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The impact of shale gas on the costs of climate policy

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The impact of shale gas on the costs of climate policy

by

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Kurzbeschreibung

Dieser Bericht untersucht die Effekte einer weltweit gesteigerten Förderung von Schiefergas-Reserven und die Auswirkungen einer erhöhten Verfügbarkeit von Schiefergas auf die Treibhausgasreduktionsziele und -kosten. Zu diesem Zweck werden ein Szenario mit globaler Schiefergasförderung und ein Szenario mit sehr eingeschränkter Förderung verglichen, die auf regional differenzierten Berechnungen mit dem Energiesystemmodell POLES beruhen. Weiterhin werden zwei Politikfälle unterstellt: ein Basisfall ohne zusätzliche Klimapolitik und ein Minderungsfall, bei dem das 2°C-Ziel erreicht wird. Die Analyse deutet nicht darauf hin, dass Schiefergas per se eine günstige Option zur Reduktion der globalen THG Emissionen durch Verlagerung auf Erdgas darstellt, da die Effekte globaler Verfügbarkeit von Schiefergas (a) kurzfristig klein sind, (b) langfristig aufgrund der niedrigeren Energiepreise zu höheren THG-Emissionen im Basisfall führen und (c) dadurch höhere Kosten zur Einhaltung von Klimazielen zur Folge haben. Im Gegenteil: Schiefergas konkurriert kurzfristig mit Erneuerbaren-Technologien, wodurch deren Kosten nicht in entsprechendem Maße absinken als ohne Schiefergasnutzung. Außerdem führen die niedrigen Energieträgerpreise dazu, dass Energieeffizienzmaßnahmen weniger rentabel sind und daher weniger in solche Maßnahmen investiert wird.

Abstract

This report investigates the effects of an increased exploitation of shale gas reserves around the globe and the extent to which it can serve as a low-cost GHG mitigation option. We compare a scenario of global shale gas exploitation with a scenario in which shale gas use is very limited. Both scenarios are modelled with the global techno-economic POLES model and rely on a high regional disaggregation. The effects of shale gas production on the energy market and, consequently, on GHG emissions are analysed in a baseline case without additional climate policy and for mitigation targets compatible with the 2°C target. We find that shale gas should not be considered a cheap option to reduce global GHG emissions due to three reasons: the effects of global shale gas availability (a) are small in the short-term, (b) lead to higher baseline GHG emissions for most countries in the long-term due to lower energy prices and (c) result in higher costs of compliance with climate targets. Further, shale gas competes with renewable energy sources resulting in smaller cost reductions for renewable energy technologies. Lower energy prices also reduce the payoffs for energy efficiency measures, leading to shortened investment in such measures.

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boe	barrel oil equivalent
Btu	British thermal unit
CGE	computable general equilibrium
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
C&C	Contraction & Convergence
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LNG	Liquefied Natural Gas
POLES	Prospective Outlook on Long-term Energy Systems
Ppm	Parts per million
tcm	trillion cubic meters
tCO_2e	tons carbon dioxide equivalent
toe	tons oil equivalent
UBA	Umweltbundesamt (German Federal Environmental Agency)
UK	United Kingdom of Great Britain and Northern Ireland
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America

Zusammenfassung

In den letzten Jahren stieg in der USA die Produktion von Erdgas aus Schieferformationen deutlich an. Dies führte einerseits dazu, dass die USA inzwischen auf Erdgasimporte verzichten kann, andererseits zu einer Zunahme des Anteils von Erdgas in der US-Stromerzeugung von 20 auf 30% zwischen 2006 und 2012. Da bei Erdgas weniger CO2 pro Stromeinheit freigesetzt wird als bei Kohle und Öl sanken die Treibhausgas-(THG-)Emissionen in diesem Zeitraum um 9%. Dies führte zu Überlegungen, dass der Welt ein „goldenes Gas-Zeitalter" bevorsteht (IEA, 2011) und dass Erdgas die Brücke zu einer kohlenstoffarmen Wirtschaft schlagen könnte (Moniz et al, 2011). Dieser Bericht untersucht die Effekte einer weltweit gesteigerten Förderung von Schiefergas-Reserven und die Auswirkungen einer erhöhten Verfügbarkeit von Schiefergas auf die Treibhausgasreduktionsziele und -kosten. Unsere Analyse basiert auf Rechnungen mit dem POLES Modell, einem globalen Energiesystemmodell mit hoher regionaler Auflösung, was eine länderspezifische Analyse der Effekte von Schiefergas erlaubt. Zu diesem Zweck werden ein Szenario mit globaler Schiefergasförderung und ein Szenario mit sehr eingeschränkter Förderung miteinander verglichen. Weiterhin werden zwei Politikfälle unterstellt: ein Basisfall ohne zusätzliche Klimapolitik und ein Minderungsfall, bei dem das 2°C-Ziel erreicht wird.

In beiden Szenarien werden bis 2030 nur geringe Mengen Schiefergas außerhalb der USA produziert. In dem Szenario mit erhöhter Verfügbarkeit von Schiefergas wächst die Schiefergasproduktion bis 2050 und macht zu diesem Zeitpunkt 18,5% der globalen Erdgasproduktion aus. Die globale Verfügbarkeit von Schiefergas verursacht verschiedene Effekte. Zum einen sorgt der direkte Einsatz von Schiefergas als Ersatz für Kohle und Öl für einen Rückgang der THG-Emissionen. Andererseits führt das zusätzliche Erdgas zu einem Absinken der Preise für fossile Brennstoffe insgesamt. Dies verursacht eine Verdrängung von kohlenstoffarmen Technologien und einen Anstieg des Energieverbrauchs. Diese Effekte verursachen einen Netto-Anstieg der globalen THG- Emissionen um 0,8% im Basisfall. Dieser Effekt variiert auf Länderebene zwischen einem 3%igen Anstieg und einem minimalem Rückgang der THG-Emissionen. Jedoch zeigen die betrachteten Szenarien in keinem Land einen substantiellen Rückgang der THG-Emissionen wenn Schiefergas weltweit verfügbar ist.

Bei den Minderungskosten führt die Verfügbarkeit von Schiefergas in den meisten Ländern zu einem leichten Absinken der Minderungskosten pro Tonne CO2-Äquivalente (CO2e). Dieser Minderungskosteneffekt wird jedoch überlagert vom Anstieg der THG-Emissionen im Basisfall, der zu einem Anstieg der benötigten THG-Reduktionen führt.

Mittelfristig entstehen bis 2030 ähnliche Effekte, aber in viel geringerem Ausmaß. Bis 2030 werden immer noch drei Viertel des globalen Schiefergas in der USA gefördert. Die globale Erdgasproduktion unterscheidet sich nur um 2% zwischen beiden Szenarien. Die Auswirkungen auf THG-Emissionen und die Kosten von Klimapolitik sind dementsprechend gering.

Diese Analyse deutet nicht darauf hin, dass Schiefergas per se eine günstige Option zur Reduktion der globalen THG Emissionen durch die Umstellung auf Erdgas darstellt, da die Effekte globaler Verfügbarkeit von Schiefergas (a) kurzfristig klein sind, (b) langfristig aufgrund der niedrigeren Energiepreise zu höheren THG-Emissionen im Basisfall führen und (c) dadurch höhere Kosten der Einhaltung von Klimazielen zur Folge haben. Weiterhin konkurriert Schiefergas kurzfristig mit Erneuerbaren-Technologien, wodurch die Kosten für Erneuerbare Energien nicht in entsprechendem Maße absinken wie ohne Schiefergasnutzung. Außerdem lassen die niedrigen Energieträgerpreise Energieeffizienzmaßnahmen weniger rentabel werden und verzögern damit Investitionen in solche Maßnahmen. Diese Analyse berücksichtigt weder die Umweltauswirkungen noch die zusätzlichen Methanemissionen bei der Förderung von Schiefergas und zeichnet daher ein eher positives Bild.

Summary

In recent years, the USA have experienced a significant boom in production of natural gas from shale formations. This has caused a surge in the share of natural gas in US electricity generation from 20 to 30% between 2006 and 2012. As natural gas produces less CO2 per unit of electricity than oil and coal, greenhouse gas (GHG) emissions decreased by 9% over that time frame. This has led to suggestions that the world economy might be entering a “Golden Age of Gas” (IEA, 2011) and that natural gas could serve as a “bridge fuel” to a future low-carbon economy (Moniz et al., 2011). This report investigates the effects of an increased exploitation of shale gas reserves around the globe and extent to which it can serve as a low-cost GHG mitigation option. We compare a scenario of global shale gas exploitation (Global Shale Gas) with a scenario in which shale gas use is very limited (US only). Both scenarios are modelled with the global techno-economic POLES model and rely on a high regional disaggregation. The effects of shale gas production on the energy market and, consequently, on GHG emissions are analysed in a baseline case without additional climate policy and for mitigation targets compatible with the 2°C target.

The analysis shows that the amount of non-US shale gas production is small until 2030. Production grows until 2050, when it accounts for 18.5% of global natural gas production in the Global Shale Gas case. The availability of global shale gas causes multiple effects. On the one hand, the use of natural gas as a replacement for coal and oil lowers GHG emissions and presents a cheap mitigation option. On the other hand, the additional natural gas lowers prices for all fossil fuels, causing replacement of low-carbon technologies and an overall increase in energy consumption. Globally, these effects lead to a net-increase in GHG emissions of 0.8% in the baseline case. The effect varies between a 3% increase in some countries and a small decrease in others. No country experiences a substantial decline in GHG emissions when shale gas is available globally.

On the costs of compliance with climate targets, the results indicate that the costs of reducing one tone of CO2-equivalent (CO2e) are smaller in the Global Shale Gas case for most countries. However, this mitigation cost effect is offset by the increase in baseline GHG emissions, which leads to an increase in the GHG reductions needed to meet a specific climate target.

In the short-to-medium-term up to 2030, similar effects apply, but on a smaller scale. The USA still account for three quarters of global shale gas production and the difference in global production of natural gas is less than 2%. Consequently, the difference in baseline GHG emissions and in the costs of climate policy is modest.

Our analysis indicates that shale gas should not be considered a cheap option to reduce global GHG emissions due to three reasons: the effects of global shale gas availability (a) are small in the short-term, (b) lead to higher baseline GHG emissions for most countries in the long-term due to lower energy prices and (c) result in higher costs of compliance with climate targets. Further, shale gas competes with renewable energy sources resulting in reduced cost reductions for renewable energies and reduces the payoffs for energy efficiency measures. This analysis does not take into account the environmental impacts or the additional methane emissions during the extraction process of shale gas. Taking those into account might further strengthen that picture.

