that Germany can apply in order to reduce its supply risk, making shale gas less of a stringent necessity and less of a game changer.

A final benefit we identify from shale gas is the positive effect it can have on employment levels and investment in the regions it interests. This, coupled with the rise in government revenues through taxes and royalties, could play an important role in changing public opinion's perception of shale gas and hydraulic fracturing, and is in line with the Energiewende's secondary goal of maintaining competitiveness and employment levels high.

On the cost side of our analysis we find environmental damage, primarily with regards to groundwater contamination. While less likely than in North America due to local geological conditions, accidents of this kind will have much stronger consequences in Germany because

of the region's higher population density. While prevention is possible, moreover, risk cannot be eliminated altogether.

In conclusion, we find shale gas production to be a potentially useful tool in tackling some of the challenge posed by changes in the worldwide energy market and by Germany's energy transition. However, our analysis suggests that it will not be the game changer it was in the United States.

Throughout our analysis, additionally, we stress the importance of a favorable legislative environment: was the German government to decide that shale production is a desirable choice, taxation mechanisms and environmental restrictions would have to be set up in order to ensure that the endeavor is potentially profitable for companies – thereby sparking interest in investment – and not dangerous to the local population.

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# Table of abbreviations

| Abbreviation | Meaning |
|---|---|
| **AEA** | UK Atomic Energy Authority |
| **bcf** | Billion Cubic Feet |
| **bcm** | Billion Cubic Meters |
| **CEE** | Central and Eastern Erope |
| **CIA** | Central Intelligence Agency |
| **DNV** | Det Norske Veritas |
| **EEG** | Erneuerbare-Energien-Gesetz |
| **EIA** | US Energy Information Administration |
| **EPA** | US Environmental Protection Agency |
| **EWEA** | European Wind Energy Association |
| **GDP** | Gross Domestic Product |
| **IAEA** | International Atomic Energy Agency |
| **IEA** | International Energy Agency |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **kWh** | Kilowatt hours |
| **LNG** | Liquefied natural gas |
| **mcf** | Million cubic feet |
| **mcm** | Million cubic meters |
| **MIT** | Massachusetts Institute of Technology |
| **mmBtu** | Million metric British Thermal Units |
| **Mtoe** | Million Tonnes of Oil Equivalent |
| **NGO** | Non-governmental Organization |
| **OECD** | Organisation for Economic Cooperation and Development |
| **OPEC** | Organization of the Petroleum Exporting Countries |
| **SHIP** | Shale Gas Information Platform |
| **tcf** | trillion cubic feet |
| **TWh** | Terawatt hour |
| **UBA** | Umweltbundesamt |

# 1. Introduction

The goal of this chapter is to provide an overview of the paper's subject matter, the methodologies that are used throughout it, and its position relative to existing literature on the topic. We do so by introducing our research question and the political and economic backdrop it is based on, and continue by identifying the relevance of our study and the contribution it can have on policy discussions on the topic. The next sections, by contrast, outline the structure of our research, and the main pieces of relevant literature that are used throughout our study.

## 1.1. Background and research question

Since the early 2000s, one of Germany's main political goals has been the development of a sustainable energy policy (Strunz 2013): this transition, officially and colloquially referred to as *Energiewende* (literally: energy transition) is built around a series of goals concerning greenhouse gas emissions reduction, improvements in energy efficiency and consumption reduction, and increased use of renewables in the energy mix (Agora 2013).

To accommodate these very ambitious goals, the country's electricity generation industry – which currently relies primarily on hard coal and lignite (Graichen 2014) – would have to undergo significant changes, with high-emissions fossil fuels like petroleum oil and coal phased out in favor of renewables and cleaner fossil fuels like natural gas (Dickel et al 2013). Natural gas is generally considered of central importance in the transition, as it provides a cleaner alternative to coal and a more reliable alternative to renewables, whose planned growth path has been criticized by many as unfeasible (Strunz 2013). However, with Germany's conventional natural gas reserves nearing depletion, the economic and political costs of natural gas imports has come under investigation as a possible hindrance to the transition's feasibility (Growitsch et al 2013, Frondel et al 2010).

Given the presence of shale basins within German territory, and given the momentous changes that shale gas has brought about in North America, the exploration of the resource has been named as a potential solution since the late 2000s (Buchan 2012). Some initial exploration took place in the early 2010s in four of the country's federal states, but amid political opposition from major interest groups, a moratorium on hydraulic fracturing – the controversial technique used to extract shale gas – has been put in place in late 2013 and is still pending at the time of this writing (Nicola 2013).

Considering the high amounts of uncertainty that surround the success of energy transition, the evolution of natural gas prices, and the possibilities offered by poorly-explored shale basins, this study aims to identify how advantageous shale gas production would be under different scenarios.

Having defined the main costs and benefits associated with shale production, we dedicate a short chapter on implementation, discussing the action that the national and local government should take in order to ensure the practice is carried out properly.

## 1.2. Relevance

Our study is relevant for a variety of reasons. Germany, while arguably more ambitious than most other major countries, is not the only entity striving for a more sustainable energy mix, and natural gas offers a clean and reliable alternative to many of the energy sources used today.

Partly because of natural gas's potential as the main "bridge source" in the transition towards renewables, international demand for the commodity is projected to rise significantly in the coming decades, but the depletion of conventional resources and their concentration in few countries could result in higher prices as well as in a major power shift in international negotiations. Partly in light of this, shale gas has been hailed as a possible solution, allowing large industrialized countries to develop indigenous resources, and lessen their dependence on energy imports. However, top of being costly, the technologies required for shale gas extraction have drawn significant controversy due to their possible adverse impact on the environment, leading moratoria in many jurisdictions, including Germany.

A cost-benefit analysis of shale gas's potential impact on German electricity generation can thus provide a more figure-based aid to policy discussion on the topic, outlining the scenarios in which shale exploration is more desirable and measure its impact.

Furthermore, possibilities for build-up on the topic are significant: a similar methodology could be utilized to analyze the potential costs and benefits of shale exploration in other markets, as well as the impact of unconventional sources on other energy-consuming activities such as transport and heating or the impact of other changes in the electricity mix.

## 1.3. Paper's structure

This paper is divided in five chapters, whose content is detailed below.

**Chapter 1** provides an introduction to our research question and its relevance within the general field of electricity generation restructuring. It then continues into a description of the methodologies that are used throughout the paper and a brief exposition of the literature that the research is based on.

**Chapter 2** provides the basic background information needed to understand the issue at stake, the legal background and the institutions involved, the economic and physical limitations to different types of development, and the implications that are tied to the specific solutions that have been proposed thus far. The chapter starts by defining the goals of the Energiewende, and provides information about the legal institutions involved and the needs of Germany, some of which transcend sustainability. The second section provides an overview of the current electricity mix in Germany and the changes that a reduction in emissions will render necessary. The next two sections describe in detail the main characteristics of both conventional and unconventional natural gas, their markets, and the concerns connected with their extraction; particular attention is paid to the shale revolution in the United States, which is what sparked European interest in shale gas to begin with. The final part of Chapter 2 analyzes future trends in energy and electricity markets worldwide and in Europe before zooming in on Germany and outlining the primary limitations connected to further natural gas and renewable sources development. These issues will be of central importance in our analysis.

**Chapter 3** is the main analytical part of our paper, and consists of a cost-benefit analysis for shale gas production. The chapter starts by defining the amount of natural gas that will be needed for electricity generation over the next decades, within the regulatory constraint of the Energiewende. We develop different scenarios for energy consumption (which depend on energy efficient as well as on economic growth) and for renewables penetration, and compare how the need for natural gas changes in all their combinations.

Our analysis continues by estimating the level of strain that electricity-generating natural gas will place on the country's trade balance, both in a scenario where no shale is extracted, and in three scenarios where hydraulic fracturing is allowed. We use this data to determine the impact that shale extraction could have on the country's trade balance over the next decades.

The next section is also related to international trade, and deals with the concept of energy security. We begin by discussing the concept of energy security and the risks associated with excessive supplier concentration, before turning our attention to the European gas market and Russia's dominance over a large portion of it. We then analyze Germany's current supplier pool, and identify various options for its future development considering the threat of supplier concentration. Finally, we determine the degree to which shale gas can reduce the country's exposure to foreign sources.

Our analysis continues with a study of environmental issues, the main reason behind the current ban of hydraulic fracturing. We analyze the risks connected to groundwater contamination, the practice's most notorious adverse consequence, before discussing excessive water use, air pollution, the use of land, and the issue of induced seismicity.

Finally, we dedicate the last part of Chapter 3 to an analysis of further macroeconomic benefits brought about by domestic shale gas production. These include job creation, investments, and increased government revenues through taxes and royalties.

**Chapter 4** touches upon the issue of implementation by providing a brief overview of the issue of profitability and taxation on one hand, and public opinion and environmental risk reduction on the other.

**Chapter 5** sums up our findings, outlining the main learning points of our analysis and the implications and limitations our study.

## 1.4. Literature review

Many of the issues presented in our paper are the subject of a significant amount of study both in the academic and corporate world. The purpose of this section is to provide an overview of the existing literature on the topics covered in this thesis, including the constraint of energy transitions, the issue of energy security, the environmental risks implied by hydraulic fracturing and the economic benefits brought about by resource extraction.

It should be pointed out that, as anticipated, a large number of studies cited throughout our paper come not from academia, but rather from energy corporations or interest groups. While this does not automatically make a study less credible, a priority throughout our research is the identification and avoidance of any potential bias in our sources. Thus, figures extracted from some of the reports are typically double-checked against publicly available data.

Our research begins with an analysis of Germany's Energiewende and, more specifically, of the feasibility of some of its goals. Important studies in this field include Schill's (2013), which analyzes different possible levels of renewable penetration in the electricity mix depending on the advancement of storage technologies, and Dehmer's (2013), which analyzes the main constraints to electricity consumption reduction in light of projected economic growth, as well as the likelihood of continuation of the feed-in tariffs that have helped finance renewables thus far. These two studies, together with BP's Energy Outlook 2050 (2013) and Scheuer's Roadmap 2050 (2011), are used to determine the values in our scenarios for both energy consumption ("high, medium and low efficiency") and renewables.

Another aspect of research on the Energiewende concerns the distribution of the emission abatement burden. Basing our analysis on the concept of emission abatement distribution according to marginal cost of abatement, developed by Chichilnisky and Heal (1994) and commonly used in cap-and-trade systems, and supplementing our initial assumption with studies by Agora Energiewende (2013), the German Federal Environment Bureau (Icha 2013) and the Association of German Engineers (VDI 2007), we determine the share of the emissions abatement burden that will be attributed to electricity generating activities.

Our research continues with an analysis of international trade and the impact of trade deficits. Literature on the topic is abundant, and there is little to no consensus on the desirability of trade surpluses, especially in the short run. Examples of studies we use are Moon's (2006), Griswold's (2011), and Morici's (1997), which have more of a generic outlook, and McKinnon's (2011), Dieppe et al's (2012), and Gorman's (2003), which focus primarily on the effects of prolonged trade deficits, the actual focus of the chapter. Our key starting point for the determination of the import price scenarios in this section is the body of work by Siliverstovs et al (2005) and Bachmeier and Griffin (2006) concerning the effect of global integration of natural gas markets on prices.

A large number of studies also exist on the subject of energy security. A common topic of research is the cost of supply disruptions, which is analyzed among others by Hedenus et al (2010), who conduct a European Union-wide study centered on policies aimed at reducing exposure. Correljé and van der Linde (2006) take a somewhat different approach, defining two different scenarios for international trade of energy commodities and identifying the risks experienced by various countries in the European continent. Metais (2013), finally, analyzes how energy security issues have evolved following the liberalization of European gas markets, and how proactive policy actions will be necessary in order to avoid complete dependence from a small numbers of exporter. As detailed later in the paper, the issue of energy security is tied to the concept of supplier diversification theorized by Swaminathan and Shanthikumar (1999) and Anupindi and Akella (1993).

On the topic of potential environmental damage by hydraulic fracturing, we base our discussion on a number of studies, analyzing the effects of the practice. On groundwater contaminations, these include Myers's (2012) research, which analyzes both the reasons behind potential links and the effects they can have on the local community, Ewen et al's (2012) work concerning remedy methods and time, Jackson's (2013) paper on exposure to the risk and on possible preventive measures, and Muehlenbachs et al's (2013) study of the economic effect of contamination risk. On the topic of water use, we base our estimates on studies by SHIP (2012), KPMG (2012), Vidas and Hugman (2008), and Schleich and Hillenbrand (2009); we also use figures from studies by less "neutral" players, such as Chesapeake Energy (2012) and the International Association of Oil and Gas Producers (2013). Finally, we base our projections on new technologies reported by Smith (2014). Our calculations for water use, finally, are based on reports by the European Commission (2011), Santoro (2011), Jiang et al (2011), and are compared to similar studies by URS (2012) and Howarth et al (2011). In more generic terms, our conclusions and reflections are based on the work of Wiener and Graham (2009) concerning the tradeoffs between environmental risk minimization and other economic benefits.

Our estimations of shale gas production's impact on employment and government revenue levels are based on studies by Wang et al (2014), Pöyry and Cambridge Econometrics (2013) for the methodology, and on information from the British Institute of Directors (2013) for the figures.

The breakeven analysis carried out in Appendix 4 is based on data and methodology from Hefley et al (2011), a study outlining the main cost and revenue drivers in the United States' Marcellus Formation. Figures are adapted to the European continent based on studies by Baihly et al (2012) and Weijermars (2013). Finally, theories on the taxation of non-renewable natural resources are abundant, ranging from older ones (Burness 1976) to newer ones (Abramzon et al 2014); we base our discussion on existing policies.

As stated, a significant amount of figures in our study comes from reports by large oil and gas producers or large organization. We briefly describe them below for the reader's convenience. BP's Energy Outlook 2035 (2014) and BP's Energy Outlook 2030 (2013) are similar projections of the general trends of the energy world over the next few decades; the studies predict demand growth and the likely future composition of both the energy and electricity mix, assuming limited and late shale development in Europe and more rapid shale development in China.

KPMG's Central and Eastern Europe Shale Gas Outlook (2012) offers a more detailed study of markets that are similar to Germany in their presence of shale resources and dependence on Russian gas. The report deems a shale revolution like the one experienced in the United States very unlikely in Europe due to different legislative environments and market situations. We build on this in our analysis of the obstacles of shale development and in our estimates of shale production

In its 2012 "Golden Rules for a Golden Age of Gas" report, the International Energy Agency (IEA) examines two distinct scenarios of worldwide development for shale gas success. On top of calculating the possible impact on prices and $CO_2$ emissions, and changes in the power balance within the natural gas market, the study sets out "golden rules" that should be followed in order to ensure risk minimization and sufficient public opinion support.

The European Commission also published a report on the potential role of unconventional gas in its transition to a more sustainable energy mix: in its 2011 "Roadmap 2050" and in its 2011 "Impacts of shale gas and shale oil extraction on the environment and on human health" the commission points out the potential role of shale gas in reducing the country's dependence on coal for electricity generation, thereby reducing $CO_2$ emissions in both the short and long run.

# 2. Background

The main purpose of this chapter is to lay the groundwork for the analytical part of the paper, by detailing some of the main variables and constraints that will be used at later stages.
The chapter begins with a brief overview of the Energiewende, the policy framework that is at the base of Germany's energy transition as a whole. It continues with an analysis of the country's current electricity market and its projected evolution in the future. It then details the main characteristics of both conventional and unconventional natural gas, and analyzes the changes in demand that are projected for the commodity both worldwide and within the European continent.

## 2.1. The Energiewende

In order to understand the future of Germany's energy consumption, it is important to understand what the country's goals are and what the rationale behind the transition is. This section thus provides a brief overview of the goals of the Energiewende and the laws and institutions involved.

### 2.1.1. Goals of the energy transition

*Energiewende* is a German term used to describe Germany's transition to a more sustainable energy policy. Through a shift towards renewable energy sources and the promotion of measures aimed at increasing energy efficiency and sustainable development, the country aims at reducing its $CO_2$ emissions to 80-95% of the 1990 level (Agora 2013).
Specific goals were set for both the share of renewables in the electricity mix and for energy efficiency: compared to 2008 levels, Germany aims to consume 10% less energy by 2020, and 25% less by 2050. Meanwhile, renewable sources are expected to make up 35% of the electricity mix by 2020, 50% by 2030, 65% by 2040, and 80% by 2050 (Agora 2013). Somewhat related to the issue of sustainability, although decisively contradictory to the emissions reduction target, is the country's decision to phase out nuclear power by 2022.

**Table 1:** Goals of the Energiewende, as determined by the Renewable Energy Act, Nuclear Power Act, Energy Strategy for the Federal Government, and the European Union's pledge to curb $CO_2$ emissions (Agora 2013)

| | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| **Greenhouse gases (to 1990 values)** | -40% | -55% | -70% | -85% |
| **Renewables in electricity mix** | 35% | 50% | 65% | 80% |
| **Electricity consumption (to 2008)** | -10% | | | -25% |
| **Nuclear energy production (2010)** | -70% | 0 | 0 | 0 |

### 2.1.2. Rationale for the transition

The two primary reasons behind Germany's decision to initiate such a momentous transition are the increasing scarcity of carbon-based sources of energy and the detrimental effects that the burning of fossil fuels has on the environment, especially with regards to human-induced climate change (Agora 2013). The reduction of emissions connected to energy creation is an issue that enjoys a large degree of political support in the country: according to 2011 polls, 66% of Germans believe climate change to be a very serious issue, and 79% agree that a more sustainability-oriented economic policy is necessary (Morris and Pehnt 2014).

The long-term goal of the Energiewende is not only to decarbonize Germany's energy supply, but also to develop technologies and best practices that can be rolled out to the rest of the world: as Europe's second largest consumer of energy and most economically powerful country, Germany is often seen as a natural location for the early development of commercially viable renewable energy (Agora 2013).

### 2.1.3. Institutions involved

From a legal standpoint, the Energiewende is a collection of laws and acts promulgated at the local, federal, and even supranational level (Morris and Pehnt 2014). One such law was the Renewable Energy Act of 2000 (*Erneuerbare-Energien-Gesetz*, or EEG for short), which set in place the aforementioned goals and guaranteed a feed-in tariff for renewable energy as well as fixed prices for the next 20 years (BMUB, Renewable Energy Act 2010). Another major step was the 2011 Nuclear Power Act, which accelerated the phasing out of nuclear power, a source that is currently used as a "bridge technology" to offset the intermittency issues that are inevitably tied to solar and wind power (Nicola 2013).

The institutions involved in the Energiewende are, as mentioned, local, federal, and supranational. Given the role these institutions play in the promulgations of acts and directives, it is reasonable to describe their degree of involvement and power over the various facets of this complex issue.

Germany is a federal republic, meaning that its states (*Bundesländer*) enjoy a rather large degree of autonomy. Their jurisdiction also includes the local implications of energy policy, such as the construction of nuclear plants and wind turbines, and the distribution of permits for hydraulic fracturing (German Constitution 1949). Some states are much more active in their pursuit of the Energiewende than others: the southern state of Baden-Württemberg, for instance, leads the country in projects aimed at improving energy efficiency (Baden-Württemberg Ministry for the Environment, Climate, and Energy Economics 2014).

*Bundesländer* are further divided into administrative divisions (*Kreise*), which however have limited political power and no real jurisdiction over energy (German Constitution 1949).

At the federal level, energy policy is primarily in the jurisdiction of the Federal Ministry of Economics and Energy, and more precisely of its Energy Department. Another ministry with significant influence over the country's energy policy is the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety. Both ministries act through specific agencies, such as the Federal Environment Agency (known as *Umweltbundesamt*, or UBA) (BMWi 2014). Federal-level legislation concerns the large-scale direction in which the country's energy policy goes. This includes decisions like the introduction of feed-in tariffs for renewables, the phase-out of nuclear power, and potential bans on fracking (German Constitution 1949).

Finally, supranational bodies have some degree of legislation over Germany's energy and environmental policy as well. Throughout its recent history, the European Union has introduced a substantial body of legislation aimed at unifying the efforts of its member states in achieving determined sustainability goals (European Commission 2014). Important examples of European Union legislation include Directive 2009/28/EC, which mandates minimum levels of renewable energy use within its member states, and Directive 2009/72/EC, defining common rules for the internal electricity market.

### 2.1.4. Constraints

The enormous infrastructural costs entailed by such a momentous energy transition, together with the economic cost of feed-in tariffs, naturally have a significant impact on Germany's economy. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety ensured in 2011 that one of the priorities in the energy transition is to maintain the coutry's economic competitiveness, as well as to guarantee that the overall level of employment is not affected negatively (Morris and Pehnt 2014). Furthermore, while an increase in electricity prices both for industry and home consumers is expected at least in the short run, it is a priority for the Ministry to ensure that this does not carry over in the long run (Morris and Pehnt 2014).

Equally important for Germany is the level of energy security. In other words, the country wishes to secure access to either indigenous resources or a diversified pool of external suppliers, as well as to non-intermittent energy sources to back up local renewables (Morris and Pehnt 2014).

## 2.2. Germany's energy market

Having determined the direction in which Germany wants to move, we turn our attention to the country's current situation, both for energy production in general and for electricity. We then analyze what development would be needed to fit with the Energiewende's goals.

### 2.2.1. The current energy mix

Germany has the largest national economy in Europe and the fourth in the world by nominal GDP (The World Bank 2013). Since economic activity is one of the main drivers of energy demand, it is not surprising that Germany is ranked sixth in the total world's energy consumption, at 341 Mtoe per annum (EIA 2014b).

Like most western countries, Germany relies quite extensively on fossil fuels, which account for 79.3% of the current energy mix. Mineral oils currently account for 31.8% of the energy mix, and are used primarily in transportation; coal, which propelled the country's economic growth throughout the 20th century, accounts for 23.5%; natural gas, which is used primarily for heating and electricity generation, is responsible for 24.8% (AGEB 2013).

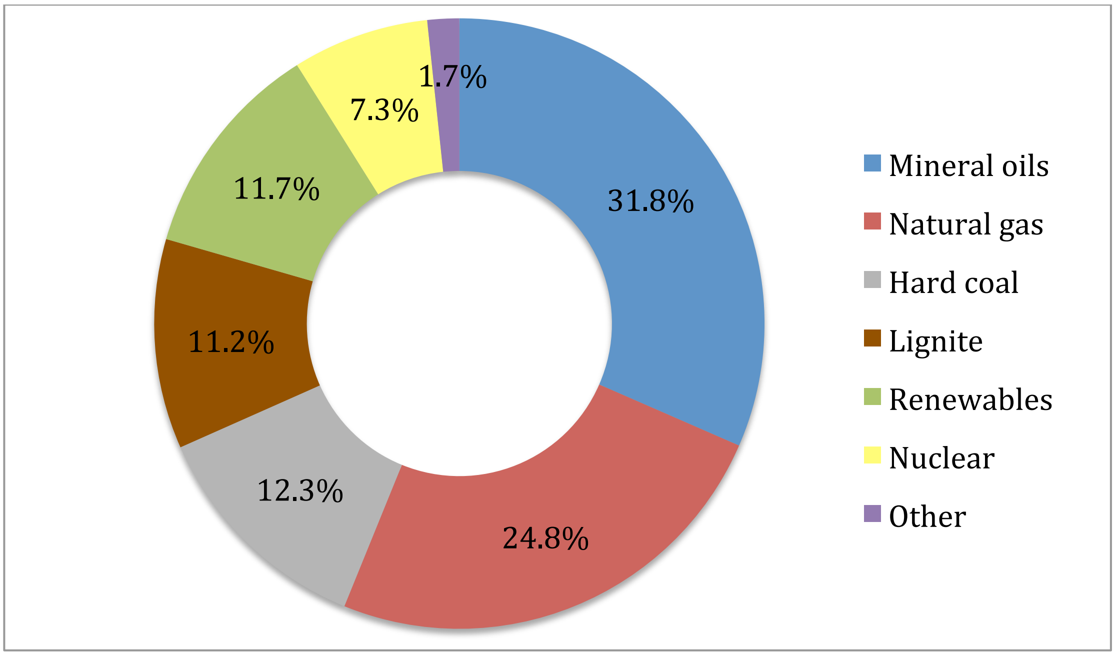


**Figure 1** Germany's primary energy consumption in 2013, by energy source (AGEB 2013)

Renewables account for slightly over 11.7% of Germany's primary energy production, up from less than 2.9% in 2000 (AGEB 2013). The main sources of renewable energy in Germany are wind power (40%), biomass (30%), solar power (16%) and hydroelectric power (14%) (BMUB, Development of renewable energy sources in Germany 2011 2012).

Nuclear power, finally, accounts for 7.3% of primary energy production. Nuclear power is used almost exclusively for electricity production, and its use in the total energy fell from 13.4% in 2010 due to Germany's decision to phase out nuclear power by 2020.

### 2.2.2. The current electricity mix

According to the Fraunhofer Institute (2013), Germany's gross inland electricity consumption in 2013 was 596 TWh. In that year, the country produced about 627 TWh, and had an export surplus of 31.4 TWh (much higher than the 23.1 TWh and 6.0 TWh surpluses of 2012 and 2011, respectively). As displayed Figure 2, the country's 2013 electricity mix was dominated by coal, which accounted for over 53% of the country's electricity production. Nuclear power still played an important role in electricity generation, at almost 20% of total generation. Only 8.2% of electricity was generated through gas-fired plants, a 21% reduction from 2012; this sudden drop is typically attributed to the availability of very cheap coal from the United States, as well as to relatively high natural gas prices when compared to the early 2000s (Fraunhofer Institute 2013, Wagstyl 2014).