1 Introduction

Natural gas production in the USA has risen by almost one third since 2006, after a decade of relatively stable production, as the result of a boom in gas production from shale formations (US EIA, 2013a). Extraction of shale gas was made possible by hydraulic fracturing, so-called fracking, a process which creates cracks and fissures in rock formations by pumping a high pressure fluid – commonly a mixture of water, sand and chemical additives - into the formation, thus releasing the gas. As a consequence of the sharp increase in gas production, US gas exports have more than doubled since 2006 (US EIA, 2014a). Due to the fast build up of capacities, a partial ban on natural gas exports[1] and limited exporting capacities[2], the high supply persists on the domestic US gas market, and led to a halving of US gas prices since 2008. The absence of a global gas market also means that US gas prices are currently considerably lower than in other regions. These low energy prices benefit economic development and put energy- and export-intensive US-based companies at a competitive advantage, resulting in increased industrial production and economic growth (Jacoby et al., 2012, Arora & Lieskovsky, 2014). However, the scale of this advantage is not clear and some authors suggest it might be negligible (Rehbock & Kolbe, 2013, Spencer et al., 2014). Mathis et al. (2014) find that the impact of shale gas on economic growth in the European Union is likely to be small. Also, fracking is feared to harm the environment, by contaminating surface- and groundwater with chemicals and radioactive elements (see PSE, 2014, for an overview), by contribution to local air pollution via gas leakages from wells (Pétron et al., 2012, Litovitz et al., 2013), by consumption of water[3], and by provoking small earthquakes. Re-injection of wastewater for disposal may also induce stronger earthquakes (Hayes, 2012, Ellsworth, 2013).

Estimates of the International Energy Agency (IEA) suggest that the USA and Canada account for about a quarter of global shale gas reserves (55 tcm). The shale gas boom in the USA led the IEA to calculate a scenario of global shale gas development in which other countries replicate the US experience, simulating a “Golden Age of Gas”. It suggests that conditions of the natural gas market “increasingly point to a future in which natural gas plays a greater role in the global energy mix”. In the IEA “Golden Age of Gas” scenario, natural gas reaches a share of 25% of the global energy mix in 2035 (IEA, 2011).

Despite the IEA’s prediction of a golden age of gas, the future of shale gas looks to be quite fragmented between countries due to the environmental concerns and the lack of a regulatory framework. Outside of Europe, most countries with significant resources, in particular Argentina, China and Mexico, are going ahead with plans for shale gas extraction (Hashimoto et al., 2013). However, in Europe the situation is more diverse. Poland, France and Romania are believed to have the highest shale gas reserves in the EU (US EIA, 2013b). While Poland and the UK are developing their first exploratory wells, Bulgaria, Czech Republic, France and Luxemburg have banned shale gas extraction via fracking (Economist, 2013). The Netherlands and Germany are currently in the process of introducing new rules. The proposed rules in Germany prohibit hydraulic fracturing above a depth of

[1] Exports of Liquefied Natural Gas (LNG) to a country that does not have a free-trade agreement with the USA need to be approved by the U.S. Department of Energy. Only a few projects have been approved and a considerable amount of applications are currently pending (Rascoe, 2014).

[2] Overseas exporting of LNG by ship requires special terminals. The USA, a former importer of natural gas, face a capacity problem and need to build additional export terminals in order to further expand its gas exports (Pearson et al, 2012, Johnson & Lefebvre, 2013).

[3] While shale gas production uses less water than the production of other fuels like coal, oil or biomass (Mielke et al., 2010, Spang et al., 2014), the consumption of water in the hydraulic fracturing process might be a concern in small and arid regions (Nicot & Scanlon, 2012).

3000 meters and in water protection areas. The legislator will review the appropriateness of this ban in 2021 (BMUB, 2014).

According to the Intergovernmental Panel on Climate Change (IPCC, 2014), global mean surface temperature in 2100 will be between 3.7°C and 4.8°C higher than the pre-industrial level, if no additional mitigation action is taken. In order to have a likely chance to limit the temperature increase to 2°C, GHG emissions in 2050 need to be reduced by 41% to 72%, compared to 2010 levels. The international process under the United Nations Framework Convention on Climate Change (UNFCCC) has formally acknowledged the 2°C target at the Conference of the Parties (COP) in Copenhagen (UNFCCC, 2009) and set itself the goal to enact an international agreement on GHG mitigation at the 2015 COP in Paris. The new agreement is scheduled to enter into force after 2020.

Direct greenhouse gas emissions (GHGs) are substantially lower when electricity is generated from natural gas rather than coal or oil. Electricity generation from natural gas emits around 400 gCO_2/kWh, which is roughly half as high as coal (785-1005 gCO_2/kWh, depending on product) and 40% lower than oil (670 gCO_2/kWh) (IEA, 2013).Consequentially, one might assume that a global surge in natural gas production might contribute to GHG reduction efforts, just as the natural gas production in the US may have contributed a large part of the decline in US GHG emissions since 2007 (Broderick & Anderson, 2012, Dröge & Westphal, 2013, Newell & Raimi, 2014). However, the extraction process of shale gas produces more GHG emissions than conventional gas due to higher energy consumption and higher gas leakage during drilling and the development of the wells (e.g. Jiang et al, 2011, Weber & Clavin, 2012). The scale of this phenomenon is still the subject of intense debate (see Box 2).

Only few studies so far have calculated the impact of shale gas on the cost of meeting climate targets. For the USA, Jacoby et al. (2012) use a computable general equilibrium (CGE) model and find that the cost of meeting a given 2050 emission target is about 10% higher if shale gas is available, as shale gas causes higher baseline emissions by partly replacing low-carbon energy technologies and increasing total energy consumption. Brown & Krupnick (2010) use a different CGE model and simulate GHG reduction scenarios up to 2030. They find that policy implementation is less costly with greater natural gas resources. On the global scale, a study by Levi (2013) uses three different energy-economy models and suggests that natural gas is of limited use for climate targets that stabilize atmospheric CO_2 concentrations near 450 ppm, but can play a larger role if the target is stabilization near 550 ppm. To the best of our knowledge, so far no studies exist that have estimated the impact of shale gas on climate targets for individual, non-US countries.

The aim of this study is to analyse the impact of global shale gas production on GHG emissions and mitigation costs, and the impact of GHG regulation on shale gas production. We employ a global partial equilibrium model to implement and compare baseline emissions and mitigation costs for two scenarios. In the *US only* scenario shale gas production is banned in all countries except the USA. In the *Global Shale Gas* scenario no such restrictions exist in any country. Consequently, in the *Global Shale Gas* scenario a country starts to exploit shale gas reserves when it is financially attractive to do so. To analyze the impacts of shale gas on mitigation costs, we first analyze the impacts of increased shale gas exploitation on baseline emissions. We further implement two mitigation cases, one for the mid-term, and one for the long-term perspective. For all scenarios we analyse the effects of international emissions trading on mitigation costs. The analysis focuses on two years, 2050 to determine long-term effects and 2030 to also analyze mid-term effects. Results are provided for individual countries.

The remainder of this report is structured as follows. Section 2 briefly reviews the literature on the impacts of shale gas availability on GHG emissions. The methodology and scenarios are described in

Section 3. In Sections 4and 5 we provide the analyses on baseline emissions and mitigation costs in the mitigation scenarios. Section 6 concludes.

2 Literature review

Direct greenhouse gas emissions (GHG) are substantially lower when electricity is generated from natural gas rather than coal or oil. Therefore, if gas replaces coal or oil in electricity generation, fewer GHGs are emitted for producing the same amount of electricity. This fuel substitution is generally considered to be the main driver for the observed decline in US GHG emissions by 11% since 2007 (see e.g. Broderick & Anderson (2012), Dröge & Westphal (2013), Newell & Raimi (2014)). However, the emergence of shale gas also causes other effects, which complicate assessing the net effect of shale gas availability on global GHG emissions.

One such dynamic concerns the overall supply of energy. The increased supply of gas lowers energy prices and therefore increases energy consumption, causing a rise in GHG emissions, ceteris paribus (Jacoby et al. 2012, EMF, 2013, Newell & Raimi, 2014).

Another important factor is the impact of shale gas on other types of energy production. If gas prices are low, shale gas not only replaces coal and oil, but also low- and no-carbon intensive energy production technologies such as renewable energy technologies (Bolinger, 2013) and nuclear power stations (Davis, 2012). Additionally, the incentive to develop new low-carbon technologies, like carbon capture & storage and innovative renewable energy technologies, is reduced. Schrag (2012) and Jacoby et al. (2012) argue that this competition between natural gas and low-carbon technologies will determine the long-term impact of shale gas on GHG emissions.

The environmental side effects of shale gas development can also cause a further increase in GHG emissions. Hou et al. (2012) argue that, if shale gas development leads to groundwater contamination, this groundwater needs to be treated before it is again suitable for use. The treatment process uses additional energy, which increases GHG emissions. The effect might be reinforced in the future, when groundwater extraction from deeper aquifers is needed due to climate change.

Furthermore, the recent US shale gas boom also affected GHG emissions in other countries. In the period 2008-2012, the US more than doubled its net coal exports (from 47 to 117 million short tons, US EIA website), as natural gas replaced coal in US electricity production. Broderick & Anderson (2012) therefore argue that the US only "exported" its emissions, and that the increased availability of another fossil fuel (shale gas) would lead to an overall increase of global emissions. However, this conclusion is controversial: Newell & Raimi (2014) find that, parallel to increased coal exports, US coal production fell by an even bigger amount (155 million short tons) and US exports primarily displaced exports from other regions. Therefore, they argue that global coal prices, coal consumption and GHG emissions were not substantially affected by the increased US exports. Also, exporting coal to regions where a substantial part of the CO_2 emissions are capped by an emissions trading scheme (e.g. the EU), cannot have large quantitative effects.

It is not clear whether the sum of these effects leads to an increase or a decrease in GHG emissions. For the USA, Newell & Raimi (2014) suggest that, to a large degree, the calculated GHG effect of an increased availability of shale gas depends on modelling assumptions and that the overall effect on US emissions is likely to be small, because of opposing effects such as an increase in baseline GHG emissions due to lower energy prices and the decreasing effect on GHG emissions in the power sector when replacing one kWh electricity from coal or oil by one kWh electricity from natural gas (see Section 4 for a detailed description of the effects in play). The analysis by IEA (2011) suggests a small decline in global GHG emissions if shale gas is developed globally. McJeon et al. (2014) simulate a global shale gas boom with five integrated assessment models and find that the impact on CO_2 emissions is small, with a majority of models projecting a small increase in climate forcing.

3 Methodology and scenario definition

In this report, we compare two scenarios.[4] In the *US only* scenario shale gas production is banned in all countries except the USA, while in the *Global Shale Gas* scenario there are no such restrictions in any country. In order to represent the uncertainty about shale gas reserves, the *Global Shale Gas* scenario also uses more optimistic assumptions about available reserves than the *US only* scenario. Specifically, the *Global Shale Gas* scenario uses data on Technically Recoverable Resources (TRR) from (US EIA, 2013b), while the *US only* scenario uses less optimistic TRR data from (BGR 2012). For the USA, this leads to a 140% difference in reserves. Overall, the *Global Shale Gas* scenario paints a much more optimistic view on the availability and the future use of shale gas than the *US only* scenario.

For each scenario we calculate a baseline, including current and already planned GHG reduction measures, as of 2013, but no further future emission reduction policies, and marginal abatement cost curves, which are used to determine the costs of emission reductions. We start with a comparison of the baselines of both scenarios in Section 4. For this purpose, we refer to the baseline of each scenario as *US only* baseline and *Global Shale Gas* baseline, respectively.

In Section 5, GHG reduction targets are introduced. These sets of targets will be referred to as *mitigation cases*. For each *mitigation case*, we again compare the *US only* scenario to the *Global Shale Gas* scenario to determine the impact of shale gas.

For the purposes of this report, all gas sources except shale gas are referred to as conventional gas. Most notably, this includes tight gas. Coalbed methane is not included in the modelling.

For the baseline and policy simulations we employ POLES, which is a world simulation model for the energy sector. POLES is a techno-economic model with endogenous projection of energy prices, a complete accounting of demand and supply of energy carriers and associated technologies. The model includes, among others, 30 different power generation technologies for 57 different countries/regions, and accounts for CO_2 and other GHG emissions. This high level of regional disaggregation allows to a very large extent for a country-specific modeling of technology availability.

Macroeconomic assumptions do not differ between the baselines: world population is expected to rise to 9.5 billion in 2050, while global GDP growth is expected to average 4.2% per year until 2050. Politically, no GHG reduction targets for any country are implemented in the baselines. However, current measures and support schemes are incorporated. For the EU, this includes the 20%-by-2020 targets on renewable energy sources and energy efficiency. As a result, the EU also reaches the 20% GHG reduction target, although it is not specifically implemented in the baselines via a carbon price. After 2020, the support schemes needed to reach the renewable energy and energy efficiency targets are progressively removed. Nuclear power development is modeled based on a cost competition with other energy sources, but political choices like the phase-out decision in Germany are recognized. Carbon Capture and Storage (CCS) is assumed to be available from 2025 on only.

Since the focus of this study lies on GHG emissions, we do not consider the direct environmental impacts of hydraulic fracturing, like groundwater contamination, earthquakes and water use. Similarly, we do not consider fugitive GHG emissions during shale gas extraction. We make this assumption,

[4] The methodology employed is similar to Duscha et al. (2014) who study the effects of a global nuclear phase out on GHG emissions and mitigation costs.

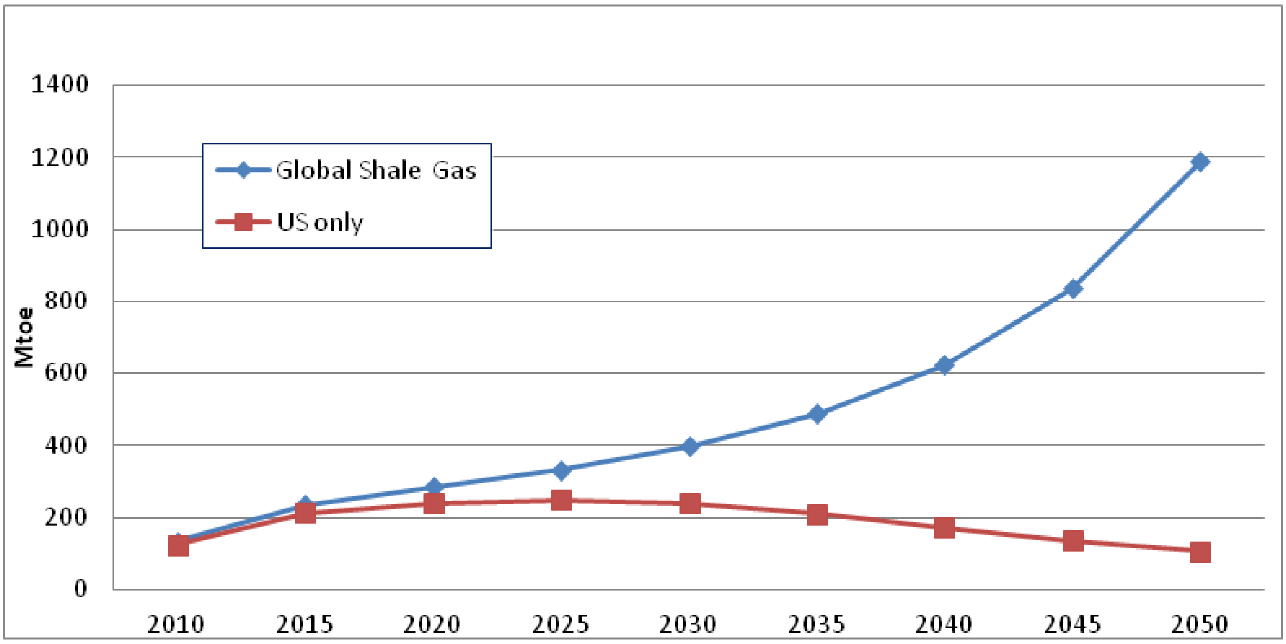
because there is no consensus on the direct GHG emissions of shale gas extraction, and the latest papers (Skone et al., 2011, Weber & Clavin, 2012) point to only a slight difference in the GHG emissions of conventional gas, LNG and shale gas, when so-called green completions are used. Our analysis does consider the difference in energy inputs into shale gas and conventional gas production, and the resulting GHG effects. Therefore, the results of our study will be more favourable to shale gas than if environmental impacts and fugitive emissions were taken into account. Figures on fugitive emission estimates as well as the impacts of the fugitive emissions from shale gas exploration are shortly discussed in Box 2. Our analysis focuses on the big economies and on countries with large shale gas reserves: Argentina, Australia, Brazil, Canada, China, EU, India, Japan, Mexico, Russia, USA. All remaining countries are aggregated in "Rest of the World". The impacts of shale gas on individual EU countries are briefly discussed separately in Box 3.

4 Development of shale gas and GHG emissions in the baselines

In the *US only* baseline, global primary production of energy rises from 13.0 Gtoe in 2012 to 22.7 Gtoe in 2050, which represents a 1.5% annual increase. Fossil fuels remain the dominant energy source with a share of 72.1% in 2050, down from 82.1% in 2012. However, gas (share of 25.7% in 2050, up from 21.7% in 2012) replaces oil (share of 22% in 2050, down from 32.7% in 2012) as the biggest single source of energy. The share of coal also decreases, while nuclear power and renewable energy sources (including hydro power and biomass) increase their share. Taken together, renewable energy sources produce 21.7% of all energy in 2050, with wind and solar accounting for 5.2 percentage points.

In 2050, electricity generation uses almost half (49.1%) of all natural gas. This is up slightly from a share of 46.5% in 2012. Large amounts of natural gas are also used in the residential and services sectors (mainly heating and cooling) and for industrial applications. Globally, 25% of natural gas is used by the residential and services sectors in 2050. This share varies between 9% (Mexico) and 38% (Canada), with countries in warmer climate zones using less gas for residential purposes. In developing countries, natural gas use in the residential and services sectors grows faster than total gas use, while in developed countries the relevance of these sectors declines or stays constant over time.In the USA, the share of shale gas in total gas production rises from 33.7% in 2012 to a peak of 44.0% in 2025. Afterwards, shale gas production declines to a share of 39.4% in 2030 and only 15.0% in 2050.

Figure 1: Development of global shale gas production in *US only* and *Global Shale Gas* baselines.

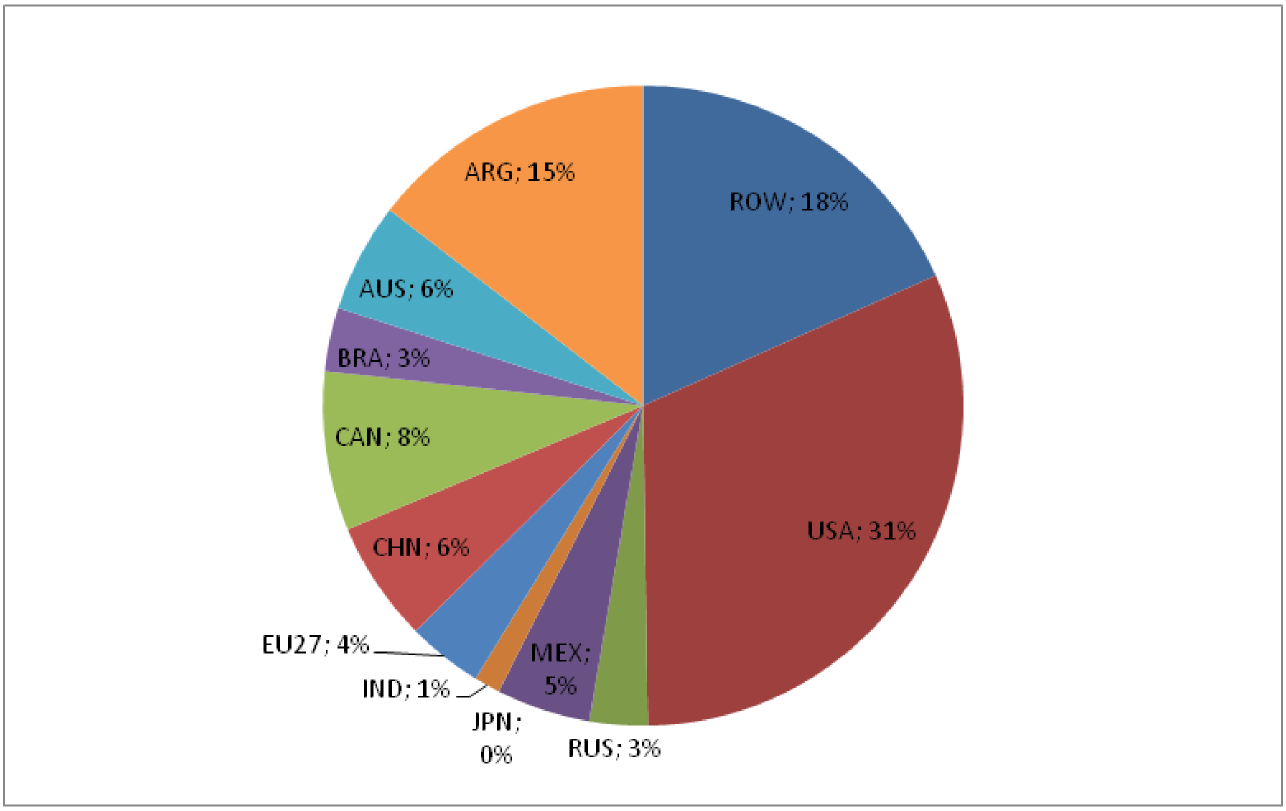


In the *Global Shale Gas* baseline, global primary production of energy in 2050 is 322 Mtoe (1.4%) higher compared to the *US only* baseline. Shale gas production is 1083 Mtoe, or 10 times, higher, when compared to the *US only* baseline. However, even with this increase, the global share of shale gas in total gas production only stands at 18.5%. In addition, the increase in shale gas production is partially offset by a decrease in conventional gas production of 494 Mtoe (8.6% of conventional gas production in the *US only* baseline). As a result, in 2050 gas accounts for 27.9% of total energy production in the *Global Shale Gas* baseline, which is only up slightly by 2.2 percentage points from the 25.7% share in the *US only* baseline. The increased supply of gas causes a decrease in the production of all other energy sources. Wind and solar are most affected and together lose 3.1% of production (37 Mtoe, representing 0.25 percentage points of total production). Coal is also heavily affected and loses 2.6% of production (145 Mtoe). The impact on other renewable energy sources (-1.1%; 42 Mtoe) and nuclear power (-1.3%; 18 Mtoe) is smaller, while the effect on oil production (-0.5%; 26 Mtoe) is limited. Overall, the share of fossil fuels in energy production increases to 73.9% in the *Global Shale Gas* baseline, from 72.1% in the *US only* baseline.