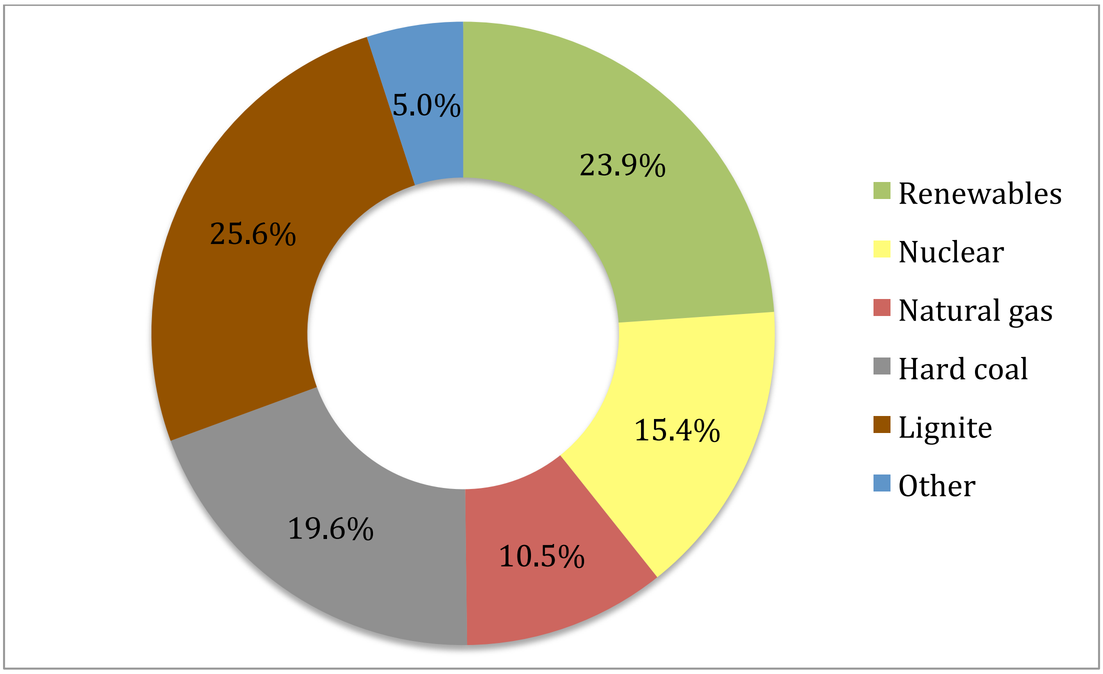


**Figure 2** Electricity mix of Germany, 2013 (Graichen 2014)

The use of coal and lignite for electricity generation, unlike that of natural gas, has increased significantly over the past few years, something which clearly rows against the country's objective to reduce its $CO_2$ emissions. This increase can be attributed primarily to the phase out of nuclear power (Keppler 2012), but other factors come into play: coal from the United States is much cheaper than natural gas, for instance, and new plants are typically justified thanks to their lower than average emissions – which are, however, still higher than those of gas-fired or nuclear plants (Knopf et al 2012).

Primarily as a result of increased coal and lignite use, Germany's electricity generation related $CO_2$ emissions actually increased from 305 to 318 million tons of $CO_2$ between 2011 and 2013 (AGEB 2013).

### 2.2.3. Projected energy mix according to the Energiewende's goals

It is possible to calculate the projected evolution of the country's electricity mix according to the Energiewende's goals. Assuming that all targets for the year 2050 (25% reduction of electricity use compared to 2008 values, 85% reduction of $CO_2$ emissions, phase out of nuclear power by 2022, renewables at 80% of the electricity supply) are reached internally within the field of electricity generation – that is, assuming that transport and heating have the same goals in emission cutting and consumption – the German electricity mix would have to evolve as depicted in Figure 3.

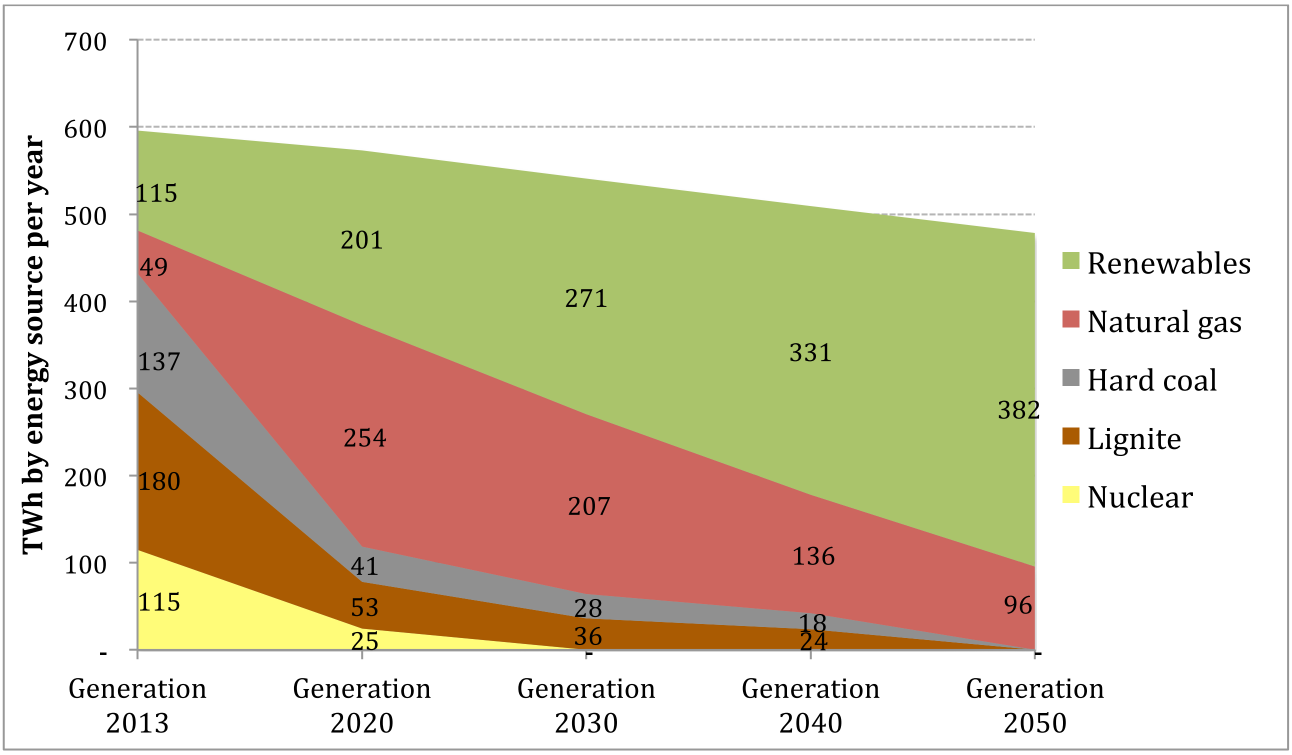


**Figure 3** Necessary evolution of the German electricity mix to keep up with the goals of the Energiewende (own calculations). Data is calculated by using emission targets as the constraint, nuclear and renewables evolving as projected by the Energiewende's goals, hard coal as a fixed percentage to lignite, and natural gas as the difference between total and other values.

Looking at the graph, it appears clear that, if Germany plans to reduce emissions by the planned amount within electricity generation, natural gas will have to play an extremely important role, especially over the next few decades. The increased use of coal, which is sometimes justified as a temporary step towards the achievement of the Energiewende's final goals (Wilson 2014), would also have to come to a stop by the 2020s.

Quite naturally, there is a significant amount of debate on whether Germany can indeed achieve the goals it set forth in the Energiewende. In particular, the 80% reduction in $CO_2$ emissions, the 25% reduction in electricity consumption despite economic growth, and the growth of renewable sources to 80% of the electricity supply are sometimes criticized as excessively optimistic. For this reason, this paper will introduce a number of sensitivity analyses to determine how the situation would look under different scenarios.

Furthermore, while some of the goals are internal – like the amount of renewables in the electricity mix and the reduction in consumption – some are shared with supranational bodies (in this case, the European Union). We will take thus take the reduction of $CO_2$ emissions as our primary constraint, and determine how much of it will come from electricity generation, since the assumption we made above about an 80% emission reduction in electricity generation is widely considered unrealistic based on current performance.

## 2.3. Natural gas

In order to determine whether unconventional gas can have a sensible impact on Germany's electricity market, it is important to understand the fundamentals of natural gas market. The aim of this section is to provide a general background on conventional natural gas, the way it is traded, and the recent demand trends that have affected this commodity.

### 2.3.1. Characteristics

Natural gas is an odorless and colorless flammable gas. It consists primarily of methane ($CH_4$), but typically also contains various levels of other hydrocarbons, such as ethane, butane, propane and naphtha (Statoil 2013). Just like oil, it formed over millions of years from the decomposition of organic matter, and depending on the formation mechanism (biogenic or thermogenic), it is found at different depths in underground rock formations or coal beds (EIA, Natural gas explained 2013). Natural gas can be used for a variety of industrial and residential activities, such as heating and cooking, electricity generation, and transportation. In order to be utilized as a fuel, it must undergo a treating process aimed at eliminating water and impurities: this activity is usually carried out at or near the extraction site (Statoil 2013). In the early days of oil extraction, natural gas was thought of as a by-product, which was typically disposed of on the spot (EIA, Natural gas explained 2013). Such a practice has not been completely abandoned: due to the difficulties in trade that will be introduced shortly, natural gas is sometimes still burned on the spot in regions where oil production is so abundant that natural gas trade is uneconomic – the Middle East being a prime example of this (Hannesson 1999).

Natural gas is also known for being the cleanest fossil fuel: while it does release greenhouse gases when burnt, its relatively simple molecular composition makes it much less polluting than oil or any type of coal (EIA 2013). Considering emissions for the entire lifecycle of each fuel, modern gas-fired plants have a 41-49% lower carbon footprint than comparable coal-fired plants (AEA 2012).

Table 2 Lifecycle $CO_2$ emissions in electricity generation by source in 2013 **(WNA 2013)**. Nuclear and renewables are larger than zero because of the emissions in their set up.

| | 1000 tons of $CO_2$ per TWh |
|---|---|
| **Nuclear** | 28.99 |
| **Lignite** | 1,054.01 |
| **Hard coal** | 888.01 |
| **Natural gas** | 498.81 |
| **Renewables** | 28.99 |

Nonetheless, natural gas is far from being environmentally neutral: the IPPC's Fourth Assessment Report (2004) estimated $CO_2$ emissions from natural gas to be already at 5.3 billion tons a year before the shale revolution, while the IPCC's Special Report on Emissions Scenario (2009) predicts them to grow to as much as 11 billion tons per year by 2030.

### 2.3.2. A regional commodity

The market for natural gas is profoundly different from the market for oil. While oil is an intercontinentally traded good with a heavily globalized market, natural gas is traded primarily within specific macro-regions, each of which is characterized by different prices and distribution systems (Hannesson 1999). This remarkable difference can be attributed primarily to the physical dissimilarities between the two energy sources: oil has a relatively high energy-to-volume ratio and is liquid, which makes transportation, storage and handling very easy and allows the flourishing of a globalized market; natural gas, on the other hand, is quite the opposite, as detailed below, resulting in primarily intra-continental markets (Hannesson 1999).

Compared to oil, natural gas is extremely bulky: 1,000 $m^3$ of natural gas have roughly the same energy content of a tonne of oil, which takes up 1 $m^3$ – in other words, at atmospheric pressure, oil requires a thousandth of the space that natural gas does for transportation and storage (Hannesson 1999). Due to its gaseous nature, moreover, natural gas is also harder to handle and transport: since it evaporates at normal temperatures under atmospheric pressure, natural gas can only be transported through pipelines or as liquefied natural gas (LNG). The threat of evaporation also makes storage a rather challenging issue (NaturalGas.org 2011). Natural gas pipelines are much costlier than oil pipelines, owing both to the bulkiness of their content and the fact that they must be airtight. While some economies of scale can be achieved in pipeline construction, the length of the pipeline is the main cost driver in natural gas distribution (Hannesson 1999).

Storage is also a major issue: since demand for energy fluctuates heavily across business cycles, seasons of the year, and even times of the day, being able to store natural gas once it has been transported to its final destination is crucial. Due to its bulkiness, natural gas is often stored in abandoned mines, salt domes, and aquifers, but their availability is often limited. This is why, especially for natural gas transported via pipeline, trade is characterized primarily by long-term contracts (Hannesson 1999).

Natural gas liquefaction aims to resolve some of the issues related to the gas's bulky nature. To be liquefied, natural gas must be compressed and cooled to very low temperatures at which it becomes liquid; to remain in this state, moreover, the temperature and pressure levels must be maintained throughout the whole transportation and storage time (Shell Global 2013). Since natural gas liquefaction is a very expensive and cumbersome procedure, natural gas is typically transported through pipelines; however, there are markets that are geographically distant from natural gas fields and are therefore served by LNG, Japan being a prime example (IGU 2011).

### 2.3.3. Importance of natural gas

Despite the difficulties in transportation, demand for natural gas has increased in recent years due to its lower greenhouse gas emissions: according to a report by the International Energy Agency, the increased use of natural gas in the United States over the past five years was responsible for a cumulative reduction in emissions of 450 million tons (Gouw, et al. 2014). Similarly, the European Commission has recognized the importance of natural gas as a mean to pursue a low carbon strategy: according to the Commission's Energy Roadmap 2050, gas will play a key role in the transition to a greener economy in Europe and in the switch from fossil fuels to renewables, both by substituting coal and by being an effective backup for intermittent renewable sources.

### 2.3.4. Location and distribution issues

The world's largest conventional natural gas reserves are primarily concentrated in relatively isolated locations: together, Iran, Russia, Qatar and Turkmenistan account for almost 55% of proven reserves (BP 2013a). With transportation being one of the chief cost drivers, the fact that geographies with significant supply are very distant to geographies with substantial demand translates into larger infrastructural needs, as well as higher prices for the end consumer (Hannesson 1999). Furthermore, the relative concentration of sources makes it more challenging for countries to diversify their supplier portfolio, something which, as detailed in Chapter 3, can greatly undermine a country's energy security (Metais 2013). Supply monopolies in natural gas provision are not rare in the world, and many countries in Eastern Europe depend entirely or almost entirely on Russia's Gazprom for their natural gas needs (Noël 2009).

## 2.4. Shale gas

This section introduces the concept of shale gas, the key variable in this paper. The aim of the section is to provide a good idea of how shale gas differs from conventional natural gas, and how its exploration, extraction and use differ across regions. Understanding the different legal and social challenges posed by shale gas development is of crucial importance in determining its feasibility in the long run.

### 2.4.1. Characteristics

Shale gas is natural gas that is found trapped within shale formations. Shale is the most common sedimentary rock in the world; it is fine-grained and typically found deep underground (EIA 2013a). While the existence of natural gas in shale formations was known since the late 1800s, the low permeability of the rocks made extraction operations economically unfeasible for much of the 20th century (Everett King 2010). Things changed in the mid 1990s, thanks to the introduction of two separate technological advances: horizontal drilling and hydraulic fracturing. By making the exploitation of shale plays economically feasible, these two technological advances opened way for massive exploration efforts, especially in North America (Everett King 2010).

Shale gas shares many of the same physical characteristics of conventional natural gas, such as low energy-to-volume ratio, relatively simple molecular composition, and tendency to evaporate (EIA 2013a). As a result, the two share a common market once they have been extracted. While slightly dirtier than conventional natural gas, shale gas remains much cleaner than other fossil fuels (EIA 2013a). The two main characteristics that set shale gas apart from conventional natural gas are the manner in which it is extracted and its presence in strategic geographical areas.

### 2.4.2. Extraction and environmental concerns

As stated, economically feasible extraction of shale gas is a relatively recent phenomenon, which was rendered possible by two technological breakthroughs: hydraulic fracturing (commonly referred to as “fracking”) and horizontal drilling.

The practice of fracking, which is described in detail in Appendix 1, is of particular concern due to the potentially detrimental impact it has on the environment. Potential negative externalities connected to fracking include the contamination of groundwater (EPA 2012), the migration of proppant chemicals towards the surface (EPA 2012), the release of methane into the atmosphere – which has detrimental effects on air quality (Down, Armes and Jackson 2013) – the consumption of large volumes of water – which is particularly problematic in arid areas – (Vidic, et al. 2013) and induced seismicity (Ellsworth 2013). On top of these environmental risks, hydraulic fracturing implies a number of inconveniences that are not shared by conventional natural gas extraction. Shale gas extraction is a very intensive industry activity with around-the-clock operations, creating noise and fumes from working diesel engines, as well as night lightening and a continuous stream of trucks (Schmidt 2011). The activities mentioned above can be problematic to perform in densely populated areas, as they have a direct negative effect on the quality of life.

Owing primarily to these negative externalities, the practice of fracking has come under severe criticism in both North America and Europe. Anti-fracking movements demanding either the banning of the practice or the introduction of tougher environmental standards have appeared in both continents, often in connection to existing environmentalist groups (Brantley and Meyendorff 2013).

### 2.4.3. Geographic location

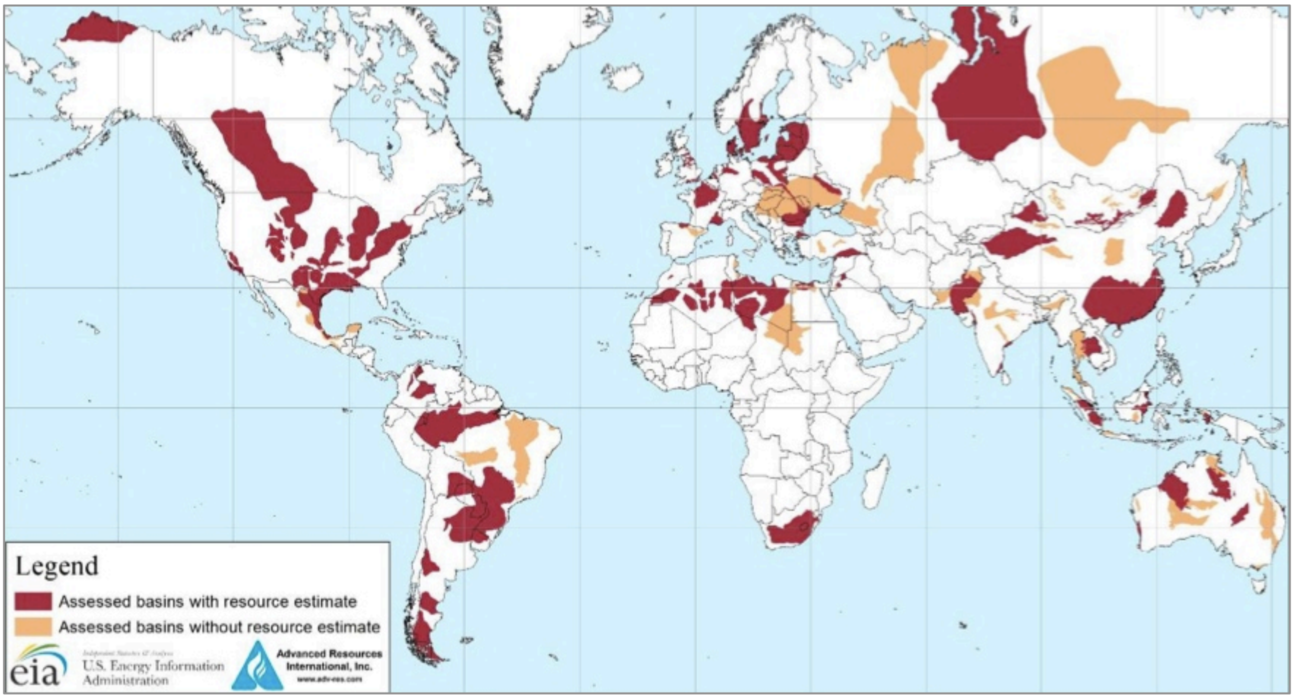


**Figure 4** Currently known shale basins, according to EIA data (2013)

While shale basins have not been explored as thoroughly as conventional natural gas reserves worldwide, current estimates suggest that many of them are located in relatively "convenient" locations – that is, geographies that have significant demand for energy. The largest estimated and proven recoverable resources are found in China and United States respectively, the two largest consumers of energy in the world (EIA, Technically Recoverable Shale Oil and Shale Gas Resources 2013). As detailed in the next sub-section, significant shale plays were also found in Europe, another large consumer of natural gas.

#### 2.4.3.1 Reserves in Europe

Within Europe, potentially viable shale plays are found in Western Poland, Northern Germany, Denmark, the Baltic countries, and Western France (EIA, Technically Recoverable Shale Oil and Shale Gas Resources 2013). According to Advanced Resources International (2013), Europe possesses about 883 trillion cubic feet of technically recoverable natural gas, while data gathered by the EU Joint Research Centre (JRC) estimates technically recoverable reserves to amount to about 561 trillion cubic feet[1]. Though these figures are lower than the United States' 1172.3 trillion cubic feet, they are likely to rise once more exploration is carried out, as is typical for unconventional resources. The amounts cited so far refer to technically recoverable reserves: in other words, this shale gas is thought to be present and recoverable, regardless of costs.

The amount we shall mostly use in the rest of this paper is economically recoverable shale gas, referring to the portion of a technically recoverable reserve for which there exist a sufficient economic incentive to extract. Given the lack of thorough exploration in Europe, it is difficult to determine how much of the technically recoverable resources are also economically recoverable, especially since the amount changes depending on gas prices and technological advancement (Hannesson 1999). The potential is however quite impressive: in the United Kingdom for instance, the Institute of Directors has projected that if only 10% of the country's estimated reserves were economically recoverable, they could satisfy 30% of the country's demand by 2030 (Institute of Directors 2013).

The development of shale gas extraction in North America – outlined more in detail in the next session – naturally provides a good technological basis upon which drilling companies in Europe can build on. However, European unconventional gas basins tend to be smaller, tectonically more complex, deeper, hotter, and more pressured (Gény 2012), something which is bound to pose some constraints on transferring American benchmarks of shale gas exploration on the European context.

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[1] The study reviewed 50 sources and proposed a high estimate (621.5 tcf), a low one (81.2 Tcf) and a best one (561 Tcf) (Centre For European Reform 2013).

Various models have been advanced to predict the possible development of shale gas in Europe, as detailed in the analytical part of this paper. According to the most optimistic scenarios, shale gas production in Europe could reach 10 bcm by 2020 and 80 bcm by 2035, covering over 10% of the European Union's gas demand (International Energy Agency 2012) and thus significantly reducing the need for foreign sources.

### 2.4.4. Energy revolution in North America

The potentially revolutionary effect of shale gas on the energy industry is best exemplified by North America's experience. After the introduction of hydraulic fracturing and horizontal drilling in the mid-2000s, the amount of recoverable natural gas in the United States increased by over 35%, and shale has rapidly become the fastest-growing natural gas source in the country (EIA, Annual Energy Outlook 2013 2013). As displayed in Figure 6, said growth is projected to continue in the future, and the EIA expects shale to be the leading source of natural gas over the next few decades.

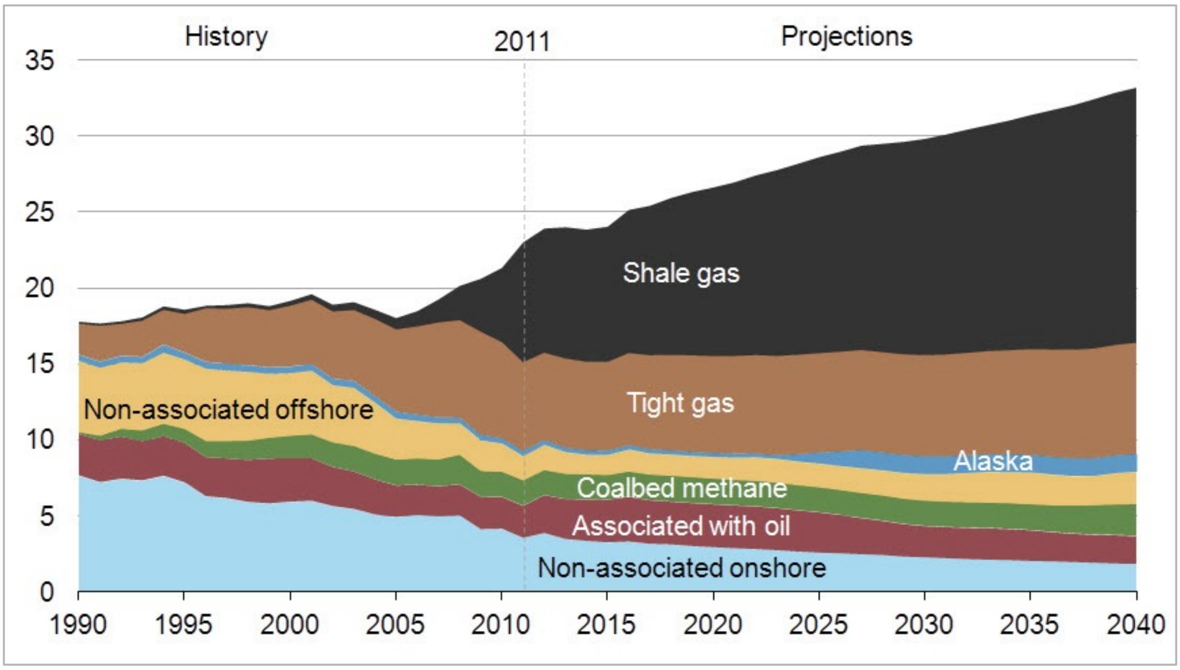


**Figure 5** United States dry natural gas production, in trillion cubic feet (estimates by the EIA, 2013)

From an economic point of view, shale gas is typically considered a game changer in North America. As a domestic source of energy, shale gas significantly reduced the United States' demand for foreign oil – imports of crude have dropped from 3.693 million barrels in 2006 to 3.120 million barrels in 2012 (EIA 2013b) – slimming the country's trade deficit and endowing it with more power when negotiating with politically hostile countries such as Iran and Venezuela (DiPaola and Tuttle 2013).

The additional supply of natural gas had a significant effect on price as well: between 2008 and 2012, the wellhead price of natural gas in the United States dropped from $7.97 per thousand cubic feet to $2.66 per thousand cubic feet (EIA 2014a). Prices for end consumers were also affected noticeably: if the same period of 2005-2012 is analyzed in both Europe and the United States, the results are striking, as detailed in the Table 3.

**Table 3** Price variation between 2005 and 2012 in Europe (average) and the United States (IEA 2013)

| | **Industry** | | **Households** | |
|---|---|---|---|---|
| | United States | Europe | United States | Europe |
| **Gas price index** | -66% | +35% | +3% | +45% |
| **Electricity price** | -4% | +38% | +8% | +22% |

The lower prices can be attributed not only to the increased supply, but also to the larger number of suppliers: during the United States' shale boom, much of Central and Eastern Europe has remained completely dependent on Russia and its monopolistic oil-indexed pricing policy (The Economist 2014).

Finally, the replacement of a large portion of the country's coal for shale gas has resulted in slightly lower carbon emissions despite increased energy consumption: the United States' carbon dioxide emissions peaked at 6 billion metric tons in 2007, and are now 12% lower (EIA 2013c).

### 2.4.5. Differences between North America and Europe

The physical properties of shale gas formations in North America and Europe are generally similar. However, geological characteristics such as depth of the formations, ground temperature and porosity, and clay content vary across formations and basins. European shale basins are located on average 1.5 times deeper than the same basins in the US and the ground has a higher geothermal gradient[2] (KPMG 2012), which might raise the problem of increased temperatures when operating a well, which will probably result in higher technological needs.

KMPG (2012) also suggests that the lack of a diversified drilling service industry in Europe – where the activity is monopolized by few large multinationals – may lead to delays in the development of appropriate technologies.

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[2] The temperature increases by 1°C for every 15 to 20 meters of drilling in Europe, while the world average is 1°C every 33 meters (KPMG 2012)

Furthermore, while most shale formations in North America are spread over large areas that happen to have a history of drilling and mining, shale formations in Europe tend to be smaller. Europe is also much more densely populated than North America, meaning that drilling rigs would have to be closer to inhabited areas (Burns, Topham and Lakani 2012).

Legislative uncertainty could also hinder the development of shale gas in Europe: since every country has full jurisdiction over the exploration of shale gas, companies and investors are met with a larger degree of uncertainty than in North America (there, while many decisions are taken at the state level, the federal government has the ultimate authority) (Burns, Topham and Lakani 2012). The European Union has thus far refrained from encouraging or discouraging the practice, deciding to instead simply recommend each member state to ensure that proper environmental precautions are put in place before exploration (European Commission 2014). Further legal complications result from land rights, which in Europe do not grant landowners the rights to exploit natural resources – whereas they do so in the United States. This naturally renders private exploration of shale gas much more difficult (Burns, Topham and Lakani 2012). A final – albeit more short-tem – hindrance for shale gas exploration in Europe is the taxation regime. No common approach to shale gas taxation exists in the old continent, and aside from Poland, no country has developed a taxation scheme that would incentivize research and development in exploration (KPMG 2012).

### 2.4.6. Legal status and public opinion in Europe

Due to the aforementioned risks implied by hydraulic fracturing, public opinion on the exploration of shale gas is split in much of Europe. Anti-fracking movements – often in connection to local environmentalist parties or "not-in-my-backyard" action groups – have developed across the continent, calling for stricter regulations or even a complete ban of the practice (Brantley and Meyendorff 2013).

Countries that have banned the practice altogether include France, the Netherlands, the Czech Republic and Bulgaria (KPMG 2012). Aviezer Tucker of Foreign Affairs (2012) has alleged that many of the protest movements in Eastern Europe (including the successful ones in Bulgaria and the Czech Republic) might be receiving funding from Russian interests, wishing to preserve their monopoly over the region's gas market. Fracking is legal in most countries in Europe, though a number of them have yet to issue permits for the exploration, owing either to lack of interested investors or widespread protests. In countries where permits have been issued, legal uncertainty remains a major issue for exploration companies and investors, as they do not guarantee that permission will be revoked when a new government sets in (Burns, Topham and Lakani 2012). Furthermore, numerous studies have pointed out that the taxation regime remains unfavorable in most jurisdictions, with Poland being the only significant exception (Weinstein 2013, Boyer, et al. 2011, Weijermars, et al. 2011).

As stated, the energy security and exploration of shale resources are national prerogatives, resulting in very different policies across the continent. Given the amount of funds involved and the large impact that public opinion has on this type of decision, bans and permits can be overturned quite frequently. Figure 6 summarizes the existing legislation as of February 2014, but will likely be subject to change over time.

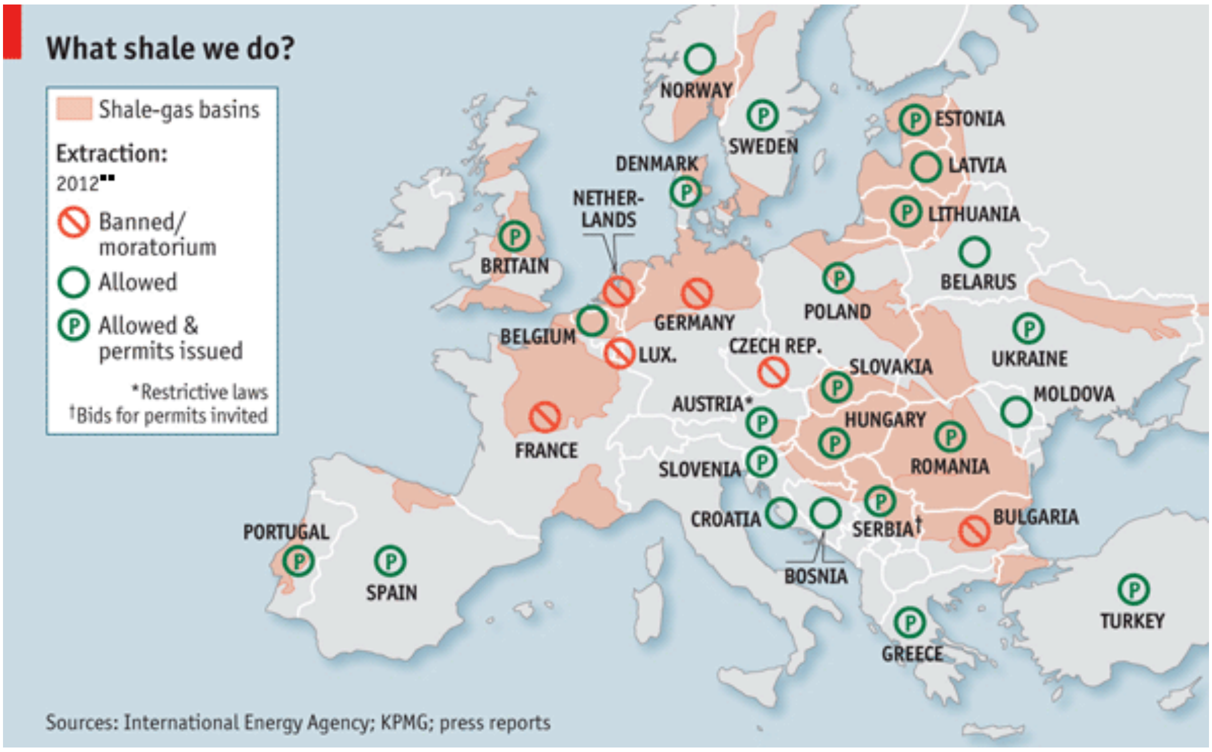



**Figure 6** Shale basins in Europe and current legislation on hydraulic fracturing by country (data by KPMG 2012, updated according to Stefan Nicola's 2013 article in Bloomberg)

## 2.4.7. The situation in Germany

Germany is estimated to have significant shale gas deposits – up to 17 tcf of technically recoverable shale gas (EIA 2013) – and is at the forefront of the shale gas discussion in Europe. As of May 2014, there is a moratorium on hydraulic fracturing, meaning that no actual exploration is taking place. As detailed in the next paragraph, the debate is still ongoing.

Discussion about potential shale gas exploration began in the late 2000s when, based on the United States' successes and the discovery of basins in Lower Saxony, explorative operations began to be set up. Opposition to the practice began soon after, drawing on the horror stories of groundwater contamination in Pennsylvania and West Virginia. The debate is still ongoing, and several environmental groups have been formed, especially at the local level, to prevent fracking in specific areas as well as in the whole national territory (Bojanowski 2013). These groups are widely supported by the Green Party, environmentalist organizations, and the renewable energy industry, who all fear that large-scale domestic gas production might drive funding and momentum away from the development of renewable technologies (Vinson and Elkins 2012) and have long-term detrimental effects on the environment.

Very little test drilling took place in Germany. In 2011, twelve exploration concessions were granted across the country: one in Nordrhein-Westfalen to ExxonMobil (which revoked before any drilling took place), nine in Lower Saxony to ExxonMobil, one in Baden-Württemberg to 3Leg Resources, and one in Thuringia to BNK Petroleum (Philippe & Partners 2011). Less than a year later, however, these permits were revoked amid stark protests both at the local and national level (Der Spiegel 2012).

A new opening took place in February 2013, when Federal Chancellor Angela Merkel announced a draft bill allowing shale gas exploration through fracking in much of the country's area (Nicola and Andresen 2013). The proposed legislation drew criticism from NGOs, the oppositions and even some members of Merkel's own party (Birnbaum 2013), encouraging all parties to postpone the debate until after the November 2013 elections (Shale Gas Europe 2013). Following the failure of pro-business and pro-fracking FDP to win any seats, Merkel's conservative CDU formed a coalition with the social-democratic SPD, and the two parties agreed on a moratorium on hydraulic fracturing that still stands as of May 2014.

German government agencies have carried out studies on the impact of hydraulic fracturing to test whether the practice should indeed be banned. According to a 2012 Federal Ministry for the Environment, Nature Conservation and Nuclear Safety report, hydraulic fracturing does not pose an extraordinary (BP 2013b) threat on the environment, so long as it is carried out away from water protection zones, as stricter regulations than mining ones be put in place, and as the exact composition of the fracking fluids are disclosed.

## 2.5. Future trends and limitations

After taking a detailed look at the characteristics of conventional and unconventional natural gas and at the direction towards which Germany aims to move, we can zoom out and see what developments are projected to take place in the world's energy markets. This is important because the German energy transition does not exist in a vacuum, and is deeply affected by external factors. After doing so, we can analyze what trends and issues Germany is likely to encounter internally in its quest for a greener energy supply.

### 2.5.1. Future trends in energy and electricity markets worldwide

World energy consumption is projected to grow at a 1.6% annual rate from 2011 to 2030, making consumption in 2030 36% higher of what it is today (BP 2013b). The key drivers behind the increase in demand will be growing population and income: by then, population is expected to increase by 1.3 billion, and the world income to double. Countries with low and medium economies outside the OECD are projected to account for over 90% of population growth, 70% of GDP growth, and over 90% of energy demand growth (BP 2013b). By contrast, OECD nations are projected to grow at a much slower rate, and their primary energy consumption is expected to only rise by about 6%. For the 2030 to 2050 period, most of these trends are expected to continue, although the pace at which energy demand grows is expected to diminish as more efficient technologies catch up in non-OECD countries (Shell Global 2012).

For electricity, by contrast, worldwide demand is expected to rise by about 65.3% by 2030, and then double between 2030 and 2050, reaching 74.433 TWh by mid-century (IAEA 2014). The main driver of this momentous growth will be South Asia, East Asia, and Africa, which are projected to increase their consumption by over 800% each. Projection on the energy sources fueling this growth vary, but most studies see renewables, nuclear, and natural gas experiencing quicker growth (7.6%, 2.6%, and 2.0% per annum, respectively) than coal or other sources (BP 2013, Shell Global 2012, IAEA 2014). BP (2013) projects such changes to be driven primarily by prices, new technologies, and policy development.

Shale gas's growth is predicted to continue in the United States: between 2011 and 2030, its production is expected to triple, accounting, together with tight oil, for a fifth of the increase in the country's energy supply to 2030 (BP 2013b). Worldwide, shale gas is expected to grow at 7% per annum, accounting for 37% of the growth of natural gas supply. North America will keep the leading position in shale gas production, but drilling technologies are expected to expand to new regions by 2020, allowing extraction in China and Europe (BP 2013b).

### 2.5.2. Future trends in energy and electricity markets in Europe

Due to the increasing efficiency of energy systems, BP projects that European energy demand will only rise by 5% to 2030 (BP 2013b), with a 29% decline in energy intensity. Oil's share in the energy mix is expected to drop by 15% and coal's by 33%, with renewables and natural gas gradually increasing their prominence. The transition away from high-emission fossil fuels can be related to the reduction of greenhouse gas emissions to 80-95% of 1990 levels by 2050 goal, which concerns not only Germany, but the whole European Union (European Commission 2011)

According to the European Commission, the share of renewable sources in the energy mix will rise substantially, reaching at least 55% of gross energy consumption by 2050 (EC 2011).

Gas is also expected to grow significantly: according to a 2011 EuroGas report, the European Union's demand for natural gas is expected to rise to 625 Mtoe by 2030 (or 26.5Tcf), an increase of 43% compared to today's consumption levels. Most of this natural gas is projected to come from outside the European Union, with imports expected to total 480 bcm – 75% of total demand – by 2035 (European Commission 2011). Imports are expected to increase by 46% to 49%, and Europe is projected to remain the world's largest importer of natural gas. This is due primarily to the depletion of conventional natural gas fields in the Netherlands, the United Kingdom, and Norway – which, while not a member of the European Union, still has strong ties with it through its membership in the European Economic Area (CIA 2011).

### 2.5.3. Future trends in energy and electricity markets in Germany

As previously stated, Germany has set forth a number of very ambitious goals concerning the reduction of electricity consumption, the use of renewables, and the abatement of greenhouse gas emissions. These goals require significant development in the field of energy efficiency and renewable energy technologies, and numerous economists and have characterized the Energiewende's objectives as unfeasible (Keil 2012). Reasons for this include the enormous burden that the feed-in tariffs used to aid the development of renewables place on the German economy (Leepa and Unfried 2013), and the fact that a 25% reduction in energy consumption despite a projected economic growth of 22% between 2013 and 2030 would require a 2.1% per annum increase in energy efficiency (OECD 2013). The failure to materialize the drastic reduction of emissions that was set as a goal for the entire European Union is typically viewed as the country's main shortcoming in its energy transition, leaving many to wonder whether the objectives were too ambitious.

Figure 3 (cfr. section 2.2.3) displays somewhat of an "ideal scenario" in which all of the Energiewende's goals are reached within electricity generation. As shown, this would require a steady development of renewable sources, as well as a sharp increase of natural gas use, especially in the short to medium run. While this projection is hardly realistic – as we will investigate further in our analytical part – it does point out the importance of renewables and gas in the future of Germany's electricity generation. In light of this, the next two sub-sections will detail some of the main issues that are connected to the two energy sources and that will be instrumental in calculating the potential future of unconventional natural gas in the German electricity market.

#### 2.5.3.1. Trends and issues with natural gas in Germany

Despite being Europe's second largest consumer of natural gas, Germany only produces 15% of its demand domestically (EON 2014). The remaining 85% is imported, the main suppliers being Russia (which alone accounts for 39% of the supply), the Netherlands, and Norway. At least within conventional natural gas, this percentage is projected to increase over the next decades, owing to the depletion of traditional natural gas fields within the country's territory (EIA 2013d, Deuse 2014).

Germany's reliance foreign gas comes with a sizable price tag: in 2012, natural gas was responsible for 4.4% of the country's imports, and at $54 billion was the second largest account after crude oil – net imports totaled $36.9 billion, corresponding to about € 28.7 billion in 2012 (Observatory of Economic Complexity 2014). At 11.13% of worldwide demand, Germany is also the second largest importer of natural gas globally, after Japan. On top of simple import costs, of course, is the strategic cost of energy dependence: as discussed more in detail in Chapter 5, lack of control over energy resources can negatively impact a country's relative power in international negotiations, if the supply base is not diversified enough (Hedenus et al 2010, Metais 2013).

Numerous alternatives have been considered to lessen the country's dependence on foreign sources of energy. Liquefied natural gas (LNG) is projected to grow significantly thanks to the United States' abundance of supply, and EON reports (2014) predict that it will account for 24% of the European gas supply by 2020 – up from today's 10%. As UPI (2013) points out, the introduction of LNG on a larger scale could help make natural gas markets more globalized by diversifying the supplier portfolio and introducing competition in areas previously characterized by a monopoly or oligopoly. This would, in most cases, result in lower prices for the end consumer in areas that were traditionally characterized by high natural gas prices, like Western Europe and Japan.

From a policy standpoint, natural gas enjoys significant support by the European Union, which recognizes its potential to clean up the energy mix (European Commission 2011) and function as a backup for intermittent energy sources (Capozza and Curtin 2012). Important factors that the Commission considered are the low upfront investment costs and set-up times for gas-fired plants and their flexibility (Shahidehpour 2005).

### 2.5.3.2. Trends and issues with renewable energy sources in Germany

Renewable energy is where Germany is placing much of its hope for the future. Renewables are particularly used in electricity generation, and in 2013, 23.9% of the electricity supply (123.5 TWh of 603 TWh) was produced from renewable sources (AGEE 2012). As previously stated, Germany plans for this share to grow to 80% by 2050 (Morris and Pehnt 2014). Wind power makes up 40% of the country's renewable electricity supply, with most of the country's over 22,000 wind turbines being located in North Germany and increasingly offshore (EWEA 2012). Despite the country's geographic location and the source's limited potential, solar power accounts for 16% of renewable electricity generation.

As previously mentioned, the development of renewable energy sources translates a wide range of costly implication for the German economy. The first of such costs are the feed-in tariffs, which make German electricity the second most expensive in Europe for industrial customers, after Denmark (Leepa and Unfried 2013, RWE 2013). For an export-driven country like Germany – they account for 51% of the GDP (CIA World Factbook 2014) – industrial competitiveness is a key issue, and the 60% increase in electricity price over the since 2007, compared to 10% in the United States in China, is neither an optimal nor sustainable situation (RWE 2013, Frondel et al 2010). Numerous economists, including a commission of experts set up by the German government, advocate for a phase-out of these tariffs, which they argue are fundamentally flawed as they fail to incentivize innovation in the green industry (Reuters 2014, Bohringer et al 2014).

Another major issue concerning renewable energy development in Germany is the grid system. Today, the grids carrying electricity from the wind-rich North to rest of the country are increasingly congested. Most of the renewable energy sources in Germany are currently connected to the distribution system rather than the transmission system, resulting in significant losses. Large investments, estimated to be between € 27.5 and 42.5 billion over the next ten years, will be necessary to reinforce 2,900 km of existing lines and construct 2,800 km of new ones (International Energy Agency 2013).

Owing partly to rising costs and partly to the failure to meet some of the goals that were set at the outset of the Energiewende, the two parties in the German government have agreed to adjust some of the intermediate goals downwards: the 2020 goal of the 10GW offshore wind-power capacity, for instance, will be lowered to 6.5GW (Hockenos 2013). The coalition is also considering a gradual downward adjustment of the feed-in system, making sure that results are attained in an affordable fashion (Berliner Zeitung 2013). Owing to these challenges, our analysis will not take the Energiewende's original goals as a given, but rather set up a sensitivity analysis considering three different development paths for German renewables.

#### 2.5.3.3. Intermittency of renewables and balancing capacity

Currently, the intermittency of renewable energy sources, primarily wind and solar, poses a major obstacle to their inclusion into the grid (Rugolo and Aziz 2010). The modern world is accustomed to readily available electricity, so tying its supply exclusively to intermittent sources would clearly not be in line with Germany's goal to maintain comfort for the end consumer and competitiveness for the industry.

The intermittency problem of solar and wind energy is typically solved by having a dispatchable source – that is, a source that can be dispatched at the request of the power grid operators, adjusting the power output on demand – to fill the electricity gap in case of low renewables supply (Rugolo and Aziz 2010). These dispatchable sources are called "balancing capacity", and are typically produced by sources that can be activated quickly whenever there is a price incentive (Parson, Milligan and Zavadil 2003).

In Germany, like in many other countries, the main balancing capacity sources are gas-fired electric plants and hydropower stations, both of which can start production with little to no warm-up time. Naturally then, as more renewables are added to the electricity mix, new balancing capacity will need to be added as well (Frunt 2011).

# 3. Cost-benefit analysis

The purpose of this chapter is to analyze the costs and benefits of shale exploration under a variety of possible scenarios and within the constraints of the Energiewende's goals. As mentioned in our introduction, the issue of shale gas exploration in Germany is a multifaceted one, covering a range of cost and benefits that are quite different in nature. In light of the heightened need for natural gas over the following decades – a likely necessity for Germany due to the goals of the Energiewende – shale gas exploration is often lauded for the positive impact it can have on the country's trade balance and its energy security standing; at the same time, its controversial extraction technique is the subject of criticism due to the adverse environmental consequences it can bring about. Finally, supporters of shale gas point to the possible effect that domestic production can have on the local economy in terms of employment, tax royalties, and so on. The goal of this chapter is to analyze the costs and benefits to which a direct market value can be placed, and provide information on the ones for which it cannot.

We start our analysis by analyzing how much natural gas will be needed in the next decades. To do that, we set $CO_2$ emissions reduction as our primary constraint, and analyze how much of the reduction burden will fall on the electricity generation industry, the subject of our analysis. We continue by determining how much electricity will be generated in the upcoming decades, considering different scenarios for energy efficiency and demand. Finally, we turn our attention to the German electricity mix: since, as stated, Germany's plan to achieve 80% renewables in electricity generation is broadly viewed as overly ambitious, we develop three possible scenarios, and calculate the minimum level of natural gas that will be required in each decade for each efficiency-renewable scenario combination.

Having determined the demand for electricity-generating natural gas, we analyze the trade balance issue: since soaring imports of natural gas could negatively affect the country's trade balance, we determine the degree to which domestic gas production could help Germany. We start our analysis by outlining three development scenarios for the import price of natural gas, and calculate how much Germany will have to pay for the commodity if it maintains its moratorium on hydraulic fracturing. We continue by outlining three possible domestic production profiles in case of favorable legislation towards shale extraction, and determine the savings on imports that shale gas could bring about.

Our analysis continues with an exploration of the energy security issue. We start by outlining the fundamentals of energy security, and the risks that an economy incurs when it is overly dependent on another for a key resource like natural gas. We then look at Germany's supplier portfolio, and how it could evolve in future years if the moratorium on shale production is maintained. Finally, we look at how the supply of electricity-generating natural gas would change with the introduction of shale gas, under different scenarios.

The next section deals with the environmental impact of shale gas production. We start by analyzing the issue of groundwater contamination – the primary risk associated with hydraulic fracturing – its possible consequences in the densely populated region where shale production would take place, and the measures that can be implemented to minimize said risk. We continue by describing the role that water use, an important constraint to production in the United States, is likely to play in Europe in light of technological advances. Finally, we analyze the issues of air pollution, land use, and induced seismicity, three other important considerations related to the practice of hydraulic fracturing.

Finally, we dedicate the last section of our analysis to the other macroeconomic consequences of shale production. The primary consequences, as observed in the United States, are increases in investment and in the employment level, while a secondary consequence is the increase in government revenue through extraction royalties and taxes. We analyze how these values have evolved in the United States and how they could develop in the future before moving on to Europe and their possible applicability in the German context.

## 3.1. Amount of natural gas needed for electricity generation

As mentioned in Chapter 2, natural gas is a cleaner energy source than other fossil fuels, so an energy mix generating fewer $CO_2$ emissions is likely to have to contain more natural gas. We dedicate this section to the identification of the minimal level of natural gas required to realize the Energiewende's emission goals within electricity generation. For the sake of simplicity, we analyze four points in the future at the beginning of each decade up to 2050. Assuming that natural gas in other sector of the economy will remain constant, the values we find can be considered as increases in total demand of natural gas.

### 3.1.1. Emission reduction in electricity generation

Electricity generation, together with transport, heating, and other industrial activities, is responsible for the release of a significant amount of greenhouse gases in the atmosphere. Given these emissions' adverse effect on the environment and their crucial role in global warming, many jurisdictions across the world have put in place legislation aimed at reducing them. As previously mentioned, the European Union's goal is to gradually reduce its emissions by 80%, and Germany – the entity's largest member in terms of votes and population – has pledged to do the same within its territory (Agora 2013).

Being an external as well as internal goal, the reduction of $CO_2$ emissions is taken as the primary constraint within this paper. In other words, our analysis of the evolution of natural gas's share in the electricity mix will take the planned emissions over the next few decades as the upper limit. While we are aware that greenhouse gases are by no means limited to $CO_2$, we deliberately limit our analysis to this type of emissions for the sake of simplicity – the main reasons behind our choice of $CO_2$ over other emission types are the abundance of data on the topic and the fact that $CO_2$ emissions are widely considered a good representation of greenhouse gases emissions in general.

To perform our analysis, it is important to determine how emissions tied to electricity generation are expected to diminish over the next decades. The German government has not put forth specific internal goals for the different industries, but assuming an equal distribution of the emission reduction task, as sometimes done in other studies and as exemplified in Figure 3, might not be the best depiction of reality. As Deutsche Umwelthilfe (DUH 2013) points out, electricity-generation-related $CO_2$ emissions amounted to 357 million tons in 1990, about 34% of total emissions (1.042 million tons); by 2012, electricity-related emissions had dropped by little over 11%, while non-electricity related ones dropped by over

27%. The study analyzes the assumption of a linear emission reduction to the 2020 goal, and an equal relative distribution between electricity generation and other activities, and notes that in 2012 electricity generation was responsible for 83% of the excess emissions (65 out of 78 million tons of $CO_2$).