Shale gas production in our *Global Shale Gas* baseline falls in line with projected production in other studies. The World Energy Outlook (WEO) by the International Energy Agency (IEA, 2014) projects global shale gas production of 859 Mtoe in 2040, the last year considered in the WEO. This is 235 Mtoe or 38% higher than our projection. However, shale gas production growth from 2035 to 2040 is slower in the WEO than in our scenario, such that production in 2050 would appear to align.

For the USA, the *US only* baseline projects lower shale gas production than the Annual Energy Outlook by the US Energy Information Administration (US EIA, 2014b). US shale gas production in our *Global Shale Gas* baseline falls between the Reference case and the “Low Oil and Gas Resource” case of the EIA Outlook.

Figure 2: Geographical distribution of global shale gas production in 2050 in the *Global Shale Gas* baseline.



Shale gas production varies greatly between countries, as Figure 2 shows. The biggest producers of shale gas in the *Global Shale Gas* baseline in 2050 are the USA , Argentina and Canada, followed by China, Australia and Mexico. In all of these countries, except China, shale gas represents 10% or more of total energy production. For China, the high total production in absolute terms pushes this share to only 1.5%, even though China produces the fourth-highest amount of shale gas in the world. Mexico has the highest share of shale gas in total production at 24%. Of the other countries considered in this report, Brazil has the highest share of shale gas production at 7%.

Figure 3: Changes in production of different fuel types as share of total primary production of energy (*Global Shale Gas* baseline versus *US only* baseline) in 2050

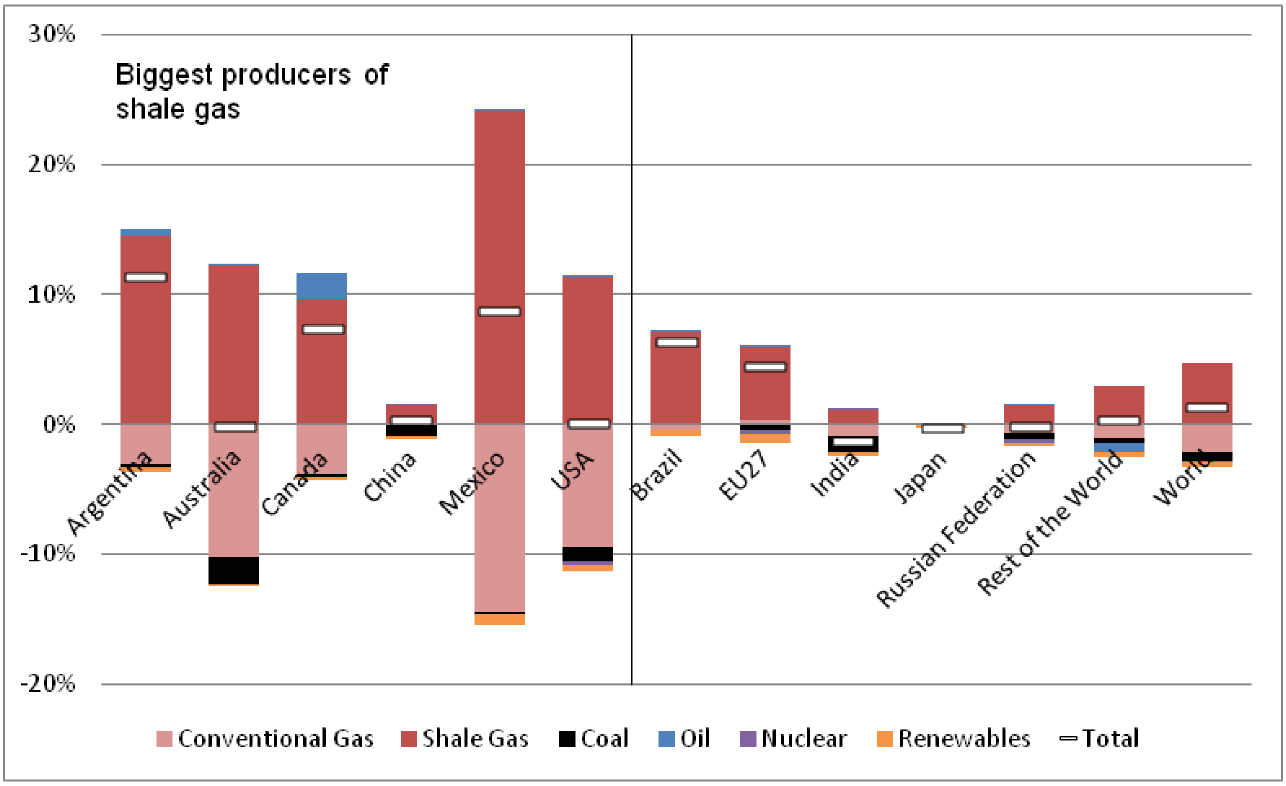


Figure 3 shows the differences in primary production of energy caused by shale gas availability. As the figure compares the *Global Shale Gas* baseline to the *US only* baseline, both in 2050, it shows the effect of shale gas on energy production, undistorted by changes in gas production over time. The differences are shown relative to the total energy production of each country, in order to be able to compare countries of varying sizes. The biggest changes can be seen in Mexico, where shale gas composes 24.1% of total production in the *Global Shale Gas* baseline. This additional gas is only partially offset by the accompanying decrease in conventional gas production, leaving a net increase in total gas production of 8.7%. Similar effects can be seen in Canada, which also increases unconventional oil production. Unconventional oil benefits from lower energy prices (see below), as the cost of the energy input into oil production decreases. The situation in Australia and the USA is somewhat different, as in these countries the additional shale gas production is fully offset by a decrease in other production (mainly conventional gas), leaving total production essentially unchanged. In contrast, in Argentina only relatively little conventional gas is replaced by shale gas. This leaves Argentina with the biggest increase in total production of all countries at 135 Mtoe or 11.3%. Similar changes can be seen in Brazil and the EU, where only little conventional gas is produced and therefore not much production can be crowded out by shale gas. The changes in the remaining countries are small, relative to total production. In China, shale gas replaces coal and renewable energy and leads to a small increase in total production. In India and Russia, relatively big amounts of coal, conventional gas and renewable energy are replaced, which leads to a slight decrease of total production. Japan does not produce a significant amount of fossil fuels in 2050 in both scenarios. Consequentially, its energy production is virtually unchanged by the availability of shale gas. A detailed picture of primary production of energy by fuel and country in 2012 and in both baselines can be seen in Figure A1 in the Annex.

While markets for oil are global markets, markets for coal and natural gas are modeled as regional markets, allowing for price differences between those markets. In all gas markets and both scenarios prices for natural gas increase significantly until 2050 by up to 50€/boe in the American Market and by 13-33€/boe in the European and African and Asian Markets (in real terms). The difference in price changes between the markets is a result of extraordinary low gas prices on the American Market in recent years. In 2005, before the US shale gas boom, prices on the American Market were actually higher than on the other markets. By 2011, prices plummeted to less than half of the other markets, such that natural gas prices were competitive to coal and substantially lower than oil. Both scenarios project gas prices in the different markets to converge, as new US export capacity becomes available. However, prices on the American Market remain lower than on the other markets, reflecting LNG transport cost[5]. Coal prices are projected to increase very little up to 2050, while oil prices increase by over 75%. Consequentially, in 2050 gas is cheaper than oil and more expensive than coal in both scenarios and on all markets.

When switching from the *US only* baseline to the *Global Shale Gas* baseline, as a consequence of the regional production amounts, the gas price on the American Market faces the biggest adjustment (-13.2%). The Asian Market experiences the second biggest effect (-12.3%), while the price on the European and African Market still is heavily affected (-11.0%). Due to the increased supply of fossil fuels, coal and oil prices also decline slightly.

Table 1: Fossil fuel prices for different markets, years and baselines (in EUR2013 / boe)

Year	Baseline	GAS European and African Market	GAS Asian Market	GAS American Market	COAL European and African Market	COAL Asian Market	COAL American Market	OIL
2005		32.19	28.35	37.27	14.31	12.76	8.91	46.10
2011		33.99	48.47	16.97	21.79	19.12	14.13	82.47
2030	US only	43.97	40.50	39.50	21.38	20.71	16.31	119.86
	Global Shale Gas	42.74	38.82	37.06	21.36	20.69	16.28	119.67
2050	US only	67.81	73.39	67.44	24.49	23.16	18.18	145.22
	Global Shale Gas	60.37	64.34	58.56	24.44	23.08	18.09	144.56

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As we have seen, the additional shale gas in the *Global Shale Gas* baseline causes various effects, which lead to differentiated impacts on GHG emissions:

- The additional supply of shale gas replaces coal and oil in electricity production. As gas releases fewer emissions per unit of electricity, this causes a decrease in GHG emissions ("fossil-fuel switch effect").

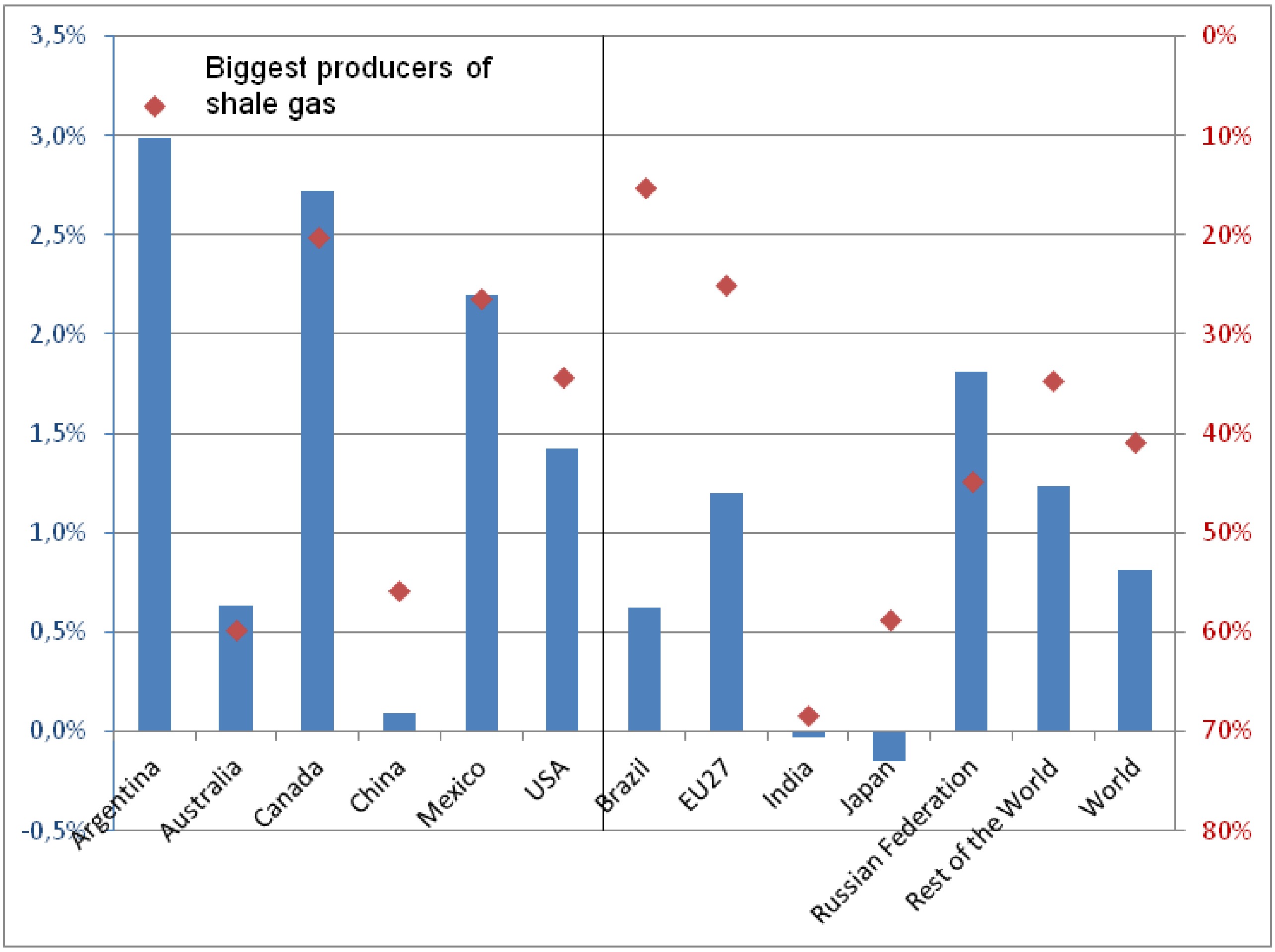
[5] In the model, gas transport cost from the US to Europe in 2030 is 11 EUR / boe.