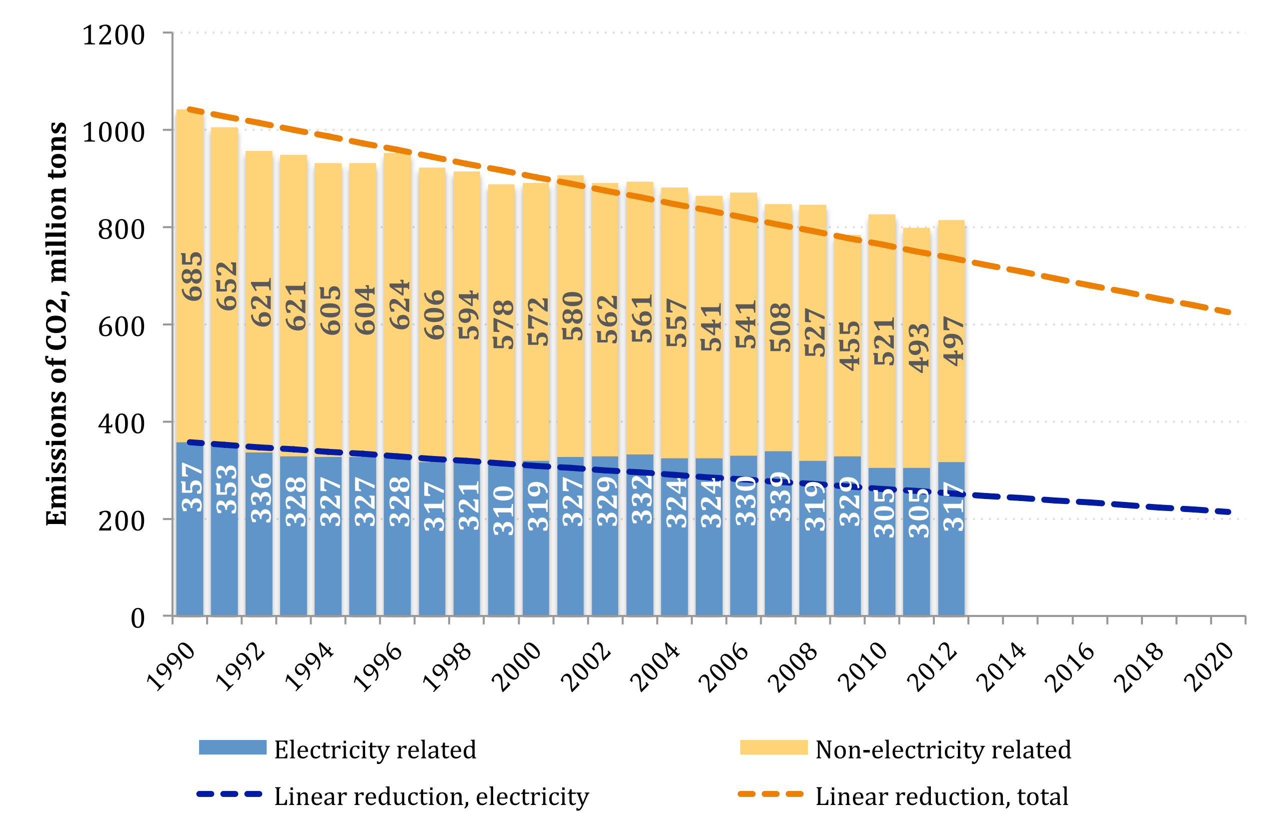



**Figure 7** $CO_2$ emissions in Germany from electricity generation and other activities. The lines represent a linear reduction to the 2020 goal assuming an equal split of the emissions reduction burden starting in 1990.

A more feasible evolutionary path, as pointed out by studies by Agora Energiewende (2013), the Federal Environment Bureau (Icha 2013) and the Association of German Engineers (VDI 2007), would be characterized by a slight shift of the emission reduction burden towards non-electricity related activities, such as heating, transportation, and industrial use. Our analysis will therefore use slightly discounted targets for electricity generation (rounded up to about 5% less per decade for simplicity) and assume that other activities will amount for a larger degree of emission reductions, as detailed in Table 4.

**Table 4** Distribution of the emission reduction burden and emission targets for electricity generation

| | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| **Emission reduction, total** | 40% | 55% | 70% | 80% |
| **Emission reduction, electricity** | 35% | 50% | 65% | 72% |
| **Emission reduction, other activities** | 43% | 58% | 73% | 84% |
| **Emission target, electricity** | 232,050 | 178,500 | 124,950 | 99,960 |

### 3.1.2. Germany's electricity production up to 2050

The amount of electricity generated over the next decades will depend primarily on demand, both within and outside of Germany. Demand, in turn, will be affected by geopolitical factors like economic and population growth as well as by technologies that increase energy efficiency. While there is general agreement that Germany's electricity consumption is likely to continue diminishing after reaching a peak in 2008 (the dip in 2009-2010 period is typically considered an anomaly due to the financial crisis the country was affected by), the rate at which consumption will diminish remains quite uncertain. For this reasons, we will from now consider three scenarios characterized by different levels of energy efficiency and demand reduction. The scenarios are based on BP's Energy Outlook 2030 and on Scheuer's Roadmap 2050, and are described in the tables below, which contain the percentage reduction based on 2008's level in TWh.

- The "**High efficiency**" scenario corresponds with the goals set forth by the German government in its description of the Energiewende. It implies a rapid reduction in electricity consumption from its 2008 value culminating in a 25% reduction by 2050.
- The "**Medium efficiency**" scenario is characterized by a more limited reduction in electricity consumption, with a decrease rate of about 0.3% per annum. This could be explained by either slower technological advances or by increased demand for power in general, something that would offset progresses made in energy efficiency.
- The "**Low efficiency**" scenario, finally, is characterized by an almost stagnating electricity consumption level, which can be attributed to both limited energy efficiency improvements and by rising demand for power deriving from economic growth.

**Table 5** Percent reduction in electricity consumption compared to 2008 in three different scenarios

| | 2014 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| **High efficiency** | 6.4%* | 10% | 15% | 20% | 25% |
| **Medium efficiency** | 6.4%* | 9% | 13% | 17% | 20% |
| **Low efficiency** | 6.4%* | 7% | 8% | 9% | 10% |

**Calculation based on electricity consumption in 2008, 637TWh* (International Energy Agency 2014) *and consumption in 2013: 596TWh* (ICIS 2013)

**Table 6** Projected electricity consumption in the three scenarios (in TWh)

| | 2014 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| **High efficiency** | 596 | 573 | 541 | 509 | 478 |
| **Medium efficiency** | 596 | 579 | 554 | 529 | 509 |
| **Low efficiency** | 596 | 592 | 586 | 579 | 573 |

### 3.1.3. Germany's electricity mix up to 2050

Having determined our analysis's main constraint and having calculated possible evolution paths for the level of energy consumption, we can now turn our attention to how Germany's electricity mix could evolve in the future, and how that would affect the country's demand for natural gas. Our analysis starts by identifying three potential development paths for renewables in the country – from an "optimistic" one, in line with the country's goals, to a "pessimistic one" envisioning very little further development over the next decades. Our analysis then continues by identifying the minimum amount of natural gas that would have to be included in the electricity mix in each of the scenarios in order to respect the emission reduction targets mentioned in section 3.1. Finally, a brief session will analyze the issue of dispatchable electricity generation and natural gas's potential role as a "backup" source.

#### 3.1.3.1. The share of renewables in the energy mix

The increase of renewable energy sources in the German energy mix is one of the primary goals of the Energiewende. As mentioned in Chapter 2, much of the growth to the current level was aided by feed-in tariffs, whose permanence in the future is quite dubious due to the high costs they imply. Furthermore, specific improvements to the grid – which might also carry a prohibitively high price tag – would be needed to further the development in the future. To cope with this uncertainty and develop a realistic analysis, we consider three different scenarios, characterized by different levels of renewables in the electricity mix.

- The "**High renewables**" scenario is the one cited in the Energiewende program's goals (BMUB 2014), with renewables rising gradually to 80% in 2050. Most studies agree that it is highly unlikely that Germany will overshoot this very ambitious target, making the choice of said goals as an upper limit a reasonable assumption.
- The "**Low renewables**" scenario is, by contrast, characterized by stagnation in the development of renewable energy. Once again, it is quite unlikely that the share of renewables in the electricity mix will diminish over the next few decades, so we simply round up the current value to 25% for simplicity and assume a constant share.
- Finally, the "**Medium renewables**" scenario is characterized by a more organic development of renewable energy sources within the electricity mix. Continuing on the same macro-pattern that has taken place since the late 1990s, renewable energy sources gain an average 1% share per annum in the electricity mix, reaching 60% by 2050. Once again, numbers are rounded to the nearest 5% to make calculations simpler.

Table 7 Share of renewables in the electricity supply in three different scenarios

| | 2014 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| High renewables | 23.9% | 35% | 50% | 65% | 80% |
| Medium renewables | 23.9% | 30% | 40% | 50% | 60% |
| Low renewables | 23.9% | 25% | 25% | 25% | 25% |

### 3.1.3.2. Minimum share of natural gas in the energy mix

The regulatory changes that have been introduced in Germany and the European Union over the last decade dictate the necessity for significant changes for the share of natural gas in the electricity mix, as maintaining a mix where coal is the primary source is incompatible with the emission reduction goals described in section 3.1.

In this section, we thus calculate the minimum amount of natural gas that will be needed over the next decades to satisfy the emission reduction goal in each of the combinations of the scenarios that we have described so far. For simplicity, we only consider end-of-decade points as a reference, and round our results to the nearest TWh of electricity produced. In our analysis, we make the following assumptions:

- Nuclear power is completely phased out by 2022, as planned.
- Emissions from electricity generation depend exclusively on the source: this is naturally not a perfect reflection of real life, since the type of plant and its carbon abatement system, together with the specific variants of the energy source may significantly change the picture. The value we use are the ones displayed in Table 2, which are averages that are supposed to represent different plant types and coal variants.
- The share of lignite to hard coal remains constant over the year, at a ratio of 1.304:1. We do this to eliminate one degree of freedom and find a unique value for natural gas.
- The emission per TWh for hard coal and lignite diminish at an annual rate of 0.75% as a result of technological advances in the field of carbon emission abatement in coal-fired power generation plants. This is consistent with the findings of DNV (2013) and Carniere (2012) on the topic.

The minimum amount of natural gas that will be needed is calculated as the residual of all other energy sources. In some scenario combinations the emissions reduction target delineated in 3.1.1 cannot be reached: in these cases, we consider the amount of natural gas needed to compose an electricity mix composed exclusively of renewables and gas, as it is the alternative that is closest to the emission reduction goal.

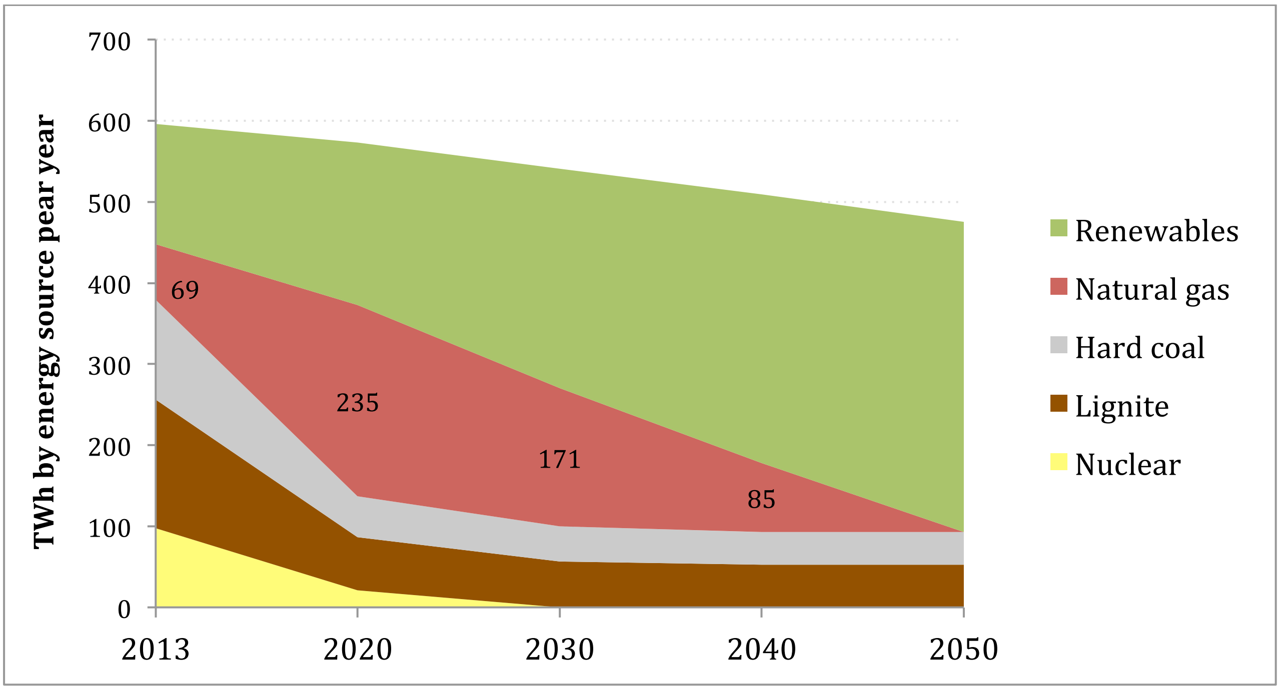
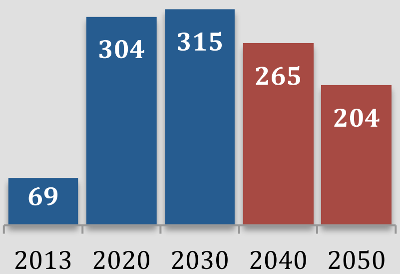



**Figure 8** Necessary evolution of the electricity mix under the "High renewables" and "High efficiency" scenario in order to keep up with the emission reduction goal

As shown in figure 8, a substantial increase in natural gas use will be necessary in order to keep up with the Energiewende's emissions reduction goal even in the optimistic of scenarios. This need will be particularly pressing over the next few years, as renewables will not be able to cover enough of the electricity production by themselves.

In order to better understand how the degree of renewables penetration and energy efficiency affect the minimum quantity of required natural gas, we perform the same type of analysis for all scenario combinations, and report the results in Table 8.



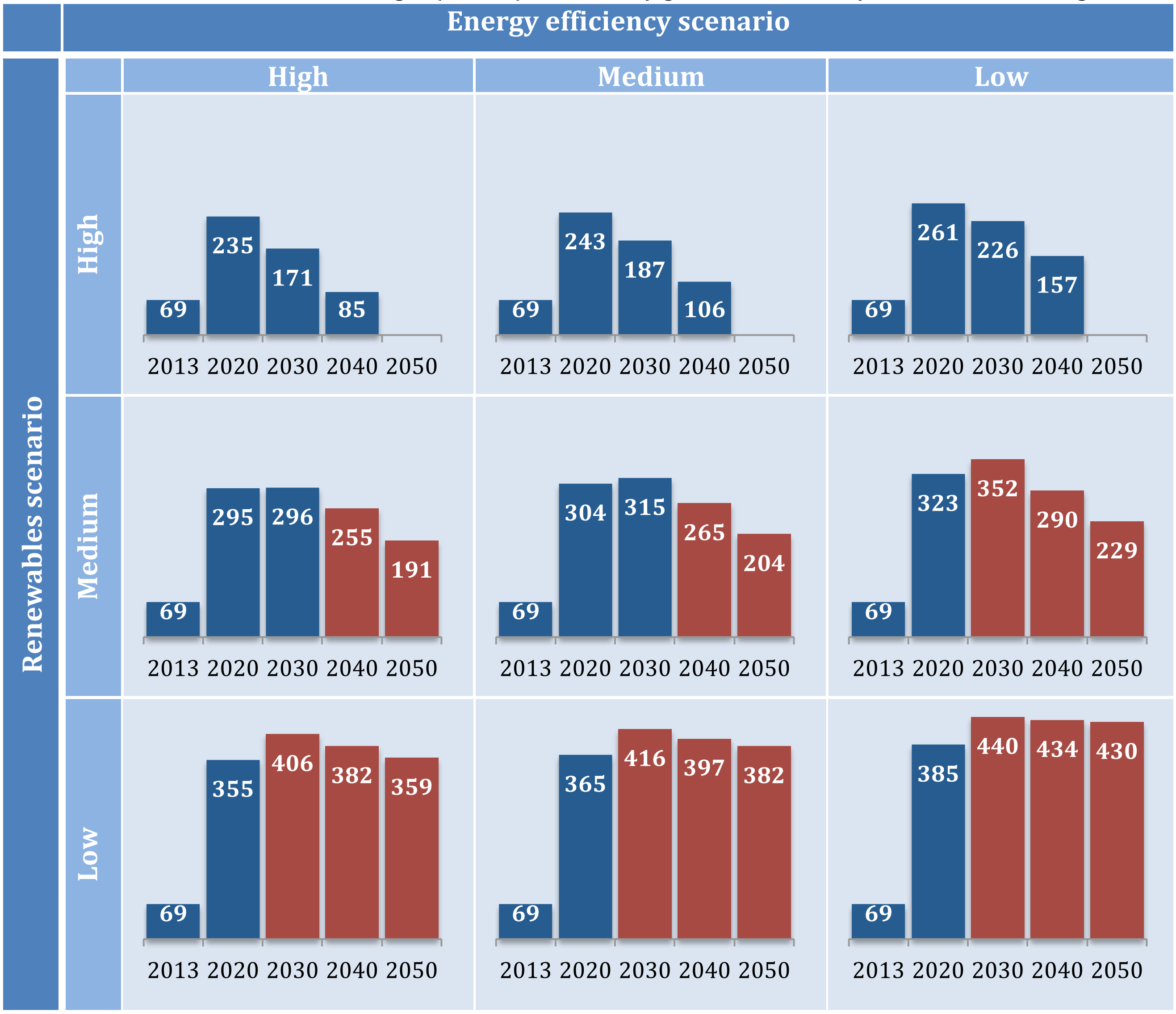

**How to interpret Table 8**

For each scenario combination, the table shows the minimum amount of natural gas required to satisfy the $CO_2$ emission reduction goal, if possible. The values are expressed in TWh.

In the circumstances where it is not possible to reach the goal, natural gas is the only energy source other than renewables, and the bar is displayed in red instead of blue.

For example, in the graph in this box reports the needed amount of natural gas that would be necessary in the "Medium renewables" and "Medium efficiency" scenario. In this specific instance, the 2040 and 2050 goals cannot be met even with the highest amounts of natural gas, but the amount in the graph minimizes emissions.

**Table 8** Minimum amount of natural gas (in TWh) in electricity generation to satisfy emission reduction goals.




An analysis of Table 8 reveals a number of interesting insights on the future of Germany's electricity mix and the feasibility of the country's emission reduction goals.

The most obvious observation is that, under the assumptions that were made, the country can reach its 2040 and 2050 goals in the "High renewables" scenario – that is, if it manages to gradually make renewables grow to 80% of the electricity mix as planned. Also noteworthy is the fact that in this scenario, regardless of the level of energy efficiency that is reached, no natural gas would be strictly necessary to respect the very optimistic emission targets.

Another interesting insight in all scenarios is the fact that substantial amounts of natural gas will be needed in the 2020s and 2030s, only to decline in following decades as renewables and increased efficiency picks up – of course, the amount of this is determined by the scenario combination. The main "jump", in all scenarios, is between today and 2020, highlighting the urgency of Germany's need for natural gas to get back on its emission reduction track.

An analysis of Table 8 also allows us to perform a slight simplification of our analysis: while the level of renewables in the electricity mix has a strong impact on the minimum needed amount of natural gas, the level of electricity efficiency does not affect the figure's development too strongly: looking at the table, one can notice the development of needed natural gas to change considerably across columns, and only marginally across lines. For this reason, the rest of this paper will, for the sake of simplicity, only consider the "Medium efficiency" case in its analysis of the data.

### Natural gas as balancing capacity

As mentioned in Chapter 2, natural gas is often used as balancing capacity for renewable energy sources such as solar and wind power. With the phase out of nuclear power, the prominence of gas for this purpose is projected to increase, since few other sources can be dispatched with such immediacy (Frunt 2011).

As pointed out by Frunt (2011), the amount of backup dispatchable power required to balance an intermittent source is highly unclear, especially in light of the complications with transmission availability that currently characterize the German market. A number of additional issues, storage being probably the most important and most discussed – arise when expanding balancing capacity.

Alternative solutions to the issue include grid integration across Europe – as theorized by Dunn, Kamath and Tarascon (2011) and as exemplified by the Nord Pool electricity market – and the development of storage technologies.

It is of course very difficult to predict how international policies and technologies will develop over the course of our long timeframe. Therefore, for the sake of simplicity, we limit our analysis to actual electricity-generating natural gas, and leave the amount that would be used for balancing capacity in the "other natural gas" category, alongside gas that is used for heating and industrial operations. Thus, even in cases where no natural gas is needed for ordinary electricity generation, it is possible that Germany will still natural gas to back up its intermittent production.

## 3.2. Natural gas and Germany's trade balance

In all our analyzed scenarios electricity generation is poised to generate a substantial growth in demand over the coming decade, while values after 2030 depend more heavily on the amount of renewable energy that the country succeeds in introducing into the electricity mix. As previously mentioned, domestic production has steadily decreased over the past few years due to the gradual depletion of resources, suggesting an increased reliance on imports.

As discussed in the literature review, the positive and negative effects of trade imbalances on national economies are a common topic of research among economists. While there is very little consensus on the topic, most economists agree that a clear distinction should be made between short-term and long-term trade imbalances (McKinnon 2011). Short-term trade deficits are typically considered the norm for most countries, representing a standard flow of goods and services in a globalized market economy, and with little repercussions on the wellbeing of a national economy. Most economists, however, point to sustained large trade deficits as a potential problem for a country's financial wellbeing: a nation borrowing capital or selling off capital assets to finance current consumption can undermine its future production, thereby making its deficit unsustainable in the long run (Gorman 2003, McKinnon 2011). Hallet and Oliva (2013) point to the prolonged trade imbalances of the Eurozone's "PIIGS" countries (Portugal, Italy, Ireland, Greece, and Spain) as one of the reasons for their endemic debt levels prior to the 2009 financial crisis.

Over the past few decades, Germany has maintained its position as one of the most export-driven economies in Europe, with constant trade surpluses for much of the post-War era (Observatory of Economic Complexity 2014). This position was further reinforced after the introduction the Euro, which allowed the country's European exports to grow significantly (Stahn 2006). Natural gas is already the country's largest import account, and while an increase in the amount imported over the next few years is unlikely to single-handedly tip the balance towards a deficit, a prolonged and exponentially increasing reliance on natural gas imports could somewhat tarnish the country's competitive position, as pointed out by Dieppe et al (2012).

We thus use this chapter to calculate the difference in additional long-term trade imbalance attributable to electricity-generating natural gas in a scenario with no unconventional domestic production and in three scenarios in which shale exploration is undertaken. We begin by analyzing domestic production of conventional natural gas, which will determine how much gas will have to be imported under the "no shale" scenario. We continue by developing a sensitivity analysis for the import price of natural gas at the German border, which we will use to determine the impact of electricity generation on Germany's trade balance in the "no shale scenario". We then turn our attention to shale gas production, outlining three possible production scenarios and determine the impact of electricity-generating natural gas imports in these cases – assuming electricity generation is prioritized with shale gas. Finally, we will analyze the impact shale gas makes in each scenario.

### 3.2.1. Domestic production of conventional natural gas

Domestic production of natural gas increased steadily throughout the 1990s and early 2000s, peaking at 823.37 billion cubic feet in 1999 and plateauing around 780 billion cubic feet until 2003. Since then, production has been falling steeply at a rate of about 6% per annum (EIA 2014b), a trend that the IEA (2012) projects to continue over the next decade, albeit at a slower pace (5% per annum). The main reason behind this is the depletion of conventional natural gas fields within the national territory: between 2003 and 2014, the country's estimated economically recoverable natural gas reserves have dropped from about 12 to slightly more than 4 trillion cubic feet. In our analysis, we assume a continuous decrease in the production of domestic conventional natural gas, as displayed in Figure 9.

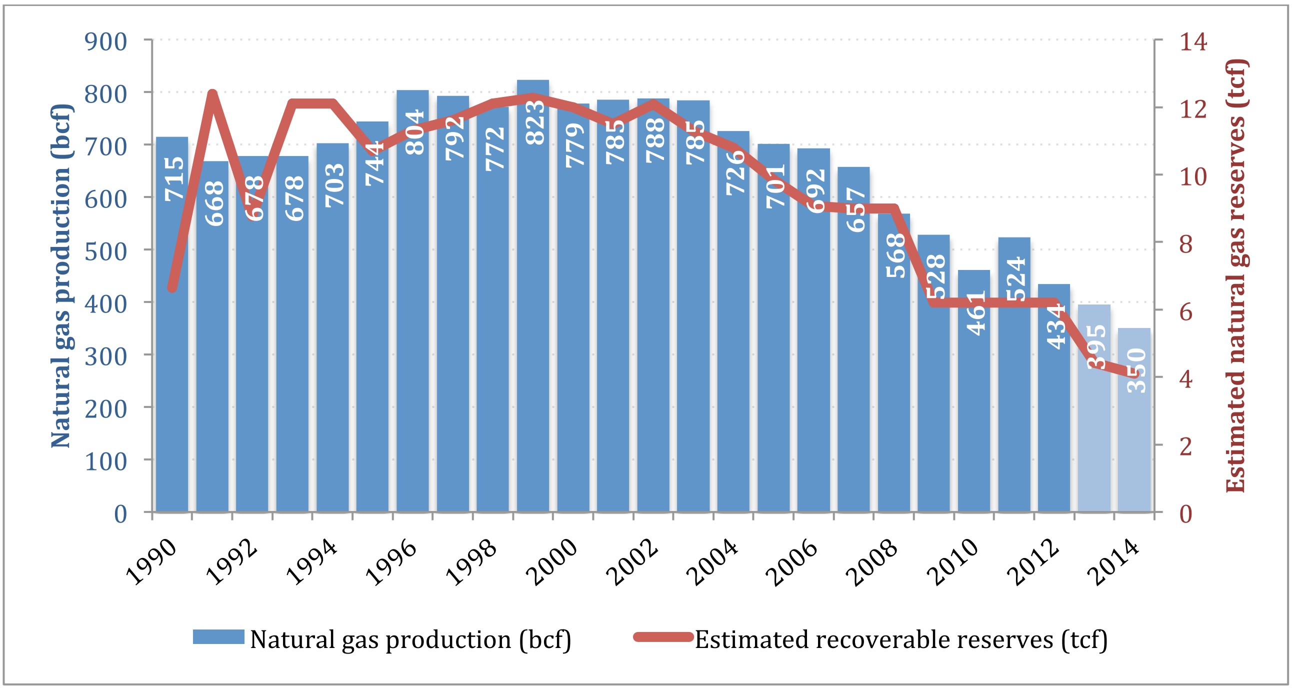



**Figure 9** Germany's natural gas production and economically recoverable resources since 1990; data for 2013 and 2014 is estimated (EIA 2014b)

### 3.2.2. Natural gas imports for electricity in the “no shale” scenario

As previously stated, domestic natural gas only accounts for a small portion of Germany’s total consumption, ranging between 12% and 16% in recent years (IEA Statistics 2012). As demand for natural gas rises and supply diminishes, imports are poised to continue rising.