- The additional supply of gas also replaces nuclear power and renewable energy sources. This leads to an increase in GHG emissions ("low-carbon fuel switch effect").
- Lower energy prices lead to a corresponding increase in demand, which also causes an increase in GHG emissions ("energy price effect").

The overall effect on GHG emissions in a country is determined by the country-specific size of the different effects, which is determined by country-specifics on shale gas availability and energy market characteristics. Since the "fossil-fuel switch effect" is the only effect with a downward impact on GHG emissions, it can provide a first estimate on whether a country's emissions in- or decrease as a result of an increased use of shale gas. The order of magnitude of the "fossil-fuel switch effect" can be estimated based on the amount of *fossil fuel replacement* in the power sector: the share of the additional gas in electricity production in the *Global Shale Gas* baseline that is used to replace coal or oil. If this indicator is high, i.e. large amounts of the additional gas are used to replace oil and coal in electricity production, we would expect the corresponding country to show a decrease (or at least only a limited increase) in GHG emissions, depending on the order of magnitude of the other two effects. If, in a country, the amount of fossil fuel replacement is already limited, it is unlikely that the use of shale gas will have an overall downward effect on that country's GHG emissions.

Figure 4 shows the difference in GHG emissions between the two baselines by country in 2050 (blue bars). The red diamonds display the corresponding fossil fuel replacement share, i.e. the share of additional gas in electricity production in the *Global Shale Gas* baseline which is used to replace coal or oil. To simplify reading the figure, the axis on the right-hand side (in red) corresponding to the fossil fuel replacement share is labeled in reverse order. That is, a high blue bar, indicating a high increase in country-wide GHG emissions, should correspond with a rather high red diamond, indicating low fossil-fuel replacement and hence a rather low downward effect on the country's GHG emissions.

Figure 4: Difference in country-wide GHG emissions between *Global Shale Gas* baseline and *US only* baseline (blue bars) and share of fossil fuel replacement[6] (red diamonds) in 2050.



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Compared to the *US only* baseline, global GHG emissions in the *Global Shale Gas* baseline in 2050 are higher, because the "fossil-fuel switch effect" is more than compensated for by the "low-carbon fuel switch effect" and the "energy price effect". The difference amounts to 582 $MtCO_2e$ or 0.8%. About 40% of the additional gas in electricity production is used to replace coal or oil. On a country level, Argentina, Canada and Mexico exhibit the biggest relative increases of GHG emissions with 3.0%, 2.7% and 2.2%, respectively. In all three countries shale gas makes up a significant portion of production in the *Global Shale Gas* baseline and total production of energy is increased by over 7% in the process. At the same time, the share of fossil fuel replacement in these countries is relatively small (10-30%), resulting in a large relative increase in GHG emissions. The biggest absolute increases can be observed in the USA (85 $MtCO_2e$), Russia (56 $MtCO_2e$) and the EU (51 $MtCO_2e$). The EU is a good example to show that global shale gas availability can lead to an increase of GHG emissions of big energy consumers. Due to lower energy prices energy demand increases, even if only a small amount of the gas in the *Global Shale Gas* baseline is produced in the countries themselves. The USA and Russia produce some additional shale gas in the *Global Shale Gas* baseline, however, the "fossil-fuel

[6] In the figure, the scale of the share of fossil fuel replacement is shown in reverse order, as a large increase in GHG emissions is associated with a low share of fossil fuel replacement, and vice versa.

switch effect" in the two countries is modest, as the shale gas production replaces conventional gas production in large parts. In addition, both countries face lower fossil fuel prices compared to the *US only* baseline and as a result increase their energy consumption. In all countries mentioned above, the effects leading to higher GHG emissions (replacement of low-carbon energy sources and increased energy consumption) dominate the "fossil-fuel switch effect".

In contrast, almost no change in GHG emissions can be observed in China, India and Japan . All of these countries use most of the additional gas in electricity production to replace coal and oil (China: 55.9%, India: 68.3%, Japan: 58.8%). Therefore, the saved GHG emissions offset the additional emissions resulting from increased energy consumption and the replacement of nuclear and renewable power.

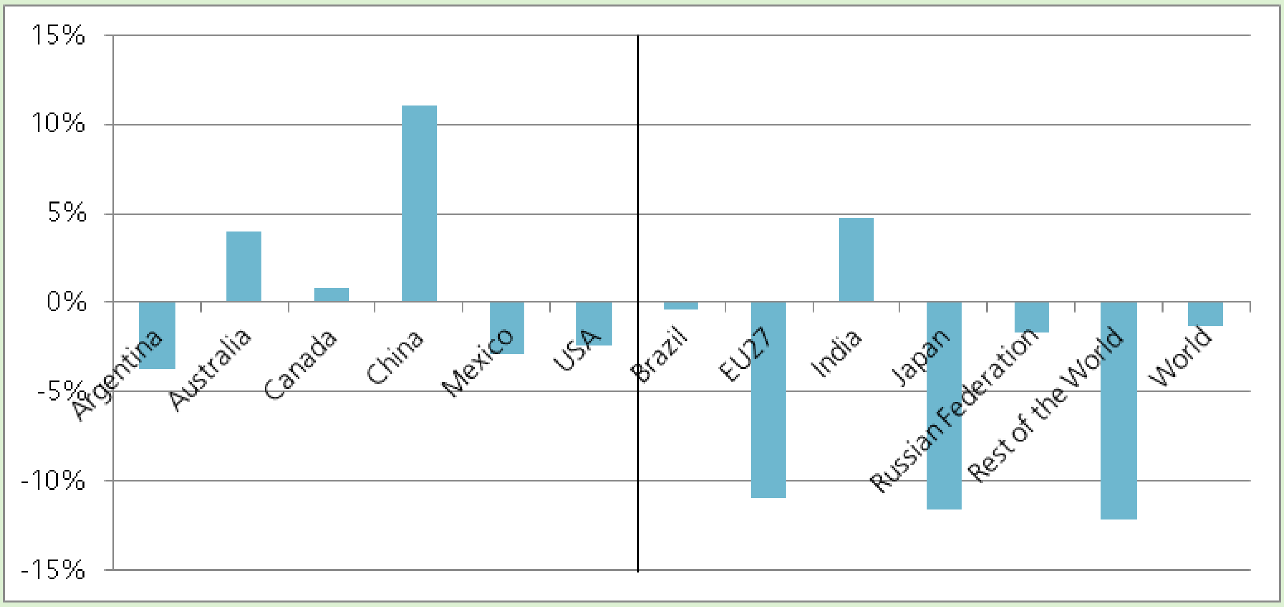
As Figure 1 indicates, the difference between the *Global Shale Gas* baseline and the *US only* baseline increases slowly over time. In 2030, the change in shale gas production is still relatively small. Due to the time needed to set up the new shale gas exploitation industry, production is concentrated in the countries where operations are already in use today. Therefore, the USA produce 75.8% of all shale gas in the *Global Shale Gas* baseline in 2030, while Canada comes in second with 12.5%. As the small global increase in shale gas production is still offset by a decrease in production of other energy sources, the variation of total production in 2030 is only 25 Mtoe or 0.1%. Accordingly, subsequent impacts are also relatively small: gas prices in 2030 are around 4% lower in the *Global Shale Gas* baseline than in the *US only* baseline and the difference in global GHG emissions is 60 $MtCO_2e$, less than 0.1%. Interestingly, Canada and the USA together only account for 31.5% of the increase in GHG emissions, while producing 70.7% of all additional shale gas. Other countries like Russia and Brazil, who produce almost no shale gas in 2030, nevertheless feel the effect of lower energy prices and therefore have a relatively high share in the global increase of GHG emissions. Changes in primary production and in GHG emissions between the two baselines in 2030 can be found in Figure A2 and Figure A3 in the Annex.

Box 1: The short-term impact of shale gas

For most countries, the short time period up to 2020 is not enough to set up a shale gas extraction industry. Therefore, in 2020 the difference between the *Global Shale Gas* baseline and the *US only* baseline is negligible, the lion's share of shale gas is still produced in the USA and global GHG emissions change less than 0.01%.

In order to get a feel for the short-term impact of shale gas, we compare the *Global Shale Gas* baseline with the *WEO2010* baseline. This older baseline is based on the "Current Policies" scenario from the World Energy Outlook 2010 (IEA 2010), which did not take into account the shale gas boom in the USA as our *Global Shale Gas* baseline does. As a result of the shale gas production boom, projected gas production in the USA in 2020 is 26% higher in the *Global Shale Gas* baseline, compared to the *WEO2010* baseline. This is despite the fact that the difference in projected global gas production between the two baselines is negligible (1%). Fossil fuel prices behave accordingly: Due to changes in the underlying scenario assumptions, projected gas prices on the European and African and Asian Markets are substantially higher (by 20% and 34%, respectively) in the *Global Shale Gas* baseline. However, the projected gas price on the North-American Market in 2020 is only slightly higher (3%) in the *Global Shale Gas* baseline, as a result of shale gas production. At the same time, , the price for coal in the *Global Shale Gas* baseline is higher on the European and African (40%) and American (23%) Markets, while it is lower on the Asian Market (-21%). The oil price on the global market is 38% higher in the *Global Shale Gas* baseline, compared to the *WEO2010* baseline.

Figure 5: Difference in GHG emissions between *Global Shale Gas* baseline and *WEO2010* baseline in 2020.



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As Figure 5 shows, projected GHG emissions in 2020 correspond well to the expected consumption changes triggered by fuel price differences. Prices on the European and African Market are higher for all fuel types, leading to lower GHG emissions in the EU in the *Global Shale Gas* baseline. On the North American Market, the gas price is stable and GHG emissions fall slightly in the USA and rise slightly in Canada. The rise of GHG emissions in Australia, China and India is explained by the lower coal price on the Asian Market. Japan uses little coal, compared to the other big Asian economies, and is therefore most affected by the higher gas price on the Asian Market, leading to lower GHG emissions. Taken together, these results show that changes in fuel prices can have significant effects on countries' energy demand and resulting GHG emissions even in the short-term.

Although the comparison is not focused on the impact of shale gas alone, it shows the changes in projected business-as-usual GHG emissions for 2020 for which shale gas production estimates and corresponding fuel price projections between 2010 and 2013 have been a major driver.

5 Mitigation cases

In order to analyze the interplay between shale gas development and GHG mitigation, this section introduces GHG reduction targets. At first, the impact of mitigation targets on the production of all energy sources, including shale gas, is examined. Secondly, the influence of shale gas on the energy market in a world with GHG reduction targets is explored. Furthermore, costs of compliance with the mitigation targets are calculated and compared between the US only scenario and the Global Shale Gas scenario.

5.1 Definition of two mitigation cases

GHG mitigation is modeled by the progressive introduction of a carbon price in the *US only* and in the *Global Shale Gas* baseline scenarios. Higher carbon prices influence the production of natural gas, but also other factors like energy production from different sources and energy efficiency measures. The set of carbon prices produces marginal abatement cost curves for each country or region. By comparing the sets of marginal abatement cost curves resulting from the *US only* scenario and the *Global Shale Gas* scenario, the influence of an increased supply of shale gas on domestic mitigation, emissions trading, compliance costs and the power sector can be explored.

We examine two mitigation cases, defined by emission reduction targets for a specific year. The long-term perspective is modeled in a mitigation case for the year 2050, while the medium-term perspective uses 2030 as its target year. While there are several different criteria to allocate emission reduction targets to countries our cases are based on the effort sharing approach "Contraction & Convergence" (C&C, e.g. Meyer, 2000). The approach works in two steps. In the first step, a global emissions path is defined, which provides the global emissions limit for the given year ("contraction"). We use a path with a "likely" chance to reach the 2°C-target, according to the UNEP Gap Report (UNEP, 2013). This path sets global emissions at 22 $GtCO_2e$ in 2050.

In a second step, the global emissions limit is allocated to individual countries. Each country's per capita emissions follow a linear path from current levels to a common level for all countries in the year 2050 ("convergence"). For the mitigation cases, convergence starts in 2014 and finishes in 2050. This means that emission reduction targets for 2050 are based on equal per capita emissions for all countries. The common per capita emission level, consistent with global emissions of 22 $GtCO_2e$, is calculated to be 2.48 tCO_2e. In 2030, each country's target per capita emission level lies between the current level and the common convergence level. Taken together, the 2030 targets result in global emissions of 36 $GtCO_2e$, which is consistent with the 2°C path in the UNEP Gap Report (UNEP, 2013). Our calculations of country targets are roughly in line with the most recent submission of the Global Commons Institute to the UNFCCC (GCI, 2012), the Carbon Budget Accounting Tool (CBAT, GCI undated) for calculations of the C&C approach and with the results of the UBA project "Minderungsverpflichtungen und faire Lastenteilung in einem neuen umfassenden Klimaschutzabkommen ab 2020" (FKZ 3713 41 102). Projections of population development were taken from the scenario for medium fertility of the UN World Population Prospects (UN, 2013).

Table 2: Target per capita emissions (in tCO_2e) for different countries in 2030 and 2050

	2030	2050
Argentina	5.48	2.48
Australia	14.10	2.48
Brazil	4.34	2.48
Canada	12.55	2.48
China	6.03	2.48
EU27	6.00	2.48
India	2.54	2.48
Japan	6.75	2.48
Mexico	3.85	2.48
Russian Federation	10.18	2.48
USA	12.35	2.48
Rest of the World (aggregate)	3.25	2.48

For a small number of countries with high population growth and low current per capita emissions, the C&C approach results in target emissions higher than business-as-usual levels (“Hot Air”). When an international emissions trading scheme is implemented, these countries are allowed to sell their excess certificates on the market. All countries with a negative reduction target belong to the Rest of the World.

Global emission reduction targets may be achieved in a cost-efficient manner, if international emission trading was allowed. As the scope of a potential international emission trading scheme after 2020 is not foreseeable, we present the extreme case of purely domestic action (*no trade* case). In addition, some figures are presented under global emission trading (*all trade* case) for comparison. While the emission trading market leads to a cost-efficient distribution of mitigation activities in the target year, the mitigation path over time is pre-determined and not necessarily cost-efficient.

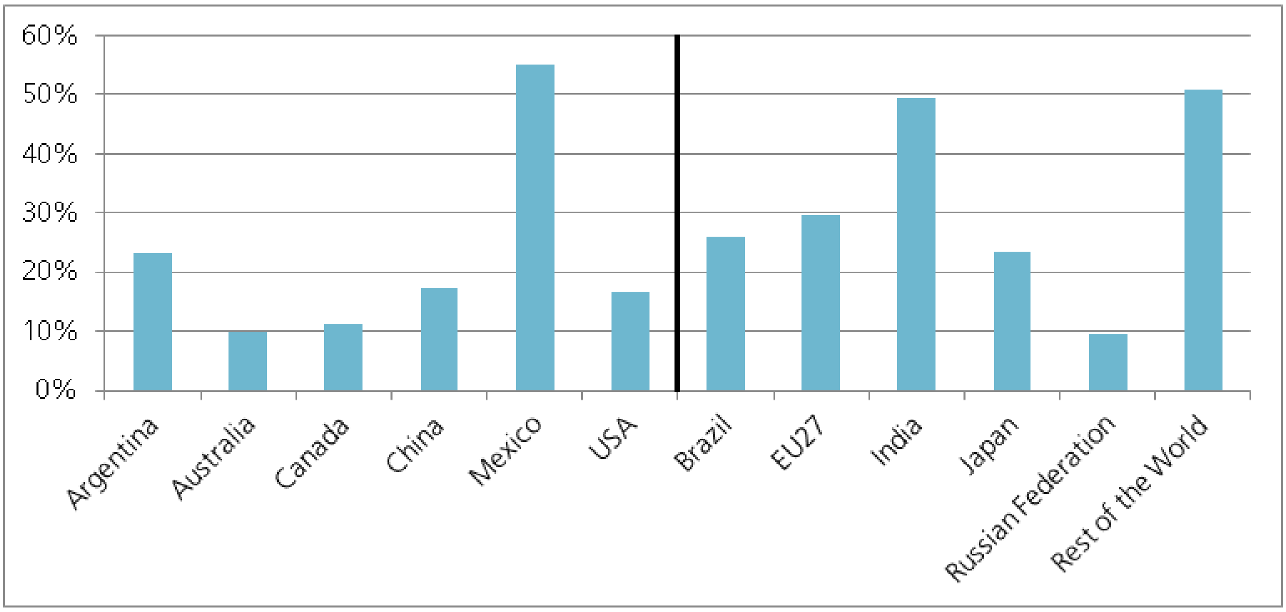
Below, country-specific effects of the mitigation cases are described. These depend on the allocation of emission targets across countries, i.e. the distribution of costs would be different under different effort sharing schemes. However, when allowing for an international emissions trading scheme, global effects on costs would be the same.

We first present the analysis for the long-term perspective, as the results and the effects are more pronounced than for the medium-term perspective. Then we show the findings for the medium-term perspective.

5.2 The Long-term perspective

The long-term perspective is based on a target of equal per capita emissions of 2.48 tCO_2e for all countries in 2050. Figure 6 shows the implied emission targets by countries, relative to the *US only* baseline. Countries with very high per capita emissions in the baseline, like Australia, Canada or Russia, face the most ambitious targets. The targets for developing countries with relatively low per capita emissions in the baseline, like India, Mexico and Rest of the World, are not as strict.

Figure 6: Emission targets in the *mitigation case 2050* in % of *US only* baseline emissions



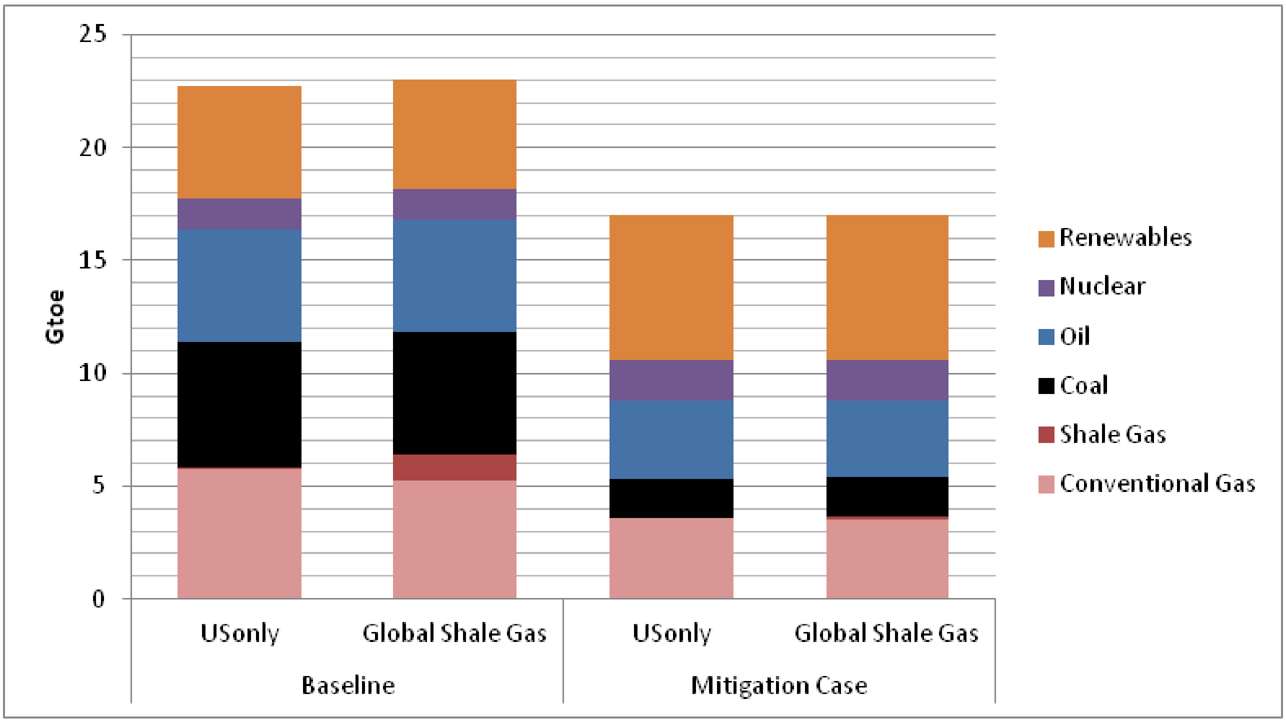
5.2.1 The energy market

Global production of energy in the *mitigation case 2050* (*all trade* case) is radically different from the baseline case, as shown in Figure 7. Total global production is 26% lower in the mitigation case than in the baseline case, due to energy efficiency measures[7]. All fossil fuels see a large decline of production (coal: -68%, gas: -43%, oil: -31%) and lower prices (coal: -5%, gas: -46%, oil: -12%) in the mitigation scenario compared to the baseline. Correspondingly, production from renewable energy sources (+33%) and nuclear energy (+30%) is considerably higher in the mitigation case.