To calculate the amount of additional import demand that the new electricity mix will imply, we must take into account that not all natural gas is used for electricity generation: the amount of natural gas used for electricity generation over the past ten years has ranged between 20% and 27% of total gas consumption – about 741 to 865 billion cubic feet in absolute values. For the sake of simplicity, we shall assume that the remaining natural gas use – for transportation, heating, and industrial activities – stays constant over the years, and concentrate our analysis on the additional import demand related to electricity generation.

As stated, we base our depletion model for conventional natural gas reserves in Germany on the one developed by the IEA (2012), which projects a per-annum quasi-linear decline in production between 5% and 6% per year starting in 2003. This implies continuously declining domestic production until 2021, when all natural gas is imported; by 2020 – the year we analyze as part of our analysis, domestic production will amount to 43.12 bcf.

It takes one billion cubic feet of natural gas can generate 0.3 TWh of electricity (Energy Markets International 2014). Based on this information, we can calculate the amount of natural gas that will have to be imported under current circumstances in the three different renewable scenario if Germany chooses to maintain its moratorium on shale gas.

**Table 9** Needed imports of natural gas for electricity generation over the next decades under the “no shale” scenario (in bcf). The values in parentheses show the amount can be covered with conventional domestic resources if current trends continue.

| | 2013 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| **High renewables** | 187<br>(39) | 786<br>(11) | 613<br>(-) | 348<br>(-) | 0<br>(-) |
| **Med renewables** | 187<br>(39) | 986<br>(11) | 1033<br>(-) | 869<br>(-) | 669<br>(-) |
| **Low renewables** | 187<br>(39) | 1179<br>(11) | 1365<br>(-) | 1302<br>(-) | 1253<br>(-) |

### 3.2.3. Import price of natural gas

As previously explained, the evolution of import prices for natural gas will be an important determinant of how much Germany's trade balance will shift over the next few decades because of the Energiewende. We dedicate this section to determining how the price the country pays for natural gas could evolve over the next few decades in light of possible trends. To do this, we draw on the information provided in Chapter 2 about the "regional" nature of natural gas prices and the potential changes that more globalizing technologies could bring about in Europe. We thus start by identifying key international trends that could have an effect on Europe and Germany, and continue by devising a sensitivity analysis covering three possible scenarios for price development.

#### 3.2.3.1. The future of international gas prices

Gas prices, as previously mentioned, are determined primarily at the regional level, although natural gas markets are slowly becoming more integrated thanks to technological developments (Siliverstovs et al 2005). Predictions for long-term price developments become more speculative as their timeframe become longer, but there is little doubt that the level of global integration of gas markets will be among the main determinants of price over the next few decades (Bachmeier and Griffin 2006).

Speculations over the long-term development of worldwide gas prices vary enormously: some predictions see them converging due to market integration – as was the case for oil in the mid-twentieth century – while others see them remaining quite region-based due to a failure of further integration to take place, due to either limited demand, excessive costs, or the development of technologies (like shale) that make global integration less of a stringent necessity (Siliverstovs et al. 2005). Another important determinant of price on the supply side is the pricing mechanism: whether gas is priced according to supply and demand, cost, or price of another commodity is naturally of primary importance. The pricing mechanism, in turn, depends heavily on the degree of integration – which determines the number of competitors and the seller's bargaining power (Åslund 2010).

Of course, supply is not the only determinant of price: international and regional demand for natural gas will also play a determinant role in the development of the import price for Germany. Factors that could positively influence demand for natural gas include increased demand for electricity in general – thus far, a corollary of economic growth – and increased reliance on gas because of its lower emissions and other aforementioned advantages. On the other hand, factors that could negatively influence demand are increased energy efficiency –

meaning that less electricity will be needed by society and that less gas will be needed to generate the same amount of electricity – and overperformance of cleaner energy sources, such as renewables and nuclear.

## Pricing mechanisms

Pricing mechanisms differ widely across regions, and they tend to reflect a market's level of competitiveness. In its 2013 Annual Energy Outlook, the EIA identifies the three most common pricing mechanisms that are currently used around the world as the following:

- **Oil-linked pricing**, where natural gas is traded under long-term contracts at a price that is indexed to either crude oil or another oil product. This pricing mechanism is typical of markets characterized by one or few suppliers with a large degree of bargaining power. Up until the early 2000s, almost all natural gas contracts in continental Europe were oil-indexed, but the onset of liberalization has forced a growing number of suppliers to opt for more competitive methods.
- **Regulated pricing**, where the government sets the price of natural gas based on production cost and either a mark-up or a discount. This method is typical of national markets where the government holds a monopoly for extraction and production, and its use in international trade is extremely rare.
- **Competitive market pricing**, where the price is determined by suppliers and consumers at trading points or hubs. This mechanism is typical of competitive markets with a large enough number of suppliers and consumers. It was first developed with liberalization in North America, and followed a similar path in the United Kingdom. In continental Europe, as detailed below, this method's use is increasing in some regions.

In comparable scenarios, Stern and Rogers (2011) find oil-linked prices to be typically higher than hub-based ones, owing primarily to differences in bargaining power between the actors in the transaction. However, they also point out that this is not always the case, as the long-term nature of the contract can lock the seller into a disadvantageous situation if the price of oil falls unexpectedly. Åslund (2010) notes that monopolies and oligopolies are not the only reason behind oil-linked prices: long-term contracts, he points out, allow suppliers to recoup the investments they made in the set-up of the pipeline network by ensuring a long-term revenue stream. As more gas is traded along existing infrastructure, Åslund (2010) and Stern (2009) agree, a market is likely to move towards more competitive pricing mechanisms.

In continental Europe as a whole, oil indexing is still the primary pricing mechanism, being used for almost two thirds of total consumption (Reuters 2013). Significant regional differences exist: while most Eastern European countries pay the entirety of their natural gas through oil-indexed contracts, Central Europe uses hub pricing for about 40% of its natural gas consumption, and Northern Europe for over 70% (D.G. for Energy 2013). This is a relatively new trend: in 2005, oil indexing was still used for 79% of all gas consumption, versus the 51% of 2012 (EIA 2013).

A large determinant for the pricing mechanism is, of course, the supplier. In 2013, Europe's second largest natural gas supplier, Statoil, abandoned oil-linked prices for many of its Northern European contracts, suggesting somewhat of an adaptation to the market's conditions (Financial Times 2013). The Russian natural gas giant Gazprom, by contrast, still operates virtually exclusively through oil-indexed contracts, the source of the company's enormous margins over the past few years (The Economist 2014). The difference between the two companies' strategies can be attributed primarily to the markets they serve, which are characterized by very different degrees of supplier diversification. It can be argued, however, that increased competition did have some effect on oil indexed prices: from 2008 to 2012, the ratio of oil prices to natural gas prices has risen from about 8.5:1 in 2005 to 11:1 (EIA 2013).

#### 3.2.3.2. The future of gas import prices for Germany

As previously stated, we use this section to develop a sensitivity analysis with three possible evolutionary paths for the import price of natural gas at the German border. As in previous analyses, we start by pointing out simplifications we make and data collection information.

- The short-term volatility of natural gas import prices is ignored. While fluctuations in this figure are quite common due to a number of factors like uneven production flow, storage issues, weather conditions, and fluctuating oil prices (EIA 2014), we find the degree of short-term volatility for German prices to be relatively low, especially when compared to the one of Czech or Italian prices (D.G. for Energy 2013).
- For our base price, we use the March 2014 price as reported by the EIA (2014), which is an average of Russian natural gas prices at the German border. We choose this specific price because it is a good representation of recent price development – compared to prices in the last six-month, one-year, and five-year periods, it does not appear to be a peak or a valley within a fluctuation – and because Russia is the main exporter of natural gas to Germany.

Having defined a base price of €8.28 per mmBtu, and having cleared the assumptions that we made, we can turn to our three scenarios. All amounts are considered in real 2014 euros.

- **Low price scenario:** In this scenario the market for natural gas does become more globalized, in a process similar to the one experienced by oil in the 1970s. Technological advances in transportation and distribution, like LNG, enable competition in more regions, allowing prices to converge towards a single one, especially in regions where a pipeline network already exists and suppliers do not need to recoup their investment. A low price scenario would also require technological advances in natural gas extraction, increasing the amount of recoverable gas from both conventional and unconventional fields. Finally, decreasing demand from other European countries – which could be a result of the development of indigenous sources or increased renewables use – would ensure little "buyer competition" for Germany.

  Various studies have analyzed the possible effect of natural gas globalization: Dickel et al (2013) argue that changes would take until about 2020 to have a significant impact, and the British Department for Energy and Climate Change estimates the price reduction to amount to about 27.4% over a 5 year period (DECC 2013).[3] Moniz (2011) and the Electric Power Research Institute (2013), additionally, estimate demand reduction and extraction technology improvements to be able to lower prices by about 1% to 3% over the next decades.
- **Medium price scenario:** In this scenario, natural gas markets remain relatively regionalized due to the high costs of LNG technology and a lack in significant technological breakthroughs in the field of gas transportation. As a result, natural gas prices in Western Europe remain significantly higher than in other regions like Russia or North America. The shift from oil-indexed to competitive pricing in Europe continues slowly, but major suppliers still hold significant power over their consumers.

  Technological advances – both in field development and in energy efficiency – play a role in this scenario, but they are not game changers; the general trends of the past few years continue, driving natural gas prices in continental Europe upwards. Studies by DECC (2013), Slade (1982), and the Energy Research Institute of the Russian Academy of Sciences (ERI RAS 2013) – which in turn is a collection of projections by gas companies –

[3] This is estimated on the basis of various "low price" estimates by major distributors.

suggest a development path with mixed but increasing price growth ranging from 0.6% to 3.5% per annum.

- **High price scenario:** Similarly to the previous one, this scenario is characterized by little to no globalization, with Gazprom strengthening its quasi-monopolist status in Europe due to the depletion of smaller fields in the continent and the lack of new competitors. Other factors on the supply side can add up to the large purchaser-distributor contractual disparities, such as lack of technological breakthroughs and increasing demand for gas-generated electricity due to socio-economic factors.

  The main difference between this and the "Medium price" scenario lies in demand: on top of facing supply issues, European consumers must now compete with demand from other markets that are quickly developing economically and that thus demand more gas-generated electricity: these could be China – sapping away Siberian gas from Europe – or Sub-Saharian and Northern Africa, making the Libyan and Algerian supply more concentrated on the local market. Such a development would likely translate in a small price increase over the next few years – since these countries would take time to grow and develop a pipeline network – followed by a period of rapid price increases that continues through the next few decades at rates of 4% to 7% per annum (DECC 2013).

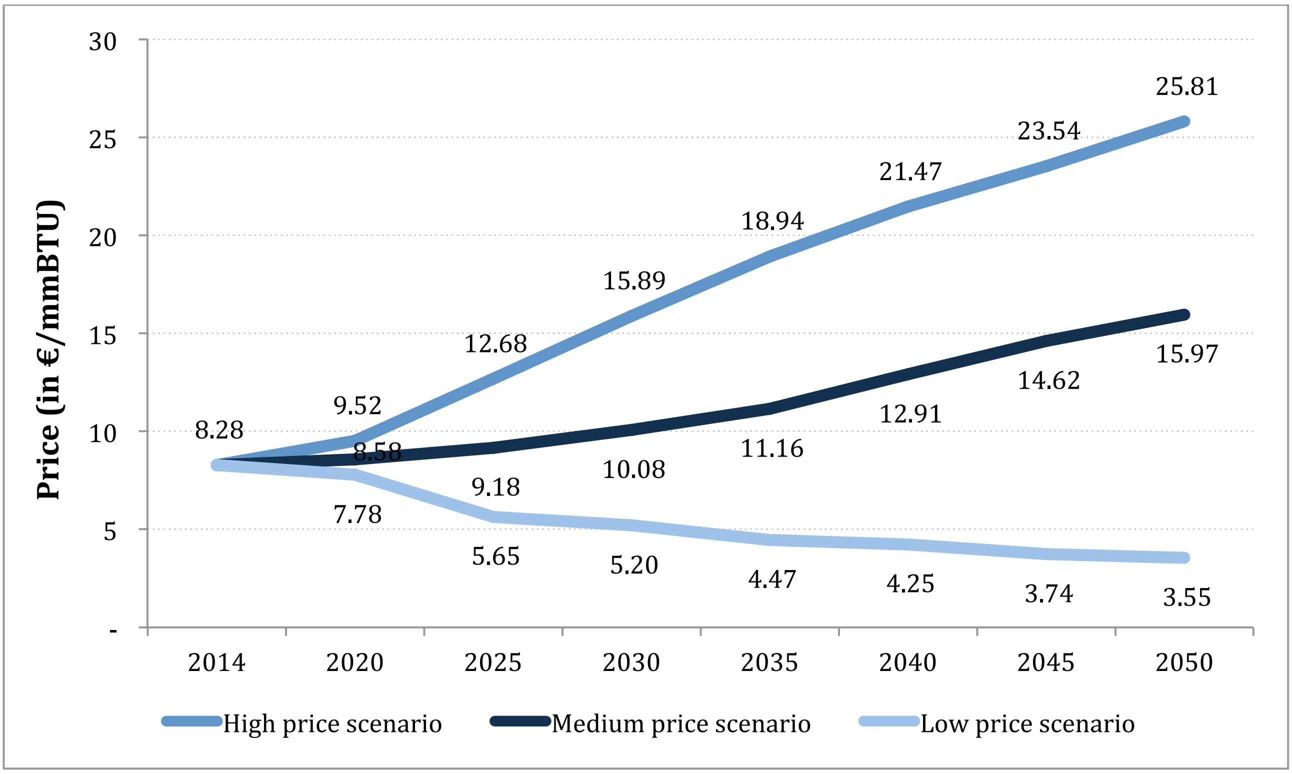



**Figure 10** Evolution of average natural gas prices at the German border in different scenarios (amounts in 2014 euros per million metric British thermal unit).

### 3.2.4. Natural gas import under the "no shale" scenario

Were Germany to choose to continue its moratorium on hydraulic fracturing, it would have to import all of the natural gas it needs for the decades from about 2023 onwards, and could only account on a relatively little amount of domestically produced natural gas until then. The impact that a cleaner electricity mix would have on the country's trade balance under different scenarios for renewables and import prices is presented in Table 10.

**Table 10** Expenditure on natural gas imports for electricity in the "no shale" scenario (in 2014 € billion).


Comparing these amounts to the current expenditure on electricity-generating natural gas (€ 1.6 billion), it appears clear that the energy transition, if performed primarily through imports as predicted, will have a strong impact on Germany's import figures already by 2020, and that the development of said amount will depend strongly on the price and level of renewables penetration.

### 3.2.5. Shale gas production

We now turn our attention to the potential production of shale gas in Germany, should the German government lift its moratorium on hydraulic fracturing and enact legislation aimed at encouraging shale exploration. As discussed, the fact that only very little drilling took place in Germany thus far makes an accurate prediction of production rather problematic. We thus use American shale basins as a blueprint, and draw on similarities with German basins to devise a sensitivity analysis with three possible scenarios of production development.

#### 3.2.5.1. Shale gas reserves in Germany

Germany's main shale basin – the only one that has been thoroughly analyzed and on which significant information is available – is the Lower Saxony Basin, a 10,000 $m^2$ area spanning from Hannover to the Dutch border, in the northwestern part of the country (EIA 2013). As reported by the EIA, the basin contains a Jurassic petroleum system (Posidonia Shale, present throughout the basin), and a Lower Cretaceous one (Wealden Shale, concentrated primarily next to the Dutch border). The former, which is deeper on average but less thick, is estimated to hold 80 tcf of shale gas, 16.9 of which are technically recoverable; the latter, by contrast, is only estimated to hold 1.8 tcf of natural gas, 0.1 of which is recoverable. The play's success factor is 100% for the former and 60% for the latter, while the prospective area's success factor is 60% for both (EIA 2013).

#### 3.2.5.2. Projections of shale gas production in Germany

To predict possible evolution paths for production in case of a positive government attitude towards shale exploration, we can take the example of American shale developments, and adapt them to the local context. Of course, since shale gas is a relatively new phenomenon in North America as well, our long-term projections will be more speculative.

As displayed in Figure 11, different shale basins in North America are characterized by very different production profiles. This can be attributed both to their physical characteristics and to a learning effect in drilling technology. Technology affects primarily production growth in the early stages of drilling: for early developed plays like the Barnett Shale, production in the first years rose at a slow pace as the technology was being perfected, while later plays like the Haynesville, Marcellus, and Fayetteville Shales were characterized by higher production volumes from the earliest drilling days. Physical characteristics, which include the amount of available amount of gas, the shale depth, and porosity, have more of an effect on the long-run development of a shale play's production profile (Mason 2012).

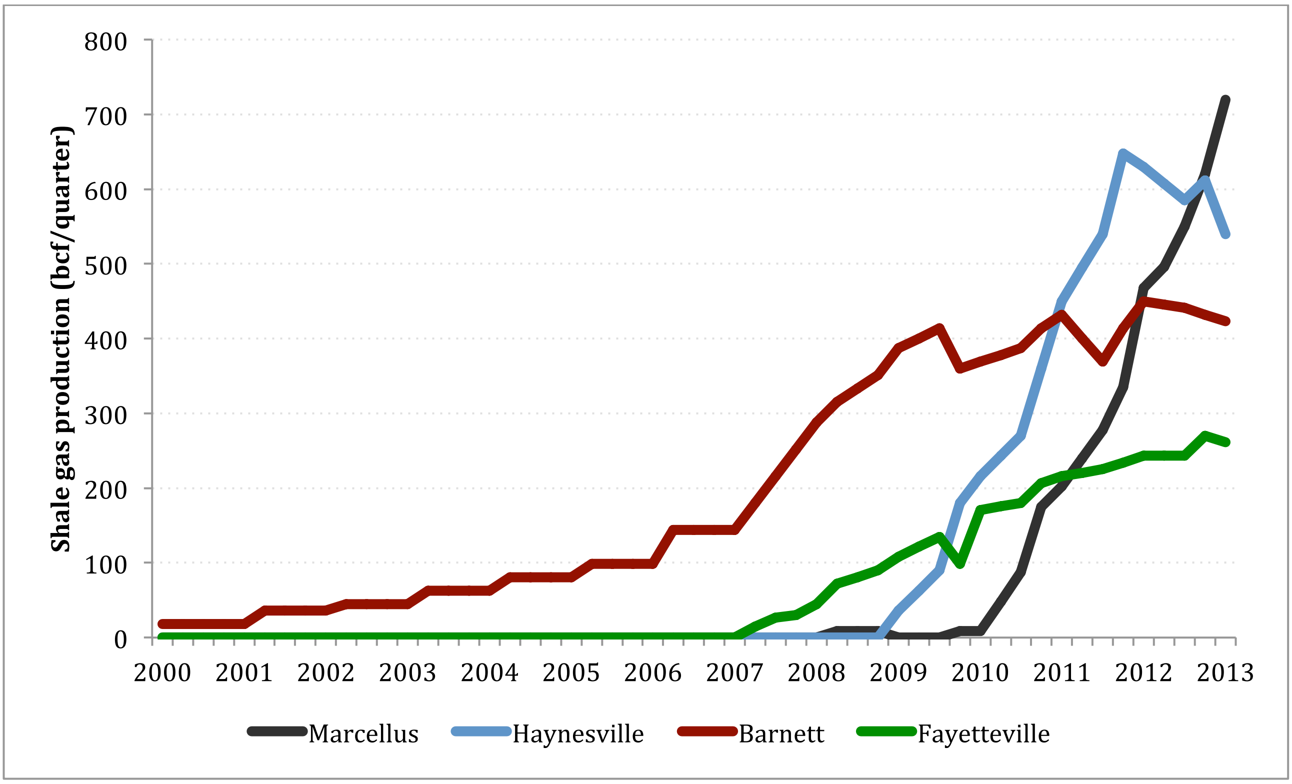



**Figure 11** Quarterly gas production from different shale basins in the United States in the 2000s (EIA 2013). Reasons for the drop in production in some plays are attributed to depletion of reserves by some economists, and to limited demand at current prices by others.

To estimate possible production profiles for the Lower Saxony Shale, we start by analyzing shale production at the well level, and then zoom out to the basin level for a cumulative projection. As previously stated, the information on the Posidonia Shale is extremely limited due to the lack of exploration in the area; therefore, we can only base our analyses on a few known parameters, detailed below.

**Table 11** Characteristics of the main shale plays in the United States and the Posidonia Shale in Germany (Roth 2012, P. Wang and Hammes 2010, Engelder 2012, Janzen 2012, EIA 2014)

| | Barnett | Haynesville | Marcellus | Fayetteville | Posidonia |
|---|---|---|---|---|---|
| Total recoverable reserves (tcf) | 72 | 161 | 369 | 48 | 17 |
| Depth (feet) | 6,000 | 12,000 | 7,000 | 4,000 | 13,000 |
| Permeability (nanodarcies) | 250 | 650 | 1000 | 800 | 150* |
| Porosity (%) | 6.4% | 8.7% | 8.0% | 8.0% | 10.2%‡ |

* The level of permeability of the Posidonia shale has yet to be reported with certainty: while most studies agree that the level is most likely lower than in most other basins, a consistent figure has not been found, suggesting that permeability could change significantly across the basin.

‡ Porosity for the Posidonia basin has been found to be as low as 8% and as high as 14% across the basin, and 10.2 to be a reasonable average across the board (Janzen 2012).

## Shale gas production at the well level

Shale production profiles for single wells differ enormously between basins, owing primarily to differences in the geological structure of the basin. However, an analysis of American shale production (MIT 2013) found some common trends to exist, most importantly in their decline profile: for all shale gas wells, initial production drops significantly after the first year, and gradually thereafter.

Initial production can differ quite significantly between basins, ranging from an average of 3 mcf per day in the Fayetteville Shale to 8 mcf in the Haynesville Shale (Roth 2013). This figure is driven primarily by the permeability and porosity of the shale formation, which can only be determined after substantial exploration has taken place.

The initial drop has been found to differ significantly between shale basins, depending on geologic properties: according to an MIT (2013) study, this figure ranges from 55%-60% in the Barnett and Fayetteville basins to 75% in the Haynesville Shale.

Similarly, the rate of the gradual decline that follows depends on geological factors that tend to differ in each play. A common model used to forecast future production rates from a well is Arp's (1956) rate-time equation (Engelder 2012):

$$\boldsymbol{q(t)} = \frac{\boldsymbol{q_0}}{(\mathbf{1} + \boldsymbol{b} * \boldsymbol{D_0} * \boldsymbol{t})^{\mathbf{1}/\boldsymbol{b}}}$$

where $q(t)$ is the production rate at year $t$ (in mcf/day), $q_0$ is the initial production, $D_0$ is the initial decline (in percentage), $t$ is the time in years, and $b$ is the hyperbolic exponent.

Based on the geological similarities between the Posidonia Shale and the analyzed basins in the United States, we develop a sensitivity analysis for the parameters cited above, and create a 10-year production profile for each of the scenarios.

**Table 12** Parameter assumptions for production scenarios

| | Low shale | Medium shale | High shale |
|---|---|---|---|
| $q_0$ (mcf) | 2 | 3 | 4 |
| $b$* | 1 | 1.19 | 1.39 |
| $D_0$ (%) | 80% | 70% | 60% |

*based on average US value for b (1.19) and ±15% variation

Using these parameters, we can calculate a well's total production over a ten-year period, as displayed in Table 13 for the "Medium shale" scenario. Performing this analysis we get **5.51 bcf/well** for the "High shale" scenario, **3.59 bcf/well** in the "Medium shale" scenario, and **2.05 bcf/well** in the "Low shale scenario". For comparison, the 10-year production profile for a well in the Marcellus Formation ($q_0$=4.2, $D_0$=69%, $b$=1.58) is 5.8 bcf/well (Engelder 2012).

Table 13 Ten-year production profile under the "Medium shale" scenario.

| Year | Daily production (mcf) | | | Annual production (bcf) | |
|---|---|---|---|---|---|
| | Beginning | Ending | Average | Annual | Cumulative |
| 1 | 3.00 | 1.80 | 2.40 | 0.88 | 0.88 |
| 2 | 1.80 | 1.32 | 1.56 | 0.57 | 1.45 |
| 3 | 1.32 | 1.05 | 1.18 | 0.43 | 1.88 |
| 4 | 1.05 | 0.88 | 0.96 | 0.35 | 2.23 |
| 5 | 0.88 | 0.75 | 0.82 | 0.30 | 2.53 |
| 6 | 0.75 | 0.67 | 0.71 | 0.26 | 2.78 |
| 7 | 0.67 | 0.60 | 0.63 | 0.23 | 3.02 |
| 8 | 0.60 | 0.54 | 0.57 | 0.21 | 3.22 |
| 9 | 0.54 | 0.50 | 0.52 | 0.19 | 3.41 |
| 10 | 0.50 | 0.46 | 0.48 | 0.17 | **3.59** |
| **Total** | **3.59 bcf** | | | | |

### Shale gas production at the basin level

The shale gas production profile of the Posidonia Shale will naturally depend on the productivity per well and the amount of wells, which we assume to be tied to the technically recoverable resources that are left (we deal with the economic feasibility of said recovery at a later stage). Building on our assumptions from above, we thus develop three scenarios for shale gas extraction in the basin:

- **Medium shale scenario:** The current estimate of 17.1 tcf for technically recoverable resources is slowly revised upwards (about to 5% per decade starting in 2020), as new technologies enable the extraction of shale gas that was previously unfeasible. Average well productivity is 3.59 bcf/decade, and the number of wells rises and falls proportionally to the amount of remaining technically recoverable resources left. Production starts at a rate slightly higher than the early Bakken years, peaking in 2025 and declining harmoniously until 2050.
- **High shale scenario:** New technologies make the amount of technically recoverable resources grow at a rate of about 10% per decade, and keep average well productivity at 5.51 bcf/decade, as calculated above. American technologies prove compatible with the requirements of European shales, enabling production to start quickly – a rate similar to that of the Fayetteville Shale – and then decline at a rate that reflects the depletion of total resources.
- **Low shale scenario:** Only 12 tcf are actually recovered between 2015 and 2050, following a bell-shaped production profile peaking in 2031, reflecting slow production growth in the early stages and a steady decline reflecting reserve depletion. We calculate the actual development of the curve using the Hubbert curve's formula (Mohr and Evans 2008).