Under strict reduction targets, the power sector also employs carbon capture and storage (CCS) to meet the mitigation targets. CCS is used for the large majority (87%) of electricity generated from coal. For gas, CCS is employed for 23% of electricity generation. This explains the remaining relatively high amount of fossil fuel production in the mitigation case.

[7] All comparisons between the mitigation scenario and the baseline case in this paragraph refer to the *Global Shale Gas* scenario. However, the numbers in the *US only* scenario are very similar.

Figure 7: Global production of different fuel types in 2050.



The decline in fossil fuel production hits shale gas significantly harder than conventional gas. In the *Global Shale Gas* scenario, 87% less shale gas is produced in the mitigation case than in the baseline case, while conventional gas only experiences a 34% decline. As a result, shale gas contributes less than 1% of total energy production, when the GHG reduction targets are to be met[8].

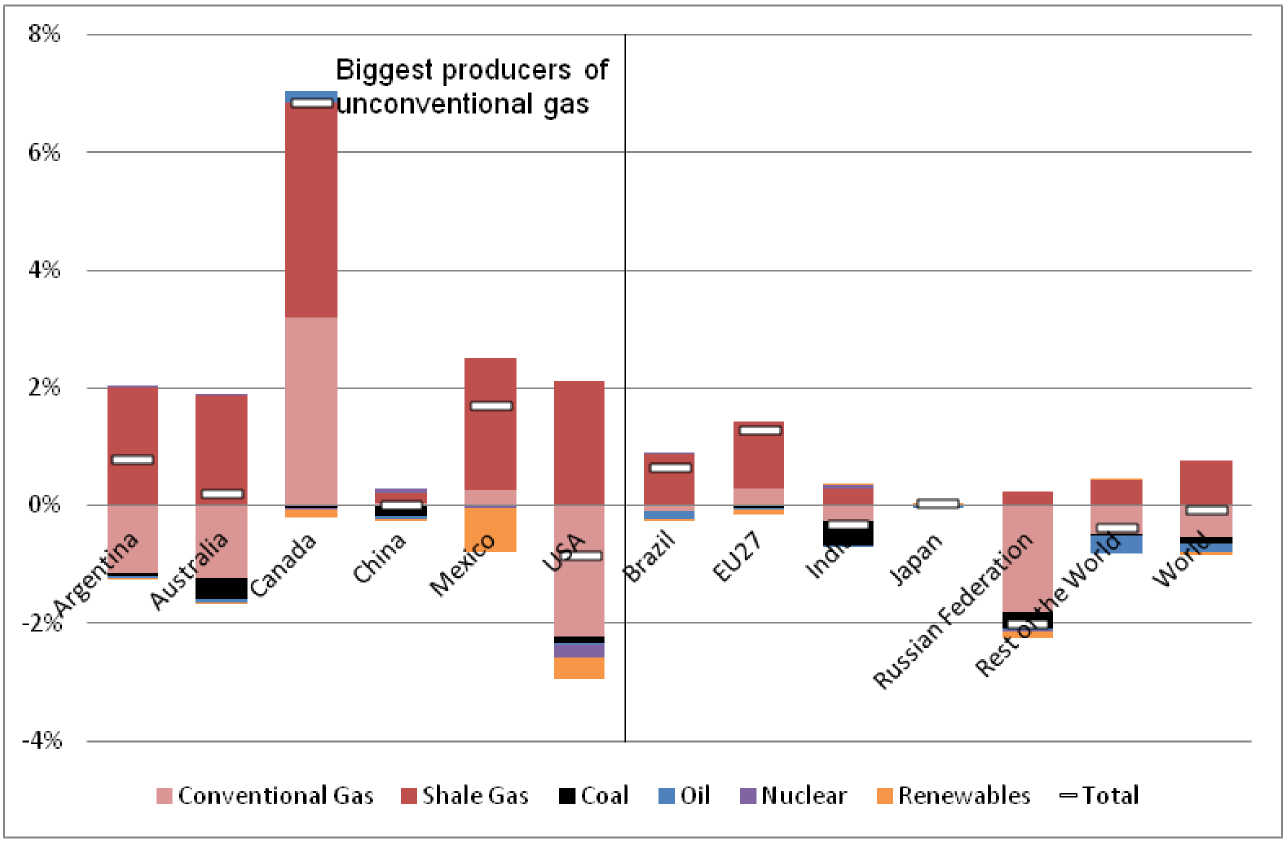
Figure 8 shows the effect of global availability of shale gas under mitigation targets on fuel production on a country level. It shows the changes in production of energy with the introduction of global shale gas development, under the *mitigation case 2050* (compare Figure 3 for the baseline case).

On a global level, effects are small. Shale gas production increases by about 1% (compared to 5% in the baseline) and displaces conventional gas, as well as oil, coal and to a limited amount renewable energy. Country-level effects are also significantly smaller in the mitigation case than in the baseline. In the majority of the big shale gas producing countries, the increases in shale gas production are at around 2% between the *Global Shale Gas* scenario and the *US only* scenario. In addition, in most of these countries (USA, Argentina, Australia) shale gas continues to replace natural gas from conventional sources to a large extent as was the case in the baseline. The replacement of other fossil fuels is limited in those countries. The highest effect is found for Canada with an increase in production from gas of almost 7%, partly replacing renewable energy sources. A similar pattern, although less pronounced, can be found in Mexico and the EU. The increase in conventional gas production in these countries is an adjustment to gas demand, which is higher due to lower prices. For Canada, the uni-

[8] The same pattern can be observed in the *US only* scenario, where shale gas contributes only around 2% of US energy production in the mitigation scenario.

quely large increase in conventional gas production is also the result of the particular modeling of the *US only* scenario[9] and should therefore be treated with caution.

Figure 8: Changes in the production of different fuel types as a share of total primary production of energy (*Global Shale Gas* scenario versus *US only* scenario) in the *mitigation case 2050*.



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Overall, the energy production simulation suggests that shale gas only plays a small role on a global level when ambitious GHG reduction targets are implemented. The main reason for that is that reaching the ambitious GHG reduction targets requires significant reductions in the demand for fossil fuels and hence the production of all fossil fuels, including gas, is substantially reduced. As a result of the demand reduction, prices for fossil fuels decrease and fossil fuels are not as scarce as in a world without climate change policies in place. However, the availability of shale gas outside of the USA causes changes on a country-level. In North America, Canada and Mexico replace part of US gas production, while in Europe the EU increases its own shale gas production and reduces imports from Russia.

[9] The *US only* scenario does not allow any country besides the US to produce shale gas. As Canada already produced a small amount of shale gas in 2012, the deactivation of shale gas production in the *US only* scenario causes a drop in total gas reserves, which is not present in other countries. As the model connects conventional gas production to gas reserves, this drop also depresses conventional gas production in Canada in the *US only* scenario.

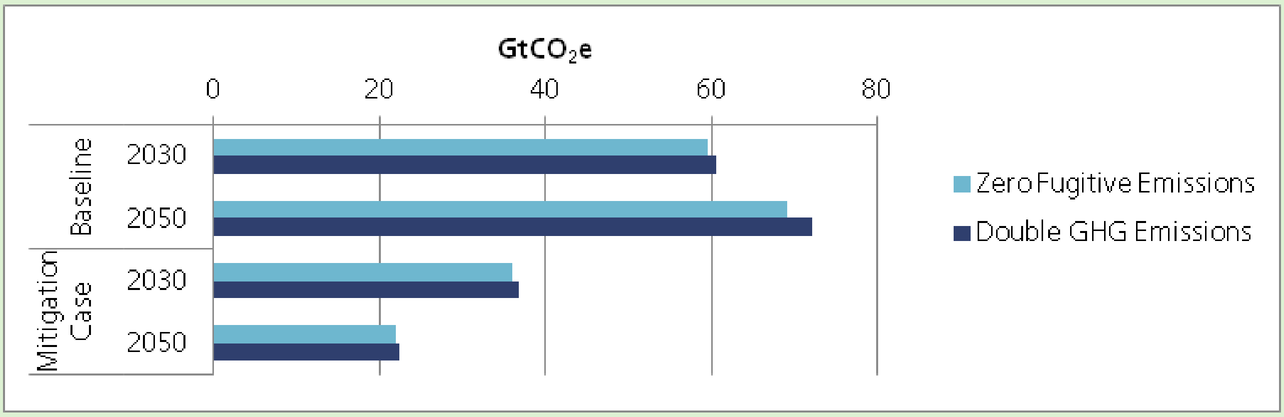
Box 2: Fugitive emissions in shale gas extraction and impact on GHG performance of shale gas

The process of hydraulic fracturing used in the extraction of natural gas from shale formations causes additional GHG emissions, when compared to conventional gas production. These additional emissions come from a variety of sources, such as the energy needed for drilling or the preparation and recycling of the water used in the process (Jiang et al., 2011). However, the biggest – and most controversial – contribution comes from excess natural gas during the development of the well. This gas might be vented, meaning a direct release into the atmosphere, creating significant GHG emissions due to the large Global Warming Potential of methane[1]. The gas can also be burned off, or flared, which converts the methane into carbon dioxide and water and therefore reduces GHG emissions. Industry best practice is the use of so-called reduced emission completions – or green completions – that capture the excess gas and prevent the release into the atmosphere (O'Sullivan & Paltsev, 2012, ICF, 2014). In the USA, green completions must be used on all wells by 2015 (US EPA, 2012).

A controversial study on this topic was presented by Howarth et al. (2011), who found that, over a 100-year timeframe, GHG emissions from fugitive methane can double the GHG footprint of shale gas and "the GHG footprint [for shale gas] is comparable to that for coal". However, the assumptions of the study were heavily criticized (e.g. Stephenson et al., 2011, Cathles et al., 2012). Subsequent studies showed that the GHG footprint for shale gas is roughly equal to that for conventional gas and around half that for coal (Weber & Clavin, 2012, provide a meta-analysis). For Germany, Fritsche et al. (2014) found that GHG emissions from electricity production from shale gas are comparable to the conventional gas mix, unless adverse geological and technical conditions are assumed.

Figure 9 shows the potential impact of fugitive emissions on global GHG emissions in the *Global Shale Gas* scenario. In order to represent the whole spectrum of literature results, we compare the assumption of zero fugitive emissions to the assumption that fugitive emissions from shale gas are as high as GHG emissions from conventional gas, causing a doubling of the GHG footprint. This is comparable to the result of Howarth et al. (2011). In total, global emissions in the baseline scenario increase by 4.5% in 2050 under the high estimate for fugitive emissions from shale gas extraction, the highest difference in all scenarios. While GHG emissions from shale gas are still dominated by carbon dioxide emissions from coal, oil and conventional gas, they represent a substantial part of global emissions and cannot be disregarded. In the mitigation cases, when shale gas plays a less prominent role, inclusion of fugitive emissions based on Howarth results in an increase of global GHG emissions by 1.8%. That is, the target of 22 $GtCO_2e$ is missed by about 400 $MtCO_2e$.