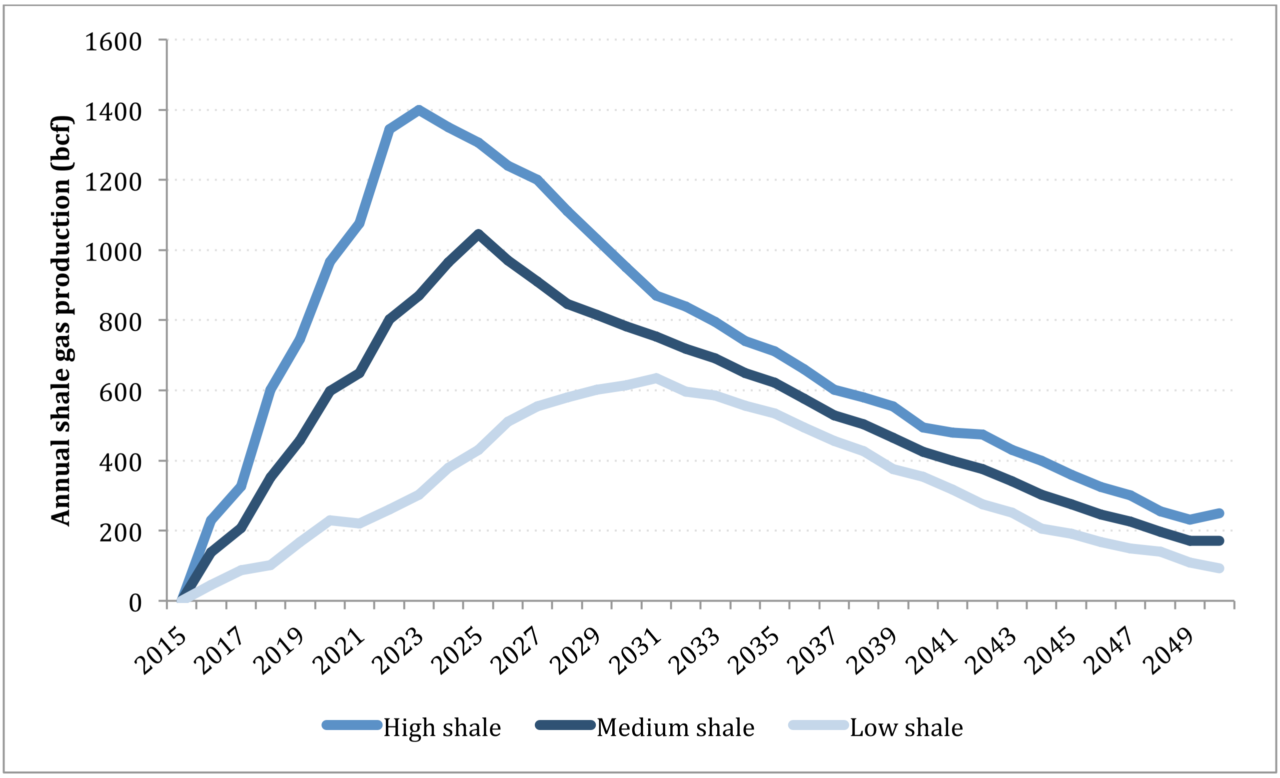



**Figure 12** Annual production of shale gas according to three different scenarios (in bcf)

As for the rest of our analyses, we take four points – one at the beginning of each decade– to make our calculations simpler and easier to understand. The data for the time points we analyze are summarized in the table below.

**Table 14** Yearly production of shale gas in different scenarios (in bcf)

| | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| **High shale** | 967 | 950 | 495 | 250 |
| **Medium shale** | 598 | 782 | 424 | 171 |
| **Low shale** | 230 | 615 | 353 | 93 |

### 3.2.6. Natural gas import with shale gas

Having outlined three possible development paths for shale gas production within the German territory, we can analyze how domestic production would affect the country's imports of natural gas, and thus its trade balance. A natural starting point for this is determining the amount of natural gas that will have to be imported, as we did for the "no shale" scenario.

**Table 15** Import of natural gas for electricity generation in different scenarios (in bcf)

| | | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| High renewables | High shale | -181 | -337 | -147 | -250 |
| | Medium shale | 188 | -169 | -76 | -171 |
| | Low shale | 556 | -2 | -5 | -93 |
| Medium renewables | High shale | 19 | 83 | 374 | 419 |
| | Medium shale | 388 | 251 | 445 | 498 |
| | Low shale | 756 | 418 | 516 | 576 |
| Low renewables | High shale | 212 | 415 | 807 | 1003 |
| | Medium shale | 581 | 583 | 878 | 1082 |
| | Low shale | 949 | 750 | 949 | 1160 |

An immediate observation is that, in the "high renewables" scenario, the amount of shale gas that is extracted from 2030 onwards (from 2020 in the "high shale" scenario) actually exceeds what is needed for electricity generation. As previously stated, we hypostatized that electricity generation would receive the priority in the use of shale gas. This, however, does not rule out that excess natural gas could be used for other purposes (such as heating and industrial operations), thereby reducing the country's dependence on foreign sources. Even if there were no other demand for natural gas in Germany, of course, shale gas production would have an effect on Germany's trade balance by enabling to export more goods.

Having determined how much natural gas would still have to be imported if shale gas extraction was allowed and encouraged, we can once again calculate the impact of the Energiewende on natural gas imports. In order to simplify any further analysis and comparison on the topic, we also report an average annual cost of natural gas imports.

**Table 16** Natural gas imports for electricity generation assuming favorable legislation towards hydraulic fracturing, under three production scenarios. In 2014 € billion.

| | | | 2020 | 2030 | 2040 | 2050 | Average |
|---|---|---|---|---|---|---|---|
| High shale | High renewables | High price | -1.79 | -5.57 | -3.28 | -6.71 | -4.34 |
| | | Medium price | -1.62 | -3.53 | -1.97 | -4.15 | -2.82 |
| | | Low price | -1.47 | -2.11 | -0.72 | -0.98 | -1.32 |
| | Medium renewables | High price | 0.19 | 1.37 | 8.35 | 11.25 | 5.29 |
| | | Medium price | 0.17 | 0.87 | 5.02 | 6.96 | 3.26 |
| | | Low price | 0.15 | 0.52 | 1.82 | 1.64 | 1.04 |
| | Low renewables | High price | 2.10 | 6.86 | 18.02 | 26.93 | 13.48 |
| | | Medium price | 1.89 | 4.35 | 10.83 | 16.66 | 8.44 |
| | | Low price | 1.72 | 2.60 | 3.94 | 3.94 | 3.05 |
| Med. shale | High renewables | High price | 1.86 | -2.79 | -1.70 | -4.59 | -1.81 |
| | | Medium price | 1.68 | -1.77 | -1.02 | -2.84 | -0.99 |
| | | Low price | 1.52 | -1.06 | -0.37 | -0.67 | -0.15 |
| | Medium renewables | High price | 3.84 | 4.15 | 9.93 | 13.37 | 7.82 |
| | | Medium price | 3.46 | 2.63 | 5.97 | 8.27 | 5.09 |
| | | Low price | 3.14 | 1.57 | 2.17 | 1.95 | 2.21 |
| | Low renewables | High price | 5.75 | 9.64 | 19.60 | 29.05 | 16.01 |
| | | Medium price | 5.19 | 6.11 | 11.79 | 17.97 | 10.27 |
| | | Low price | 4.70 | 3.65 | 4.28 | 4.25 | 4.22 |
| Low shale | High renewables | High price | 5.51 | -0.03 | -0.11 | -2.50 | 0.72 |
| | | Medium price | 4.96 | -0.02 | -0.07 | -1.54 | 0.83 |
| | | Low price | 4.50 | -0.01 | -0.02 | -0.36 | 1.03 |
| | Medium renewables | High price | 7.49 | 6.91 | 11.52 | 15.46 | 10.35 |
| | | Medium price | 6.75 | 4.38 | 6.93 | 9.57 | 6.91 |
| | | Low price | 6.12 | 2.62 | 2.52 | 2.26 | 3.38 |
| | Low renewables | High price | 9.40 | 12.40 | 21.19 | 31.14 | 18.53 |
| | | Medium price | 8.47 | 7.86 | 12.74 | 19.27 | 12.09 |
| | | Low price | 7.68 | 4.69 | 4.63 | 4.55 | 5.39 |

To calculate the effective impact of shale gas production on the trade balance, we simply subtract the "low", "medium" and "high shale" scenarios from the "no shale" one. The value is naturally the product of the price of gas and amount produced, and is thus independent on the level of renewables in the electricity mix. In order to simplify our analysis, we report only the average annual saving in imports.

**Table 17** Average difference in natural gas imports between "no shale" scenario and scenarios in which shale extraction is allowed and encouraged. In 2012 € billion.

| | Low shale | Medium shale | High shale |
|---|---|---|---|
| High price | 5.70 | 8.23 | 10.76 |
| Medium price | 3.70 | 5.52 | 7.35 |
| Low price | 1.78 | 2.95 | 4.12 |

In Table 18, we map out the average changes in the trade balances in different scenarios of shale development.

**Table 18** Average annual decrease in the trade surplus attributable to electricity-generating gas in various scenarios of shale production (in 2014 € billion). ■: no shale; ■: low shale; ■: medium shale; ■: high shale.


At the end of 2013, Germany's trade surplus amounted to € 198.9 billion (Rising 2014), the highest value in the country's history. It thus appears clear that, even in the worst-case scenario (low renewables and high price), imports of natural gas for electricity generation alone would not tilt the country's trade balance towards a deficit. Therefore, there is no scenario in which shale gas is instrumental in avoiding a trade deficit, unless the current trade surplus level declines significantly over the next years. This being said, development of domestic shale gas can help significantly to reduce import expenditure over the next decades.

## 3.3. Shale gas and energy security

Energy security is one of the primary reasons behind the support of shale gas exploration and exploitation in much of Central and Western Europe. The development of domestic resources can be instrumental in not only improving a country's trade balance, but also in securing a steady supply flow regardless of external political developments – something which is crucial in a world where industrial operation and daily life comforts depend intensely on readily available energy.

From an historical perspective, availability of domestic resources was an instrumental factor and a key determinant of a country's economic development during the Industrial Revolution: in Germany's case, the coal-rich Rhineland region was in many ways the locomotive of economic growth for much of the Twentieth century (Taylor 2001). Compared to previous time periods, of course, today's world is characterized by a much larger volume of international trade, making abundant domestic resources a much less pressing necessity, especially when it comes to availability (Dicken 1992). However, a non-diversified energy supplier portfolio can carry a significant amount of risk, especially in the short-run: as the 1973 Arab oil embargo, and the Russia-Ukraine gas disputes of the late 2000s exemplify, energy sources can be used as a powerful tool in negotiation, shifting the power balance towards the player that controls the energy supply (Hedenus et al 2010, Metais 2013).

Energy security in today's world is thus inevitably connected to the level of diversification in the supplier pool, as this factor determines how much of an impact the withholding of supplies will have on the importing country. Natural gas, as opposed to commodities like oil and coal, is particularly vulnerable to short-term supply disruptions, as the need for an expensive pipeline infrastructure creates a "lock-in" effect of sorts, making the switch to a new supplier much more problematic (Ratner et al 2013). As previously mentioned, Germany's main supplier of natural gas is Russia's Gazprom, which also holds the monopoly for natural gas provision in many Eastern European countries (Ratner et al 2013).

This section thus discusses the current situation in the European market – especially with regards to Russia's position as a dominant supplier – and the current and projected level of diversification for the German supplier portfolio, before analyzing the impact that shale gas can have on imports as a whole.

### 3.3.1. Russia in Central and Eastern Europe's gas markets

In 2013, Russian natural gas exports to Europe (including Turkey) amounted to 6.32 tcf, accounting for 41.3% of the continent's entire imports (EIA.gov 2014). The amount of Russian natural gas in Europe has increased significantly since the liberalization of the European Union's gas markets, and Gazprom has expanded in many countries' downstream market through local subsidiaries and joint ventures (Ratner et al 2013). As displayed in Figure 13, Russia is the main provider of natural gas in almost all of Central Europe and the sole provider in in a number of countries in Eastern Europe.

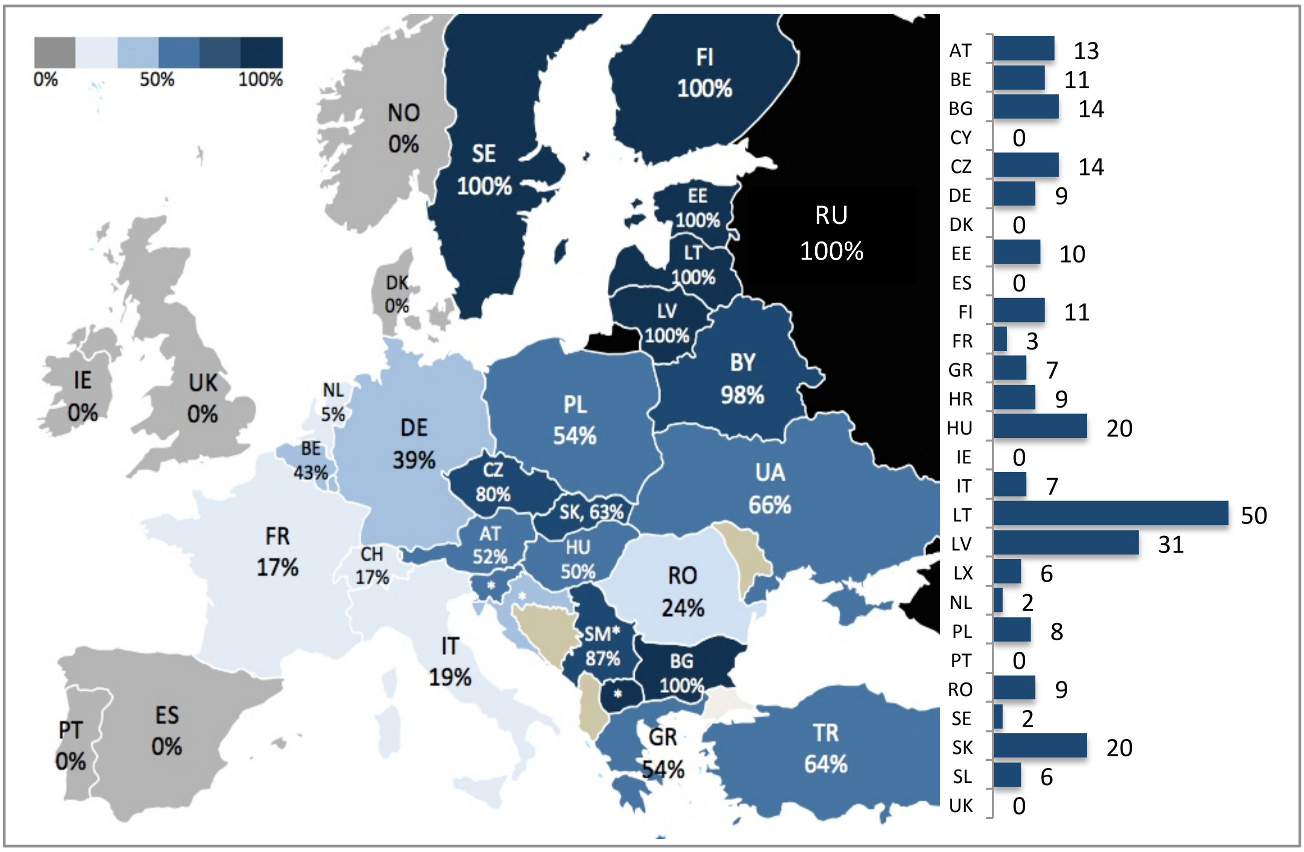



**Figure 13** Percentage of Russian gas in European countries' natural gas mix (map) and in primary energy generation mix (graph, European Union only). Ratner et al (2013).

The issue of energy security in relation to Russia's dominance of the natural gas sector is a central topic of discussion within the European Union, partly due to assessments by the European Commission finding countries in the Western Balkans and on the Baltic to be very vulnerable to Russian gas disruptions (European Commission 2012). The issue is particularly pressing given the precedents: since the early 1990s, Russia has cut off its supply of oil and gas to neighboring countries (specifically the Baltic Republics, Belarus, Ukraine and Georgia) or threatened to do so in what have been described as "clear attempts to influence policy or negotiation outcomes" (Swedish Defense Research Agency 2007, Stern et al 2010).

Particularly concerning, according to Cohen (2007), are Russia's attempts at increasing its position as a monopolist through tactics such as demand lock-in through long-term contracts, supply lock-in through control of pipelines, refineries and electric grids, derailment of competition, external consolidation through supply agreements with Central Asian countries, internal consolidation through state ownership, and the possible creation of a "gas OPEC".

Solutions have been proposed both at the European Union level and at the national level in some countries characterized by low supplier diversification to reduce the dependency on Russia. Two such projects concerning natural gas include the construction of a liquefied natural gas terminal in Lithuania (the Klaipėda LNG FSRU), which is projected to be completed by the end of 2014 and have a capacity of 2 to 3 bcm a year, and the proposed construction of the Nabucco, a pipeline connecting the Central European Gas Hub of Baumgarten an der March, Austria with the Bulgarian terminus of the Trans-Anatolian pipeline, which in turn would feed into Azerbaijan and Iran's Shah Deniz gas field in the Caspian Sea. While the first project is expected to be completed despite stark Russian opposition (Boldova 2014), the Nabucco pipeline's construction was effectively aborted after the Shah Deniz II Consortium awared the transportation contract to the much smaller Trans-Adriatic Pipeline, a Russian-sponsored project transporting natural gas to Southern Italy through Turkey, Greece and Albania (Patnaude and Hromadko 2013). At the same time, Russia is increasing its pipeline network through the expansion of the Nord Stream – a pipeline connecting Russia and Germany through the Baltic Sea, bypassing transit countries – and the possible construction of the South Stream, a pipeline connecting Russia with the Balkans through the Black Sea, bypassing Ukraine.

It is in light of the growing Russian presence in Europe's energy markets, as well as of preoccupations over the country's recent foreign policy decisions, that a number of European think tanks and leaders have called for the development of domestic resources such a shale gas (Coats 2014, Mathiesen 2014, Chambers 2014).

### 3.3.3. Germany's supplier portfolio

Having determined Central and Eastern Europe's dependence on Russian gas, we can turn our attention to Germany. As previously mentioned, Germany's supply of natural gas is relatively well diversified, especially when compared to the rest of Central Europe. Russian imports currently make up slightly over 39% of the total imports, with Norway and the Netherlands following at about 32% and 27%, respectively (IEA 2014). While this makes the German natural gas supply much more secure than some of its Eastern European counterparts, the current supplier pool is very likely to change over the next few years, primarily as a result of depletion of Dutch supplies (IEA.org 2014), which peaked in the late 1990s and declined since (EIA.gov 2014). To project whether increased dependency on Russia is as inevitable as some warn, we analyze the current levels of production and proved reserves for Germany's supplier countries and other countries that have the potential to replace the existing ones. In the following subsections, we analyze various possible suppliers for Germany in the long run.

#### Russia

Along with Iran, Russia is the country with the world's largest proven reserved of natural gas, amounting to 1,688 tcf in 2012 (EIA 2014c). It is also the world's largest producer of natural gas, with a total extraction level of 21.6 tcf in 2012, a value that has risen from 19.2 tcf per year in the early 2000s (EIA 2014c). Natural gas production is expected to rise over the next decades, thanks in part to increasing demand both from Europe and China – with whom Gazprom signed an important agreement in 2014 (BBC News 2014). According to RIA (2013), gas production is expected to increase by 23.7% by 2020, and keep growing at a slower pace into the 2030s. In terms of pipelines, Russia is by far the best-connected large supplier to Germany, having both direct pipelines and pipelines transiting in other Eastern European countries (Coats 2014). Figure 14 summarizes continental Europe's current pipeline network.

#### Norway

Norway has the largest proven natural gas reserves in Western Europe, amounting to 73.8 tcf in 2014 (EIA 2014c). The country's production level has historically been relatively low, at about 1 tcf per year; but over the past two decades it has increased to the current level of 4.1 tcf per year. Domestic consumption of the commodity is relatively low, and most of the natural gas that is produced inside the country is exported to the rest of Europe. According to the Norwegian Petroleum Directorate (2013), the level of petroleum production is projected to keep growing, albeit at a relatively slow pace, throughout the rest of the decade. Norway is connected to Germany through pipelines in the North Sea.

### The Netherlands

Natural gas production has historically been an important part of the Dutch economy, and the commodity accounts for over half of the country's energy consumption (Dutch Government 2014). At 2.8 tcf per year, the Netherlands is the largest producer of natural gas within the European Union, holding the largest reserves at almost 40 tcf in 2014 (EIA 2014c). However, conventional reserves are now nearing depletion, and the Dutch government predicts a yearly decline rate in production of about 3% until 2025, when the country will become a net importer of natural gas (Dutch Government 2014). Exports are expected to drop accordingly. Thanks in part to its proximity with the country and its long history of natural gas trade between the two, the Netherlands and Germany are connected through a series of pipelines, both in the shale-rich Lower Saxony and in the coal-rich and industrial Nordrhein-Westfalen.

### Algeria

Algeria has the world's ninth largest natural gas reserves, estimated at 159.1 tcf in 2014. Production has grown consistently since the early 1980s, and currently amounts to about 3 tcf per year (EIA 2014c). Although domestic consumption has started growing since the mid 2000s, production has historically been targeted towards exports: the country, which is the world's fifth largest exporter according to the IEA (2013), is connected to Europe through a series of pipelines, the primary ones being the Trans-Mediterranean one through Sicily and the Italian Peninsula, and the Maghreb-Europe one through Morocco and Spain. Current production levels could, according to a KPMG (2013) study, be kept up for over 80 years; however, a more likely outcome, according to the same study, is a quick surge in production, doubling current levels by 2025. Exports to Germany are limited to inexistent, as more proximate countries like Italy, Spain, Morocco, and Portugal account for all of the imports. As Algeria's production volume increases, however, there is a possibility for Germany to become an import country, as pointed out by Wrede (2014).

### Other non-LNG suppliers

Suppliers with characteristics similar to Algeria – large reserves, growing production, large physical distance with Germany – include Libya, Nigeria (which will become connected to Algeria if the plans for a Trans-Saharan pipeline come to fruition), and Azerbaijan and other Caspian countries (EIA 2014c). Lack of transportation infrastructure is of course the largest obstacle in using these suppliers as a diversification tool, coupled with uncertainty about the level of production that the fields in these countries can deliver.

### Liquefied natural gas

Liquefied natural gas is of course another possible solution through the monopolization problem faced by much of Europe, as mentioned both in this chapter and in the analytical part of our paper. Of course, the availability of economically convenient liquefied natural gas will depend on a number of factors that Germany has little to no control over, such as the price for the commodity in different regions, the availability of excess supply in gas-rich areas like North America and the Persian Gulf, the evolution of liquefaction and gasification technologies, and the worldwide spread of regasification terminals.

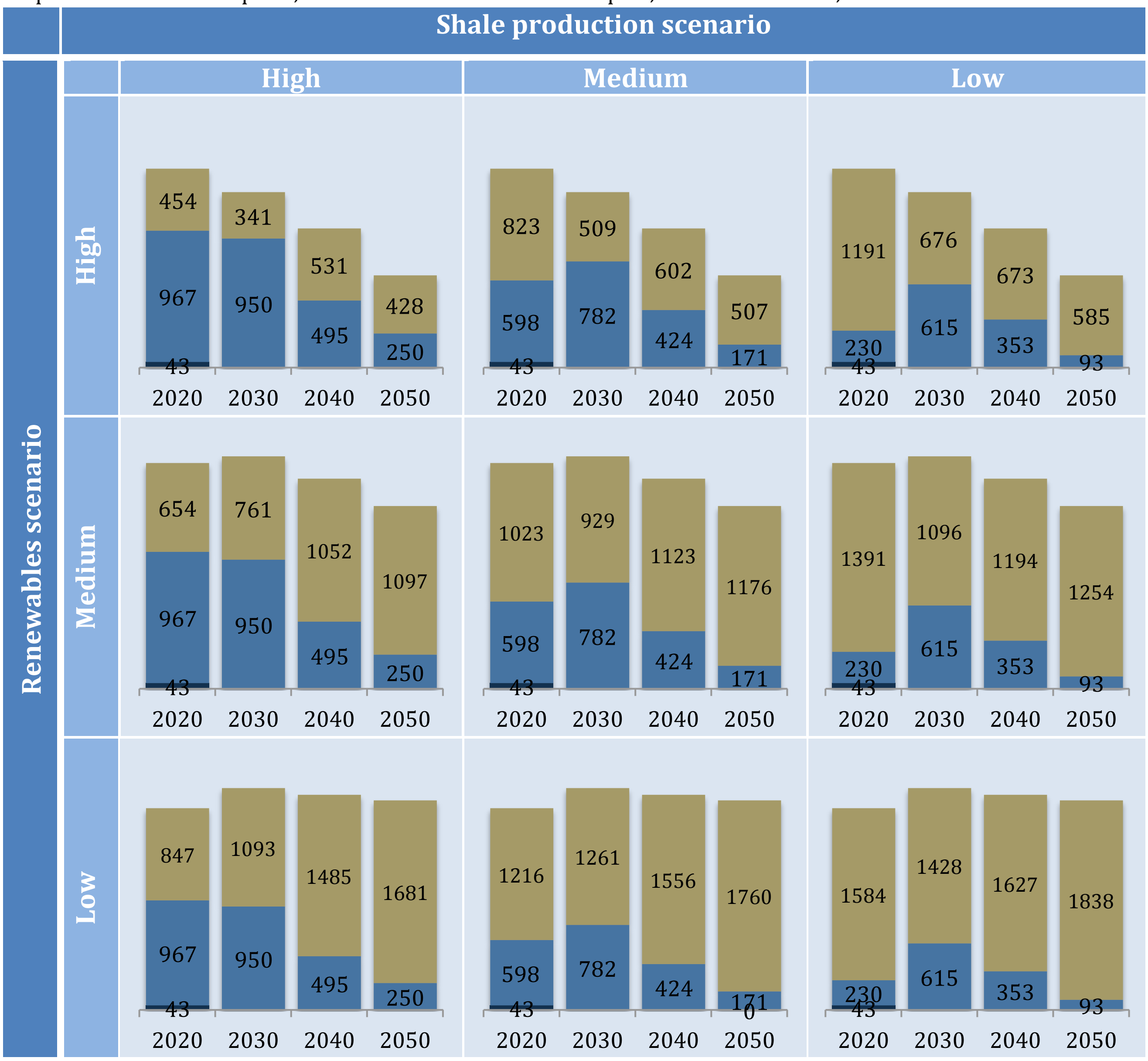
Based on the existing sources, it could be argued that while a certain degree of diversification exists today, there is a risk that excessive dependence on a single supplier will develop in the medium to long run. Since other viable sources of natural gas do exist, it can be argued that overdependence on Russia would not be an automatic consequence of increased reliance on foreign sources. However, as pointed out by a number of Germany's governing coalition's members (Chambers 2014), an effective diversification of supply would require a conscious effort in infrastructure development, especially with regards to alternative routes, as the current network of pipelines favors increased Russian dominance over the industry.

**Figure 14** European natural gas pipeline network (■: transit pipeline, ■: transmission pipeline). Pipelines connecting Russia to the rest of the continent are more numerous and have larger capacity (Source: IEA.org 2014).

## 3.3.3. Shale gas and Germany's exposure to foreign sources

Having determined the main risks connected to excessive dependence on foreign sources and Germany's current state in natural gas, we can measure the country's level of exposure and the amount to which shale gas could alleviate it. We do so by using the figures found in previous sections, but this time considering total natural gas. As previously stated, electricity generation accounts for 20% to 27% of total consumption of natural gas every year, and in calculating variations in consumption for electricity generation, we assumed constant levels of consumption for other uses – such as heating and industrial operations. Thus, assuming a value of 25% and maintaining the same level of non-electricity gas consumption for the duration of our analysis, we can calculate import amounts.

**Table 19** Imported and domestically produced gas in various scenarios (in bcf). The height of the column represents the consumption, and the color the source. ■: import, ■: domestic shale, ■: domestic conventional.



The effect of shale gas on Germany's energy security – together with the importance of the level of renewables and the actual productivity of the Posidonia basin – is quite evident from Table 18, where the level of imports that shale gas prevents is presented in light blue, while the "inevitable" imports are presented in brown. Depending on the level of productivity and the success of renewables in the German energy mix, shale gas would be able to cover up to 59.7% of total domestic demand[4] in the most optimistic scenarios, and as little as 16.5% in the most pessimistic ones. While the value range is quite wide, it should be pointed out that currently domestic production only covers approximately 15% of total demand, and that the percentage is projected to fall to zero by 2023.

To conclude, the argument that a successful shale gas exploration would significantly impact Germany's exposure to foreign natural gas sources is, according to our analysis, well-founded, as in a majority of cases dependence is reduced from complete dependence after 2023 to as little as 40.3% per year, on average (most optimistic scenario). What is somewhat played up, by contrast, is the direct connection between dependence on foreign sources and dependence on Russia: while Gazprom's share in the market is currently increasing, there are a number of suppliers that Germany has the economic power to turn to, provided it is ready to invest in the required infrastructure.

In terms of our cost benefit analysis, this translates into somewhat of an ambiguous result: while developing domestic resources would certainly be positive for Germany's energy security standing, failure to do so will not inevitably result in the grim scenario often painted by shale proponents. In light of this somewhat revised "cost of doing nothing", the impact of energy security in our analysis becomes relatively more contained.

[4] Total domestic demand includes non-electricity demand, value calculated as the average percentage.

## 3.4. Environmental impact of hydraulic fracturing

Having analyzed some of the benefits that domestic shale gas production offers, we turn to the costs. As mentioned in our introduction and background chapters, hydraulic fracturing is a controversial practice implying a number of adverse consequences for the environment. The main issues that the practice implies are the risk of groundwater contamination, the large amounts of water used to fracture the rocks, and increased air pollution. Concern over these potential negative externalities is the main motivation behind groups that oppose shale gas development and, quite directly, behind the bans and moratoria that a number of countries have placed on the practice of hydraulic fracturing.

The goal of this section is to analyze three of the main environmental concerns that are connected to the exploration and extraction of shale gas, reporting the magnitude of the consequences for the German case, and analyzing possible practices that can be put in place in order to minimize risk or adverse consequences.

### 3.4.1. Groundwater contamination

Of the various negative externalities that hydraulic fracturing can bring about, groundwater contamination is perhaps the most commonly cited by shale gas opponents as a ground for banning the practice. This is quite understandable, as a contaminated groundwater basin, if not identified promptly, can have devastating consequences on the local population's health. Fears over the practice's potentially negative consequences were somewhat compounded by a number of incidents in the United States, where leaks in early wells in the Marcellus Formation resulted in the contamination of several communities' groundwater (Jackson, Vengosh and Darrah 2013). This section is dedicated to determine how leaks are caused, their likelihood, the potential effect a leak can have on the surrounding community, and what practices can be implemented in order to minimize risk.

As specified in our description of the process, water used in hydraulic fracturing is typically mixed with a small quantity of chemical components aimed at reducing friction. Boreholes puncture through a number of layers, which typically include a groundwater basin at relatively low depths. Contamination can take place either as the water is pumped out of the well upon extraction, or as it reemerges through the rocks at later stages of the process (Myers 2012). Contamination by leakage through the borehole is more likely and was much more frequent in early wells in the United States, so a number of practices to minimize risk have been put in place. These include coating the borehole with several layers of steel and cement, and ensuring that isolation mechanisms are in place at all stages of the operation (MIT 2011). Contamination by residual water returning to the surface, by contrast, depends on the depth of the horizontal drilling and the permeability of the rock layers separating it from the groundwater basin (Myers 2012).

Risk levels in Europe are generally similar to the ones in North America when it comes to borehole contamination, and risk reduction mechanisms can be transferred relatively easy across the continents. The risk level for residual water is, by contrast, much lower for the Lower Saxony shale, since the shale basin is found at deeper levels and the rocks separating it from the groundwater basins are much less permeable (Myers 2012). While low, the risk of a leakage can of course not be completely removed: according to a study carried out by a panel of experts in conjunction with ExxonMobil (Ewen, et al. 2012), at least one leak 300 wells and 4,000 fracking operations will occur during the development phase in Lower Saxony.

The effect of a leak depends on its magnitude as well an on response time. Large quantities of fracking liquid in the groundwater basin naturally have a stronger impact on the local community's health, but they are also easier to be detected. Ewen et al (2012) report that leaks of average size (35 cubic meters) can be detected and stopped immediately, while for smaller leaks (up to 6 cubic meters) it can take as long as a week for the identification and remediation process to begin. The clean up process for the groundwater basin consists primarily in drilling a protective well to pump out contaminated water and prevent it from advancing into drinking water wells. Such measure typically costs over € 10 million. Wells that have experienced a borehole leak can in most cases not be recouped (Ewen, et al. 2012).

An important difference between Germany and the United States, in terms of magnitude of potential damage related to groundwater contamination, is population density. As previously mentioned, the flatlands lying over the Posidonia basin are one of Germany's most populous and industrial areas, containing large urban centers like Osnabrück and bordering the northern portion of the Rhine-Ruhr megalopolis, Germany and Europe's largest urban area. By contrast, the Appalachian region (site of the Marcellus Formation) and the Ozarks (Fayetteville) are relatively sparsely populated, with much fewer households and fewer groundwater basins that are tapped into. A study by Jackson (2013) found that "at-risk" households are those located within 1 kilometer from wells, suggesting that heavily populated areas are more likely to see households actually affected by groundwater contamination.

Interestingly, a study by Muehlenbachs et al (2013) found risk of groundwater contamination to have somewhat of an economically measurable effect: through a study of property values in shale-rich regions in North America, the authors find that while shale production generally has a positive effect on land value in the areas it brings employment and royalties to (as detailed in section 3.5), properties that are located in close proximity to the wells actually experience a loss in value that not only offsets, but exceeds the gains brought about by shale production. The results are controlled for a number of unobservable variables at the property level that might bias the property's value, as well as for the possibility of contamination prior to shale gas drilling.

### 3.4.2. Water use

As described in Appendix 1 and as hinted by the practice's very name, one of hydraulic fracturing's main implications is the use of water as a rock fracturing tool. Water for the operations is typically obtained from nearby surface waters, or pumped from existing municipal sources (SHIP 2012). Given the growing scarcity of freshwater in some regions, the practice of fracking is sometimes criticized as a wasteful.

The estimated amount of water for the entire multi-stage fracturing operation of a single well in the Marcellus Formation ranges, according to a New York State Department of Environmental Conservation study, between 9,000 and 29,000 cubic meters. Most studies seem to agree on the amount needed in North American basins (Vidas and Hugman 2008 being an example), but some have questioned the degree to which these amounts are plausible for Europe. According to KPMG (2012), the required amount of water in the Posidonia Shale could, given the basin's greater depth and the higher geothermal gradient, be far greater than in North America. A 2012 Eurostat study, analyzing existing wells in Europe, estimates the average water use within the first three months – where most, but not all the water use is concentrated – to range between 10,000 and 20,000 cubic meters.

Compared to other externalities, water use is not the subject of much discussion in the European continent, primarily due to the relative abundance of water in most of the regions where hydraulic fracturing would take place (Schleich and Hillenbrand 2009).

Defendants of hydraulic fracturing furthermore argue that if the amount of water used is projected for the whole lifespan of a well, it is actually lower than that of coal mines, nuclear plants, or solar power concentration in terms of water per unit of energy produced. The American shale drilling company Chesapeake Energy (2012), for instance, points out that a shale well can use as little as 15% of the water used by a coal mine for the same amount of energy. An assessment by the International Association of Oil and Gas Producers (2013) also points out that, depending on geological conditions, up to 70% of the water used in hydraulic fracturing can be recoverable in the first two to five weeks of production. Finally, technologies are being developed to enable the use of saltwater for hydraulic fracturing, which could, logistics aside, solve the issue of water use altogether (Smith 2014).

### 3.4.3. Air pollution

The extraction and production of virtually all energy sources is connected with some degree of greenhouse gases emissions. For the shale gas production cycle, emissions arise in the site preparation, drilling, hydraulic fracturing, waste water treatment and completion stages.
During site preparation, emissions are associated with the use of equipment to clear the site and the construction of initial infrastructure. Estimates for this type of emissions vary from 158 to 390 tons of $CO_2$ per well, depending on a variety of factors such as shale geology and technologies used to carry out operations (European Commission 2012, Santoro 2011).
Emissions during the drilling stage are driven by the work of diesel engines that carry out the drilling itself and pump water into the well. Jiang et al (2011) estimate these emissions to range between 840 to 1,800 tons of $CO_2$ per well, again depending mainly on technology.
Emissions during the hydraulic fracturing phase can be ascribed primarily to the transportation of the materials used in the process and the production of the chemicals. Estimates for transportation, according to Jiang et al (2011), range from 64 to 475 tons of $CO_2$ per well, depending mainly on the well's location, while estimates for the chemicals range between 200 and 1,188 tons of $CO_2$ per well (Santoro 2011).
Emissions related to the treatment of wastewater are estimated to 300 tons of $CO_2$ per well.
The well completion stage, finally, is the most uncertain source of greenhouse gas emissions, which are generated by the fracturing fluids reemerging. Estimates vary significantly across studies, with URS (2012) suggesting about 281 tons of $CO_2$ per well and Howarth et al (2011) suggesting a much higher amount of 27,247 $CO_2$ per well.

Based on this information, we can calculate how emissions from shale gas differ from emissions from other types of natural gas per unit of energy. Assuming a well's average productivity is 2 bcf /year[5], we calculate the energy produced by a well[6] at $250.6 * 10^6$kWh.

[5] This value is suggested by studies by the European Commission and is consistent with our previous assumption of 3 bcf initial production followed by a gradual decline.
[6] We use 1kWh per 0.00798 mcf for conversions, as suggested by the EIA (2013).

We then take the arithmetic average of the amount of $CO_2$ produced per well at 8,503 tons, and find the emissions per kWh to amount to 33.92 $gCO_2/kWh$.

This makes the production emissions per unit of energy of shale gas about fifteen times higher than those of conventional natural gas (2.34 $gCO_2/kWh$ according to a 2012 European Commission study) and twice as high as those of liquefied natural gas (15.18 $gCO_2/kWh$ according to the same study). While the values are significantly high, it should be pointed out that the pre-combustion phase only accounts for about 9% of total lifecycle greenhouse gas emission of natural gas.

### 3.4.4. Land use and induced seismicity

Compared to conventional natural gas, shale gas typically requires smaller tracts of land for similar level of extraction. This can be attributed primarily to horizontal drilling, which allows operators to access larger reserves from a single well pad, drastically reducing the number of necessary wells (Rahm 2011).

A more recent concern that has been brought up with regards to shale extraction and land management is the correlation between hydraulic and seismic activity. A study by Pater and Baisch (2011) found the practice to be the cause of minor earthquakes in the United Kingdom and the United States over the past few years. The risk has been found to be minimal, as are the consequences of earthquake with such low magnitude, but shale opponents occasionally cite the possibility of stronger earthquakes as a reason to ban the practice.

### 3.4.5. Environmental cost of producing shale gas

In conclusion, it can be argued that the main environmental cost of producing shale gas in Germany is the risk of groundwater contamination. While dirtier than conventional gas, shale gas is cleaner than other fossil fuels, and the issue of water use is not as stringent due to abundance of water in the country and the introduction of technologies allowing seawater. Groundwater contamination risk can, as mentioned, be minimized through certain practices, which the local and federal government can require upon lifting its moratorium on fracking, as detailed in the next chapter. However, the possibility of a leak cannot be completely eliminated, and given the population density of the interested area (ranging from 86 inhabitants/$km^2$ in the Nienburg/Weser district to 164 inhabitants/$km^2$ in the Osnabrück rural district), the number of people and used groundwater basins exposed will be higher than in North America.

## 3.5. Other macroeconomic consequences

Naturally, there are other benefits that domestic production of shale gas can bring about in Germany, as proved by the North American experience. As mentioned in our background chapter, shale gas production resulted not only in diminished reliance on imports and lower electricity prices, but also in positive consequences for the economy as a whole, such as higher employment and investment figures and higher tax revenue for the local government.

German shale gas would, as witnessed in our analysis, have a very strong impact on the domestic supply of natural gas for Germany, but would have a very minimal impact on total continental supplies – in other words, Germany shale gas reserves are a tiny fraction of total reserves in the Eurasian continent. As such, a significant change in natural gas or electricity prices due to shale gas in Germany alone is relatively unlikely. This is in strong contrast with the United States, where national and continental reserves are much closer in magnitude (the country being one of two large producers, with Canada) and where the introduction of new national reserves had an inevitable impact on prices.

Unlike electricity prices, job creation, investments, and tax revenue are independent of the total supply of natural gas in the continental market, meaning that the favorable conditions generated by shale gas production in North America could potentially be recreated in Germany. We thus dedicate this section to a discussion of these three factors.

### 3.5.1. Job creation and investments

Since the practice of hydraulic fracturing became economically viable in the 2000s, shale gas production has already created an estimated 600,000 new jobs in the United States, 150,000 of which directly (Wang, et al. 2014), and a projected 830,000 jobs by 2035 according to a 2012 IHS Global Insight report. The link between direct and undirect employment is particularly important: a second 2012 IHS study finds that for every job created by the shale gas industry, three related jobs are created – a figure higher than that of the finance or construction industry. In terms of investments, shale gas is predicted to account for nearly $1.9 trillion over the cumulative period from 2010 and 2013 in the United States.

The obvious question going forward is the degree to which these changes could apply to Europe. According to a Pöyry and Cambridge Econometrics study (2013), widespread shale development across the whole European continent could add between € 1.7 and 3.8 trillion to the general economy, and trigger the creation of between 600,000 to 1,100,000 jobs by 2050.

According to a 2014 IHS study, shale gas could add up to € 138 billion to the German gross domestic product over the course of its development. The study, which analyzes various scenarios of compliance with the Energiewende's goals and competitiveness for the German economy, finds that the scenario where shale gas was introduced is the one with the highest employment, totaling at 944,000 (368,000 of which are induced, meaning outside the energy industry, unlike direct and indirect ones) for electricity generation as a whole.

We can calculate the projected impact that shale gas production alone will have on employment in Germany by using existing estimates. According to the British Institute of Directors (2014), every 17 jobs (direct, indirect, and induced) are created for every € million of capital invested or operational expenses in shale gas. Following this assumption, we can calculate the amount of jobs created by finding total investment in the industry, which we estimate by multiplying the number of wells by capital expenditure per well (in turn, given more in detail in Chapter 4). Using 2040 as our reference year, we find the values reported in the table below. It should be pointed out that the number of wells is estimated by dividing 2040's production by average yearly production per well as opposed to total production by total productivity, as that would not take into account the jobs released after the dismantling of the well, resulting in excessively high estimates.

**Table 20** Jobs potentially created by shale gas production in Germany, 2015-2040

| | Low shale | Medium shale | High shale |
|---|---|---|---|
| **New jobs** | 114,728 | 221,220 | 431,720 |

### 3.5.2. Government revenues

Another positive consequence from shale gas development is the increase in government revenues, in the form of both royalties for exploration and tax incomes. These funds can then be reinvested to promote further development of the local or national economy, or they can substitute tax revenue from other sectors, thereby reducing fiscal pressure and increasing their competitiveness. As shown in Appendix 3, a 10% royalty rate on extraction would result in the following cumulative revenue levels for the German and Lower Saxon government over the entire extraction period.

**Table 21** Cumulative royalties from shale production by 2050 (in 2014 € billion)

| | Low shale | Medium shale | High shale |
|---|---|---|---|
| **Royalties** | 12.3 | 19.1 | 25.1 |

## 3.6. Summing up costs and benefits of shale exploration

In conclusion, it can be argued that even in the most extreme of scenarios, shale gas in Germany will not be the game changer it was in the United States. Owing primarily to the country's relatively limited reserves, especially when compared to the ones existing in the rest of the continent, German shale gas development is extremely unlikely to have a significant impact on the price of the commodity in Europe. The benefits of domestic shale gas development will thus be primarily of strategic and macroeconomic nature, concerning the country's trade balance, energy security, and internal economic development.

While there is far from a consensus over the desirability of a trade surplus at all costs, most economists agree that prolonged trade deficits can hurt a nation's economic status in the long run. In the most "pessimistic" renewable penetration scenarios, Germany's reliance on foreign natural gas for electricity generation would prove to be a burden for the country's trade balance. In our analysis, we find shale gas production to decrease the needed amount of imports quite significantly, ensuring that Germany's primary import account does not grow excessively. However, comparing imports of natural gas – even in the most pessimistic of scenarios – to the country's total trade surplus, we find that natural gas alone is very unlikely to tilt the balance towards a deficit.

On the issue of energy security, shale gas offers a similarly positive but somewhat limited advantage. While domestic production can effectively reduce exposure to foreign sources – as much as by 40.3% per annum in the most optimistic scenarios – Germany is currently characterized by a sufficient level of supplier diversification, which can be maintained if the country is willing to invest in dedicated infrastructure. The threat of Russia as the sole provider of natural gas, while not completely outlandish, is thus not inevitable, making the development of domestic sources less of a stringent necessity.

A more tangible benefit of shale gas development is the effect it is likely to have on employment and investment levels in the regions it interests. Similarly to areas in the United States with shale basins, Germany's Lower Saxony could experience an job creation boom, both directly and indirectly related to the significant investments that operations would bring about. Furthermore, local and regional governments could see their revenues increase thanks to extraction royalties and taxes, enabling them to invest more funds in the state's economic development.

On the cost side of our analysis we find both potential and realized environmental damage from hydraulic fracturing. The contamination of groundwater resources is the practice's most commonly cited risk, as it can have potentially disastrous consequences on the local population's health, especially in densely populated areas such as Lower Saxony. While this risk can be minimized through a number of practices, its potential remains. Water use is, by contrast, less of an issue in Europe than it is in the United States, due to the abundance of water in the Old Continent. Furthermore, the development of technologies enabling the use of saltwater for gas extraction effectively minimizes the issue's impact. Air pollution is a third adverse consequence of shale development, as its extraction is over fifteen times more polluting than that of conventional gas. While this could be an issue, especially within the framework of the Energiewende, it should be noted that all other fossil fuels remain significantly dirtier in terms of air pollution.

To conclude our analysis, therefore, the strategic needs of Germany should be compared against the environmental impact the country is willing to undergo in determining whether shale gas is desirable. In terms of strategic costs and benefits, it should be noted that shale gas is always more attractive in the "middle" and "low" renewable scenarios. In other words, domestic development of natural gas should be considered if renewables growth does not match the Energiewende's goals.

# 4. Notes on implementation

Having determined the key costs and benefits associated with domestic shale gas production in Germany, we briefly discuss two of our key assumptions regarding implementation. Firstly, we look at the automatic connection we drew between a lift of the fracking moratorium and actual shale production. Secondly, we discuss the issue of public opinion, and how a shift in the perception of fracking at the local level would be necessary in order for shale production to be implementable.

## 4.1. Summing up costs and benefits of shale exploration

Throughout our analysis, we took the implicit assumption that a lift on a hydraulic fracturing moratorium would automatically result in shale gas production from private companies. In reality, of course, this is not the case, and operators only take on the considerable investment that is shale exploration and extraction if they foresee a profit. Projected profitability, in turn, depends on a number of variables, ranging from projected extraction volumes and going natural gas pricing on the revenue side to site preparation and extraction expenses and royalties on the costs side. Additionally, a significant amount of legislative risk exists, as local, national, or supranational entities could, as they have done before, halt operations on environmental safety grounds.

In light of this, should the German government decide that domestic shale development is desirable based on estimated costs and benefits, legislative action should be enacted in order to ensure that exploration and production are an attractive perspective for companies. Such action would have to include a taxation scheme that aids the amortization of risky investment expenditure in the early days of exploration and extraction over a large period, and guarantees that – should future regulation of hydraulic fracturing change again, the financial burden will not fall entirely on the companies.

Examples of favorable taxation for resource policies include the Norwegian petroleum taxation system, which includes capital uplifts and immediate write-offs for investment expenses (Hannesson 1999), the American shale taxation system, allowing deductions for intangible expenses as well as depletion of the property value according to the amount of resources left (Kielmas 2014), and the Russian tight oil mineral extraction tax exemptions, which associate a tax discount figure to geological characteristics such as permeability and layer thickness. Such tax systems are reported as examples, and not as models that Germany should directly build on, as local industry issues, property law, and even geological characteristics ought to be taken into account in the development of such policy. To test the effect of a simple taxation scheme based on existing mining laws, we carry out a heavily simplified cost-benefit analysis for shale exploration from a company's perspective in Appendix 4.

## 4.2. Public opinion, transparency, and environmental protection

The primary reason behind Germany's moratorium on hydraulic fracturing is, as mentioned, widespread public opposition to the practice. A May 2013 survey, taken during a period of heated debate over the practice, found 66% of Germans to be opposed to the practice, 23% to be in favor, 3% to be undecided, and 7% to not be aware of what shale gas is (TNS Emnid 2013).[7] The primary source of concern is, as mentioned in Chapter 2, the risk of groundwater contamination, an externality with potentially disastrous consequences on health and safety.

Public support is especially important in Germany given its highly federative structure, which allows local governments to ban extraction operations on their premises. Thus, should the German government decide that domestic shale production is the most desirable activity, a number of practices should be put in place in order to ensure transparency, risk minimization, and benefit sharing with the communities that shale drilling takes place in.

An example of such a measure would be the public disclosure of the fracking fuels used for extraction on a well-to-well basis, ensuring full transparency and accountability to the local community. Other examples would be the requirement of a minimal number of isolation layers in the well, a ban of fracking in specifically sensitive areas, and a cap on the amount and type of chemicals that can be used as proppants.

Risk reduction should, of course, be viewed not only as a measure aimed at increasing support, but also as part of a larger commitment to the safeguard of people's health and safety.

[7] Interestingly, the same poll taken in March 2013 found the percentage of people claiming to have never heard of fracking to amount to 50%.

# 5. Conclusion

As stated in our introduction, the goal of this thesis was to analyze some of the main strategic costs and benefits of shale production in Germany in order to support the electricity generation goals of the Energiewende. As such, chapters dealing with chiefly strategic issues – energy security and trade balance – contain more detailed calculations, while chapters relating to other costs and benefits – environmental and macroeconomic – are based primarily on adaptation of existing studies to the European context. This being said, we use this chapter to provide reflections on our key findings, to point out some of the key limitations to our study, and to identify possibilities for further research that build on our analysis.

## 5.1. Summary of findings and reflection

In our discussion of the Energiewende's renewable penetration and energy efficiency goals, we came across several constraints to their realization, both of financial nature (unsustainability of feed-in tariffs) and technical nature (storage and intermittency issues, among others). Even in the most optimistic scenario, we find natural gas to be of primary importance in the electricity mix, especially over the 2020s and 2030s. This information, together with the gradual decrease of domestic conventional gas reserves, was the main reason behind our investigation of shale gas as a potential part of the solution for Germany.

In our sensitivity analysis of renewable penetration and energy efficiency, we found the amount of natural gas in the electricity mix needed to keep up with emission reduction goals to depend heavily on the amount of renewables, and to be considerably higher than today's value already by 2020 in all scenarios. An analysis of current reserves further revealed that, under current conditions, the entire amount would have to be imported, placing a significant strain on the country's trade balance and energy independence.

Our projections of shale production reveal that, given the limited amount found in existing reserves, shale gas is unlikely to be a game changer by lowering prices, since its quantity would not shift the supply curve significantly. What we do find is, as predicted, a reduction in the country's import expenditure and in its reliance on foreign sources. While both are arguably desirable, however, an analysis of the context reveals that natural gas imports alone would not tilt Germany's large trade surplus towards a deficit even in the most pessimistic of scenarios, and that the country's energy security risk could also be contained through other measures aimed at maintaining supplier diversification. For what concerns these two strategic issues, therefore, domestic shale gas production to aid changes in the power generation industry could be characterized as helpful – especially in a scenario where Germany cannot reach its renewable penetration goals – but not indispensible.

On the issue of environmental damage, we find the risk of groundwater contamination to be more potentially dangerous in Germany than in the United States given the higher population density in the area where exploration and production would take place. Thus, while the risk of an actual leak is inherently smaller due to geological conditions, the German government should enact specific regulations to increase transparency and minimize risk. On the issues of water use and air pollution, we find the negative consequences to be inevitable but relatively limited, especially given their similarities to externalities implied by other energy sources.

Finally, we find domestic gas production to have a potentially significant positive impact of employment and investment in the area where it is carried out, as it did in the United States. Furthermore, the collection of taxes and royalties could further support the local economy through government investment.

In conclusion, while shale gas will not be the same game changer it was in the United States, it could still provide Germany with some strategic advantages as it transitions towards a more sustainable energy mix. Should the country's government decide that shale production is the more desirable choice, it should put in place legislation aimed at both ensuring that the practice is attractive for companies and that the risk of environmental damage is minimized, as discussed in Chapter 4.

## 5.2. Limitations of the study

Due to the lack of complete information and the need for simplifications in various areas, this paper presents a number of limitations that should be taken into account when analyzing its findings. We use this section to provide information over the key limitations of the study.

Firstly, given the novel nature of the topic in the European context and lack of extensive technical data, a significant portion of the paper is based on incomplete data (key examples being the geological characteristics of German shale plays and the amount of technically recoverable reserves). The methodology we utilize for much of our calculations on shale development consists in starting from North American values and adapting them to the European continent according to characteristics that are known. While in line with most of the literature on the topic, this method could prove to be wrong once shale development begins in Europe and Germany.

Secondly, the emissions goals set forth by the Energiewende are taken as constraints throughout our analysis, meaning that we rule out the possibility of a downward adaptation of these goals in light of failure to meet previous ones. Other goals, such as the level of renewables penetration in the energy mix and the level of energy consumption, are however not taken as constraints, and are fully questioned through a sensitivity analysis.

Thirdly, a number of simplifications and assumptions are made throughout the analysis in order to maintain the focus on the key issues. One of the most important assumptions is the constancy of non-electricity-generating natural gas over the analyzed period, while an important simplification is the elimination of yearly and monthly fluctuations of gas prices.

Finally, the calculations provided in the breakeven analysis are based on the existing costs rather than future costs of the technology. The capital and operational costs of starting the shale gas rig will likely to change over time and at different rates. Relatively new renewable technologies are expected to decrease in cost at a much higher rate than mature fossil fuel technologies. Furthermore, the regulations of the industry are also likely to change over time.

## 5.3. Possibilities for further research

This study, which was set out to investigate the potential role of shale gas in helping Germany meet the goals introduced by the Energiewende in electricity generation, provides a general overview of the main strategic costs and benefits of shale operations based on information available and conditions existing as of Spring 2014. Further research could be performed once updated data on shale basins is available or once the regulatory framework changes again.

The study's methodology could be applied on a more elaborate research, performing a more detailed analysis of parameters such as future gas prices or economic costs of environmental damages. Similarly, a specific regulatory tax system could be developed to ensure an incentive for companies to take on explorative endeavors.

The focus of the study could be broadened from simply the electricity mix to the entire energy mix, analyzing how natural gas could substitute not only coal and nuclear power, but also petroleum oil. All major energy-consuming operations, from transport, to heating to industrial operations would have to be considered.

The methodology developed for this study could be applied to another country or jurisdiction. While Germany is one of the world's leaders in pursuing emission reduction goals in such a rapid pace, many countries are at least attempting to follow the example. The issue of trade imbalances and energy security would be particularly interesting for countries with a less diversified energy mix and a smaller trade surplus.

Finally, the topic of natural resource rent taxation with regards to Germany and shale gas, which we mentioned very briefly in Chapter 4, could be expanded significantly, especially if more information on potential extracting conditions was to become available in future years.

# Appendix

## 1. How hydraulic fracturing and horizontal drilling work (Chesapeake Energy 2012)

The first step of shale gas extraction is the drilling of a borehole. Shale formations are found at very large depths, so it is not uncommon for these boreholes to be over 2.5 km deep.

To prevent spills and leakages at later stages, the borehole is enclosed in steel and cement castings that isolate it from its surrounding – this is particularly crucial at low depths, since where aquifers are located. Drilling continues well below the groundwater layer into solid rock layers such as granite, which will serve as insulators once hydraulic fracturing is put into place. Once the shale layer is reached, the drilling tool is adjusted so that the drilling slowly becomes horizontal. Horizontal drilling can continue for lengths surpassing 1 km into the shale formation, which allows companies to minimize the number of wells needed to extract shale gas from a given area. A further cement casing (production casing) is inserted at this point in order to secure the borehole and prevent unwanted leakages of fluids.

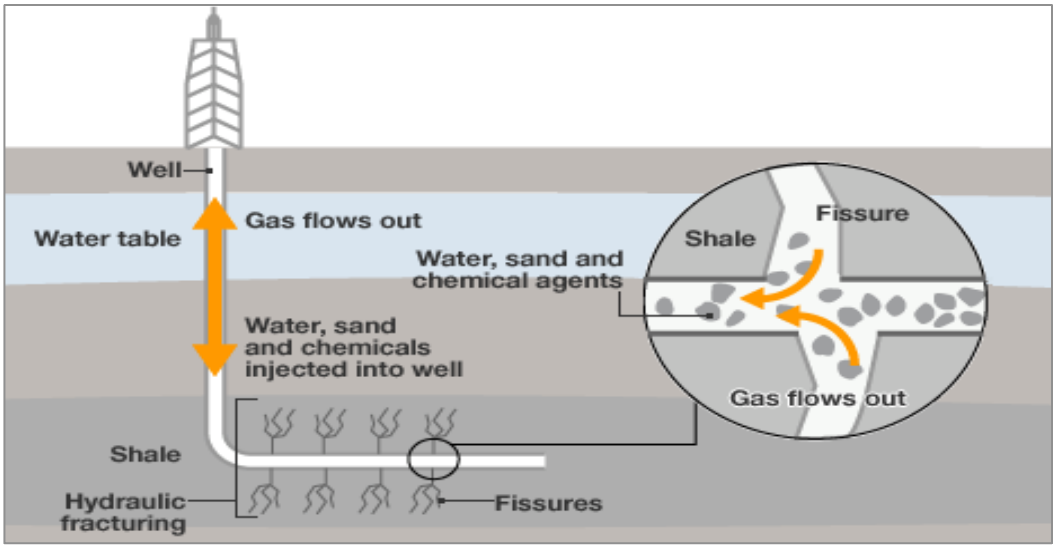



**Figure 15** A graphic representation of shale drilling (not to scale). Source: ProPublica 2012

It is at this point that hydraulic fracturing begins: perforating guns containing explosive charges are inserted in the horizontal portion of the borehole and set off, puncturing the shale formations around the borehole.  A mixture of water, sand and chemicals is pumped into the hole, putting pressure on the perforations and causing the shale formation to fracture around natural zones of weakness. As water enters these fractures, proppants are added to the fracking fluid in order to keep them open. As water is removed from the hole, the natural gas that was previously trapped in the shale formations also surfaces, thus bringing the first stage of extraction to an end. The area around the first perforation is sealed, and the fracking operations are repeated along the length of the horizontal drilling.

## 2. Shale gas and job creation

We begin our analysis by analyzing the production per well according to the Arp model, finding the average yearly production (in bcf) in each of the scenarios.

**Table 22** Average production per well (bcf/year).

| | Low Shale | Medium Shale | High Shale |
|---|---|---|---|
| **1** | 0.57 | 0.88 | 1.20 |
| **2** | 0.34 | 0.57 | 0.83 |
| **3** | 0.25 | 0.43 | 0.66 |
| **4** | 0.19 | 0.35 | 0.55 |
| **5** | 0.16 | 0.30 | 0.48 |
| **6** | 0.14 | 0.26 | 0.42 |
| **7** | 0.12 | 0.23 | 0.38 |
| **8** | 0.10 | 0.21 | 0.35 |
| **9** | 0.09 | 0.19 | 0.33 |
| **10** | 0.09 | 0.17 | 0.30 |
| **Average** | 0.21 | 0.359 | 0.55 |
| **Total** | 2.05 | 3.59 | 5.51 |

We continue our analysis by dividing total production in 2040 by average yearly production, obtaining the average amount of shale wells operating per year up to 2040. We then multiply this number by the cost per well, obtaining total investment, and divide by 17 (number of jobs created per million invested in shale according to the Institute of Directors). We thus obtain the data presented below.

**Table 23** Calculating the number of jobs created by shale gas production

| | High Shale | Medium Shale | Low Shale |
|---|---|---|---|
| **Avg. yearly production/well (bcf)** | 0.21 | 0.36 | 0.55 |
| **Total production in 2040 (bcf)** | 495 | 424 | 353 |
| **Cost of one well (million €)** | | **10.52** | |
| **Investments in 2040 (million €)** | 25,395.3 | 12,424.7 | 6,751.9 |
| **Job creation 2040 (#)** | 431720 | 211220 | 114782 |

## 3. Shale gas royalties

We calculate the royalties by 2050, we take the annual production, multiply it by the Medium Scenario Price of gas and take 10% of that equation.

**Table 24** Shale gas royalties to 2050

| | High Shale | Medium Shale | Low Shale | Medium Price | High Shale | Medium Shale | Low Shale |
|---|---|---|---|---|---|---|---|
| **2015** | 0 | 0 | 0 | 8.28 | 0 | 0 | 0 |
| **2016** | 230 | 137 | 45 | 8.28 | 190.44 | 1138.50 | 372.60 |
| **2017** | 327 | 207 | 87 | 8.28 | 270.75 | 1713.96 | 720.36 |
| **2018** | 602 | 352 | 102 | 8.28 | 498.45 | 2914.56 | 844.56 |
| **2019** | 747 | 457 | 167 | 8.28 | 618.51 | 3783.96 | 1382.76 |
| **2020** | 967 | 598 | 230 | 8.58 | 829.68 | 5135.13 | 1973.4 |
| **2021** | 1077 | 649 | 221 | 8.58 | 924.06 | 5568.42 | 1896.18 |
| **2022** | 1345 | 802 | 260 | 8.58 | 1154.01 | 6885.45 | 2230.80 |
| **2023** | 1400 | 870 | 302 | 8.58 | 1201.20 | 7464.60 | 2591.16 |
| **2024** | 1350 | 965 | 380 | 8.58 | 1158.30 | 8279.70 | 3260.40 |
| **2025** | 1306 | 1045 | 430 | 9.18 | 1198.90 | 9593.10 | 3947.40 |
| **2026** | 1240 | 970 | 510 | 9.18 | 1138.32 | 8904.60 | 4681.80 |
| **2027** | 1200 | 910 | 555 | 9.18 | 1101.60 | 8353.80 | 5094.90 |
| **2028** | 1112 | 846 | 580 | 9.18 | 1020.81 | 7766.28 | 5324.40 |
| **2029** | 1030 | 815 | 601 | 9.18 | 945.54 | 7486.29 | 5517.18 |
| **2030** | 950 | 782 | 615 | 10.08 | 957.60 | 7887.60 | 6199.20 |
| **2031** | 870 | 752 | 635 | 10.08 | 876.96 | 7585.20 | 6400.80 |
| **2032** | 840 | 718 | 597 | 10.08 | 846.72 | 7242.48 | 6017.76 |
| **2033** | 796 | 690 | 585 | 10.08 | 802.36 | 6960.24 | 5896.80 |
| **2034** | 740 | 648 | 557 | 10.08 | 745.92 | 6536.88 | 5614.56 |
| **2035** | 711 | 622 | 534 | 10.08 | 716.68 | 6274.80 | 5382.72 |
| **2036** | 660 | 577 | 494 | 10.08 | 665.28 | 5816.16 | 4979.52 |
| **2037** | 601 | 528 | 456 | 10.08 | 605.80 | 5327.28 | 4596.48 |
| **2038** | 580 | 503 | 427 | 10.08 | 584.64 | 5075.28 | 4304.16 |
| **2039** | 554 | 465 | 376 | 10.08 | 558.43 | 4687.20 | 3790.08 |
| **2040** | 495 | 424 | 353 | 12.91 | 639.04 | 5473.84 | 4557.23 |
| **2041** | 480 | 398 | 317 | 12.91 | 619.68 | 5144.63 | 4092.47 |
| **2042** | 475 | 375 | 276 | 12.91 | 613.22 | 4847.70 | 3563.16 |
| **2043** | 430 | 340 | 251 | 12.91 | 555.13 | 4395.85 | 3240.41 |
| **2044** | 399 | 302 | 205 | 12.91 | 515.10 | 3898.82 | 2646.55 |
| **2045** | 359 | 275 | 192 | 14.62 | 524.85 | 4027.81 | 2807.04 |
| **2046** | 325 | 246 | 168 | 14.62 | 475.15 | 3603.83 | 2456.16 |
| **2047** | 301 | 225 | 149 | 14.62 | 440.06 | 3289.50 | 2178.38 |
| **2048** | 255 | 197 | 140 | 14.62 | 372.81 | 2887.45 | 2046.80 |
| **2049** | 232 | 171 | 110 | 14.62 | 339.18 | 2500.02 | 1608.20 |
| **2050** | 250 | 171 | 93 | 15.97 | 399.25 | 2738.85 | 1485.21 |
| **SUM total:** | | | | | **25,104.53** | **19,118.79** | **12,370.59** |

## 4. Break-even analysis

As anticipated, we perform a very simplified break-even analysis for German shale gas under current taxation conditions in order to determine whether companies have an incentive to take up such a risky and investment-heavy endeavor. We use the NPV approach to calculate this, listing the main cost and profit drivers and depreciating them over time accordingly, and finding the price level that equates the NPV to zero. The result of this analysis is the minimum going price at which companies have an incentive to start operations; while the going price of the commodity is, as calculated in Chapter 3, likely to vary significantly over the next decades, we concentrate our analysis on the early years of the “Medium price” scenario for simplicity.

Since, as previously stated, very little exploration has taken place outside of North America, we will take information on the Marcellus Formation as our base, and adapt them to the local environment in Germany accordingly.

### 4.1. Profit and cost drivers

As stated before, the primary difference between shale gas and conventional natural gas lies in their extraction technique. The technologies required for shale gas extraction – namely, hydraulic fracturing and horizontal drilling – are generally more complex, and imply higher costs per well than their conventional counterparts. According to a Hefley et al (2011) study analyzing production statistics for the highly successful Marcellus Formation, the main cost and profit drivers for shale gas production are the following:

- Initial production and production rate
- Finding and development costs (F&D)
- Operating expenses (OE)
- Transportation costs (TC)
- Royalties & taxes
- Site preparation costs
- Costs of well drilling and completion
- Cost of capital

#### Initial production level and production rate

The topic of initial production and subsequent decline at the well level has already been analyzed in Section 3.7.2.1. We thus report the values we found for Arp’s rate-time equation (1956) below, where $\sum q_t$ represents the well’s cumulative production over 10 years.

**Table 24** Arp’s parameters and cumulative production over ten years.

| | Low shale | Medium shale | High shale |
|---|---|---|---|
| $q_0$ (mcf/d) | 2 | 3 | 4 |
| $b$* | 1 | 1.19 | 1.39 |
| $D_0$ (%) | 80% | 70% | 60% |
| $\sum q_t$ (bcf) | 2.05 | **3.59** | 5.51 |

**Finding and development costs (F&D)**, or exploration costs, include the cost of acquiring mineral leases, purchasing equipment to develop the property, and acquiring and analyzing seismic data. These costs are measured in €/mcf, and in our cash flow analysis, they are amortized over the life of the drilling period, and expensed throughout the gas production.
These costs can reasonably be assumed to be relatively similar to the ones in the United States if the legislative environment is favorable. According to Baihly et al (2012), this amounted to about **€ 0.92/mcf** in 2012, so we will use this for our analysis.

**Operating expenses** refer to the expenditures associated with gas extraction itself, such as labor, well repairs and maintenance, materials and supplies, and administration; like exploration costs, they are measured in €/mcf. Stevens (2010) points out that the absence of operators with shale-specific expertise in Europe will result in higher operating expenses, especially in the short run: for this reason, we mark up the Marcellus figure – € 1.27/mcf (Hefley 2011) – by a factor of 1.15 for our analysis, obtaining an expense of **€ 1.46/mcf**.

**Transportation costs (TC)** depend primarily on the distance between the well and the existing pipeline network's hubs, and refer to the expenditures directly related to moving the commodity – meaning that the initial investment in pipeline setup is not counted here, as it is included in the site preparation account. Transportation costs are measured in €/mcf.
The technologies required to transport shale gas are the same as the ones used for conventional gas, which are relatively equally available in most OECD countries (Makhatab and Poe 2012), meaning that the **€ 0.21/mcf** of the Marcellus Formation (Hefley 2011) are a good estimate of transportation costs in Germany, at the same level of distance. Distances between wells and the existing pipeline network is thus the main differentiating factor between the Lower Saxony Shale and the Marcellus Formation; while the potential positioning of wells in Lower Saxony cannot be determined with certainty due to the lack of exploration, an analysis of the existing pipeline networks in the Appalachians and Lower Saxony reveals area with a large density of existing infrastructure, suggesting that distances will not be enormously different. We thus take the Marcellus figure for our analysis.

**Royalties** (Förderabgabe) on natural resources in Germany are paid to the government – as opposed to the landowner in the United States – and are quoted in percentage of future production (revenue) from a well. In order to incentivize domestic production of natural gas, Germany has opted for a competitively low royalty rate, setting it at **10%** of the resource extracted based on their market value (BJV 2014).

The **corporate tax** in Germany is **29.58%** as of 2014 (KPMG 2014).

**Site preparation** costs refer to expenditures related to both permitting and preliminary infrastructure – in other words, they include leasehold, set-up of road infrastructure, ponding for hydraulic water, and construction of the drilling pad among others.

Land lease and purchase expenses vary enormously between geographies due to differences in key factors like as land scarcity and population density. A major legislative difference between Europe and North America refers to ownership rights of natural resources: while in the United States these belong to the owner of the land on top of the reserves, in Europe they belong to the state. What this translates to in terms of land lease and purchase expenses is much lower prices and the lack of a need to pay royalties to the landowner. A common practice for oil and gas companies in Germany is to pay the landowner a higher rent than what he or she would get if the land was leased for agricultural activities (Sidley 2014). These costs, which range between € 300,000 and €600,000 per well pad, are negligible compared to investments in drilling and preparatory activities.

Preliminary infrastructure also includes the physical construction of pipelines. The main cost driver of pipelines is length, and 1 km of gas pipelines costs approximately €2.05 million as of 2013 (Oil and Gas Journal 2013). A study by Gagnolet (2012) finds the average gathering pipeline to stretch for about 1.65 miles (2.65 km) per well pad in the Marcellus Formation; having assumed existing pipeline density to be similar in Lower Saxony, we can calculate a cost of about € 5.43 million per well pad. Since we are calculating the costs per a single well, we will assume that there will be on average 2 wells per a well pad. Thus, the cost per well will be **€ 2.72 million.**

**Cost of well drilling and production** are divided into two categories:

- Tangible drilling costs (TDC) refer to the direct costs of drilling, which we assume to be 25% of the total drilling costs[8] (a division we use only in our cash flow analysis for depreciation). These costs offer a salvage value, and are depreciated in our analysis over a period of ten years using the Modified Accelerated Cost Recovery System (MACRS).
- Intangible costs include labor, chemicals, drilling fluids, and all other expenses that cannot be depreciated over time. Since the vast majority of these expenses is carried out prior to the production phase, we include all of them in year 0 of our analysis to make calculations simpler.

[8] This assumption is based on standard industry trends (American Petroleum Institute 2014).

The 2013 Goldman Sachs report "Top 380" analyzes various unconventional gas wells in different shale basins, and finds the primary driver of well cost to be the depth of the reservoir. We therefore run a linear regression for the cost of the well and depth of the formation, using data on major shale formations in the United States reported in Table 19.

**Table 26** Depth and average cost of drilling per well in the United States' major shale basins (data in 2013 $)

| | Barnett | Haynesville | Marcellus | Fayetteville | Woodford |
|---|---|---|---|---|---|
| **Depth (feet)** | 6,000 | 12,000 | 7,000 | 4,000 | 9,000 |
| **Cost of drilling ($ mln)** | 3.5 | 9.5 | 6.0 | 2.8 | 7.0 |

We find the equation's parameters to be $a = -0.843$ and $b = 0.0008688$, suggesting that

$$\text{Cost of well (mln\$)} = -0.843 + \text{Depth(ft)} * 0.0008688$$

Inputting the depth of the Posidonia Shale in the equation, we calculate the cost of drilling per well to amount to $ 10.56 million, or € 7.8 million (converted into real 2014 €). Adding the costs of infrastructure and drilling, we get **€ 10.52 million** per well. This figure is consistent with the drilling and prepping costs incurred in Polish wells, which according to Medlock (2013) range between € 10.27 million and € 11.74 million per well.

**The cost of capital** is determined by the minimum return that a company expects on its investments. This is of course dependent on a variety of factors, such as the going interest rate and the industry a company operates in. Based on average data for the industry in Germany (Weijermars 2013), and rounding up to the nearest integer, we assume an internal rate of return (IRR) in capital investment of **10%**.

### 4.2. Cash flow analysis

Having analyzed cost and profit drivers, we can place them into a cash flow analysis to determine the break-even price. Again, intangible drilling costs and costs taking place in the preparation phase are placed at year 0, while all the other costs incur throughout the well's lifespan, and are therefore analyzed on a yearly basis. To calculate free cash flow from the net income, we will add back depreciation as a non-cash expense and subtract the cash expenses. The breakeven price is obtained trough back-calculations after setting the present value of future cash flows to zero The full table is presented in the next page.

Our result of € 8.83/mcf is equivalent to € 9.13/mmBtu, and is higher than both the current and projected 2020 (medium scenario) import price of Russian gas at the German border, according to our piece analysis – the two are €8.28/mmBtu and €8.58/mmBtu respectively. What this suggests is that, under current legislative conditions and within the simplifications of our analysis, there is no economic incentive for companies to initiate shale gas exploration.

**Table 25** Cash flow analysis

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Annual Extraction (Bcf)** | 0.00 | 0.88 | 0.57 | 0.43 | 0.35 | 0.30 | 0.26 | 0.23 | 0.21 | 0.19 | 0.17 |
| **Breakeven price of gas (€/Mcf)** | | | | | | **8.83** | | | | | |
| **Revenues (In million €)** | 0.00 | 7.74 | 5.03 | 3.81 | 3.10 | 2.63 | 2.29 | 2.04 | 1.84 | 1.67 | 1.54 |
| | | | | | | | | | | | |
| F&D(1) | 0.00 | 0.81 | 0.52 | 0.40 | 0.32 | 0.27 | 0.24 | 0.21 | 0.19 | 0.17 | 0.16 |
| OE(2) | 0.00 | 1.28 | 0.83 | 0.63 | 0.51 | 0.43 | 0.38 | 0.34 | 0.30 | 0.28 | 0.25 |
| TC(3) | 0.00 | 0.18 | 0.12 | 0.09 | 0.07 | 0.06 | 0.05 | 0.05 | 0.04 | 0.04 | 0.04 |
| Royalties | 0.00 | 0.77 | 0.50 | 0.38 | 0.31 | 0.26 | 0.23 | 0.20 | 0.18 | 0.17 | 0.15 |
| Preparation of the site | 1.84 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Intangible drilling | 5.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tangible drilling | 0.00 | 0.20 | 0.35 | 0.28 | 0.22 | 0.18 | 0.14 | 0.13 | 0.13 | 0.13 | 0.13 |
| MARCS depreciation schedule | | 0.10 | 0.18 | 0.14 | 0.12 | 0.09 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| **Total Costs** | 7.69 | 3.24 | 2.33 | 1.78 | 1.44 | 1.21 | 1.04 | 0.93 | 0.85 | 0.79 | 0.73 |
| | | | | | | | | | | | |
| Earnings before income taxes | -7.69 | 4.50 | 2.70 | 2.03 | 1.66 | 1.41 | 1.25 | 1.11 | 0.99 | 0.89 | 0.81 |
| **Taxable income** | -7.69 | 4.50 | 2.70 | 2.03 | 1.66 | 1.41 | 1.25 | 1.11 | 0.99 | 0.89 | 0.81 |
| | | | | | | | | | | | |
| Taxes (30%) | 0.00 | 1.33 | 0.80 | 0.60 | 0.49 | 0.42 | 0.37 | 0.33 | 0.29 | 0.26 | 0.24 |
| **Net income** | -7.69 | 3.17 | 1.90 | 1.43 | 1.17 | 1.00 | 0.88 | 0.78 | 0.69 | 0.63 | 0.57 |
| | | | | | | | | | | | |
| Depreciation | 0.00 | 0.20 | 0.35 | 0.28 | 0.22 | 0.18 | 0.14 | 0.13 | 0.13 | 0.13 | 0.13 |
| Capital expenditure | -1.89 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Free cash flow** | -9.57 | 3.37 | 2.25 | 1.71 | 1.39 | 1.18 | 1.02 | 0.91 | 0.82 | 0.75 | 0.70 |
| Discounted (IRR 10%) | -9.57 | 3.03 | 1.82 | 1.25 | 0.91 | 0.69 | 0.54 | 0.43 | 0.35 | 0.29 | 0.24 |
| **Total** | **0.00** | | | | | | | | | | |

**Table 28** Parameters used in the cash flow analysis

| Tax Rate | IRR | F&D(1) (€/Mcf) | OE(2) (€/Mcf) | TC(3) (€/Mcf) | Royaltee (%) | Leasehold (€) | Permitting fee (€) | Preparation (€) | Well Cost (€) | Share of intangibles |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.30 | 0.10 | 0.92 | 1.46 | 0.21 | 0.10 | 25000 | 2500 | 1810000 | 7800000 | 0.75 |

(1) F&D – Finding and Development costs

(2) LOE – Operating expenses

(3) TC – Transportation Costs

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