Figure 9: Global GHG emissions for different assumptions about fugitive emissions from shale gas extraction.



5.2.2 Cost of compliance

This section examines the consequences of the additional supply of shale gas in the *Global Shale Gas* scenario on compliance costs for individual countries. Figure 10 shows the country-specific compliance costs as a share of GDP for the *mitigation case 2050* in the *US only* and *Global Shale Gas* scenarios, and for the *no trade* and *all trade* cases. Russia has the highest emissions intensity[10] of all countries considered in the 2050 baselines. It is also projected to have a lower population in 2050 than today, and is therefore assigned a very ambitious GHG reduction target by the C&C approach. As a result, Russia emerges with the highest compliance costs of all countries in both scenarios.

On the global level, the additional supply of shale gas in the *Global Shale Gas* scenario causes a small increase in compliance costs (1.7% in the *no trade* case, 2.5% in the *all trade* case). This trend holds for most countries, although the scale of the effect varies across countries.

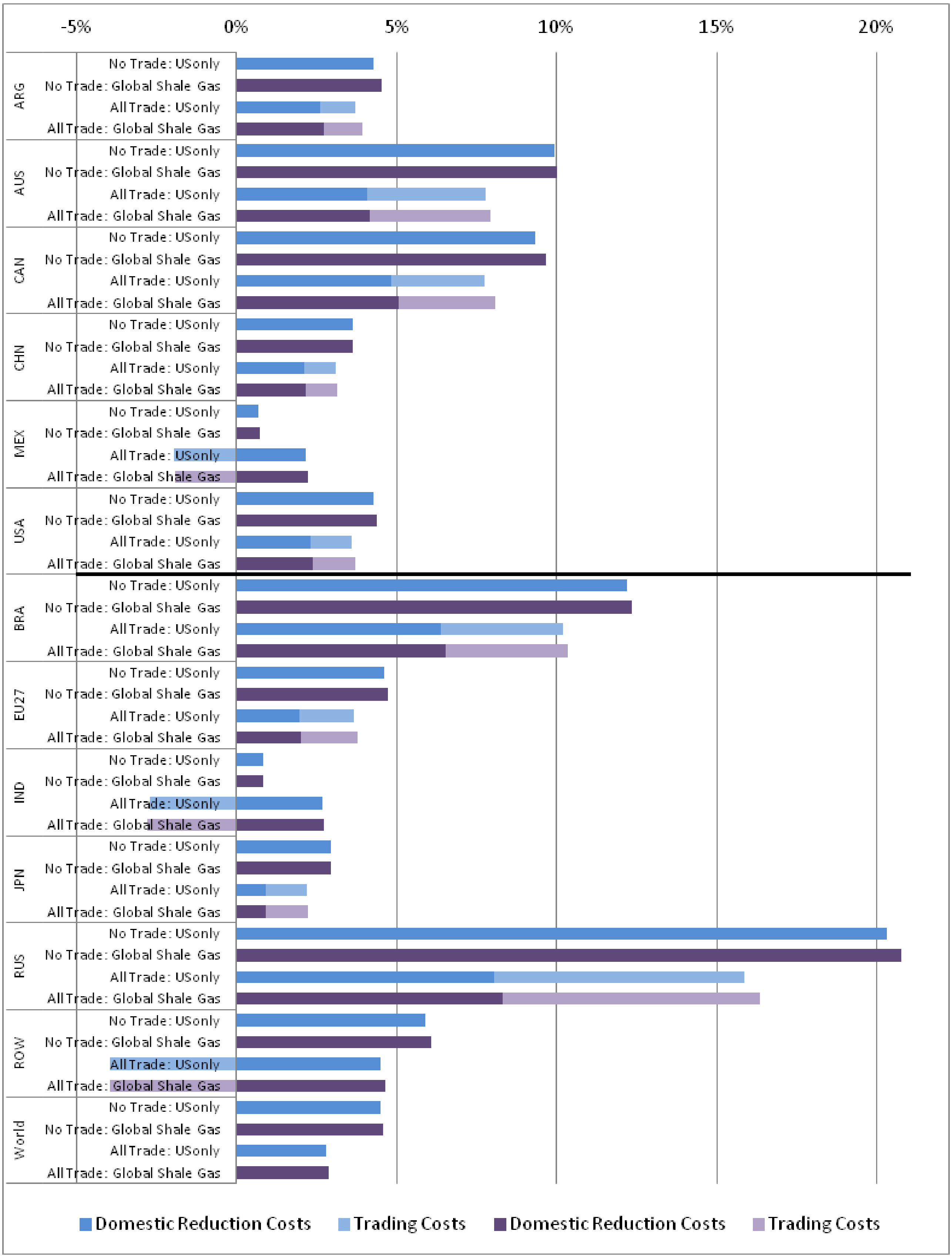
The differences in compliance costs between both scenarios are caused by two types of effects, which are outlined here and will be quantified later in this section.

The *baseline effect* stems from the difference between baseline GHG emissions in the *US only* scenario and in the *Global Shale Gas* scenario. As the target emission level in the *mitigation case 2050* is constant for each country, higher emission reductions are needed if baseline emissions are higher. In this case, the *baseline effect* is positive because it causes an increase in certificate prices and compliance costs. Section 4 showed that baseline emissions are higher in the *Global Shale Gas* scenario for most countries and on a global level. Notable exceptions are India and Japan, for which the *baseline effect* is negative.

On the other hand, the *mitigation cost effect* captures the changes in the cost of mitigating a specific amount of GHGs. Therefore, it complements the *baseline effect* and shows the remaining cost differential between both scenarios. The *mitigation cost effect* not only depends on the country, but also on the level of ambition and on the timing of the mitigation case. Suppose the mitigation case is for the short- to mid-term and the targets are not very ambitious. In this case, it may be sufficient to replace coal with gas in electricity production and the *mitigation cost effect* of shale gas may be negative (because the availability of shale gas renders mitigation cheaper). However, if the mitigation target is for the long-term and is very ambitious, it may require replacing all fossil fuels (including gas) with renewable energy technologies. In this case, the additional supply of gas delays significant cost reductions for renewable technologies. Also, mitigating one ton of CO_2 requires the employment of a larger amount of renewables if gas, rather than coal, is to be replaced by these renewables, making it more costly. Therefore the *mitigation cost effect* of the additional supply of shale gas may be positive.

[10] GHG emissions per GDP

Figure 10: Compliance costs as a share of GDP for the *mitigation case 2050* in *US only* and *Global Shale Gas* scenarios (*all trade* and *no trade* cases).

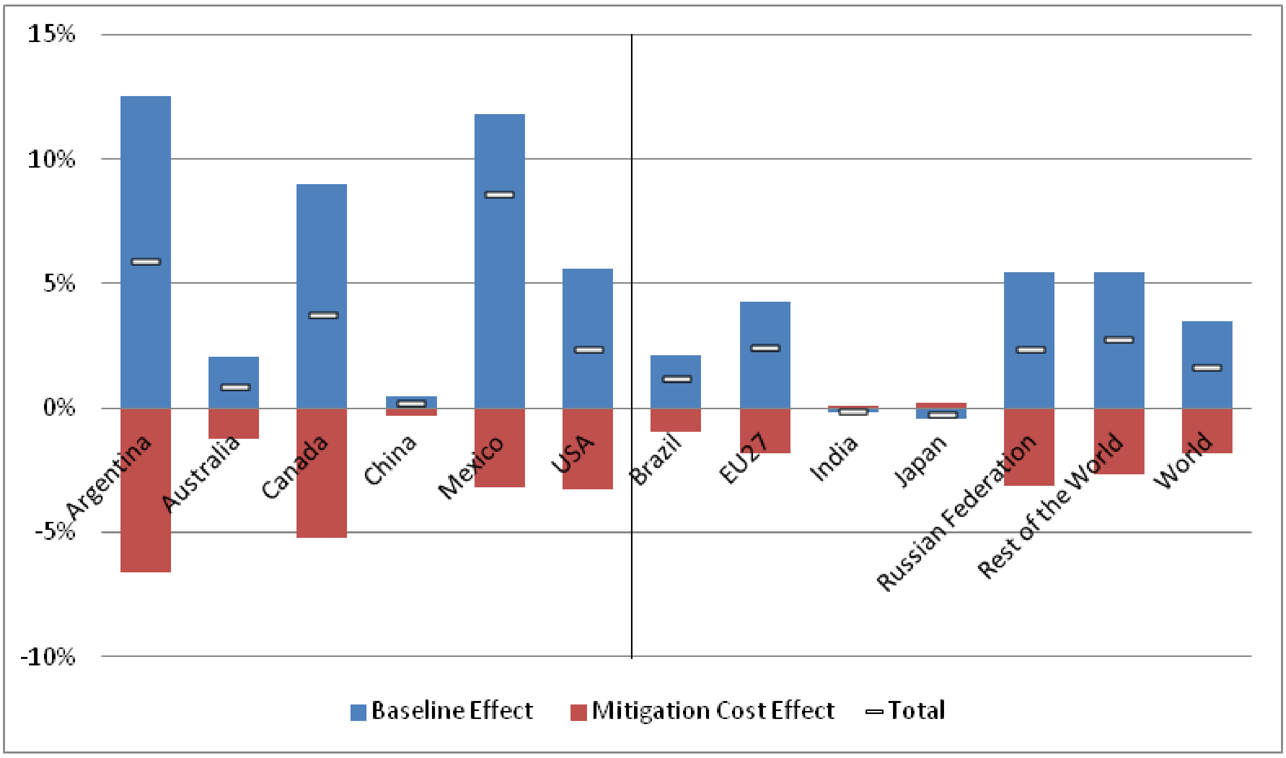


Note: Negative bars indicate earnings from the sale of emission certificates.

In order to quantify the decomposition of the change of compliance costs in *baseline effect* and *mitigation costs effect*, we create an additional, intermediate scenario. For this new scenario, we use the baseline emissions of the *Global Shale Gas* scenario and the marginal abatement cost curves from the *US only* scenario. Therefore, when comparing the *US only* scenario to the intermediate scenario, only the effect of the change in baseline emissions and corresponding emission reductions is measured. This is the *baseline effect*. On the other hand, the comparison between the intermediate scenario and the *Global Shale Gas* scenario leaves baseline emission levels constant and only changes the marginal abatement cost curves. This is the *mitigation cost effect*.

We first discuss these effects and the resulting total effect in the *no trade* case. Figure 11 shows the results. The *all trade* case is briefly discussed afterwards.

Figure 11: Change in compliance costs induced by global availability of shale gas in 2050, decomposed in *baseline effect* and *mitigation cost effect* (*no trade* case)



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For most countries the baseline effect is positive, the mitigation cost effect is negative and the total effect is positive. This confirms the intuition that additional energy options, like shale gas, should lead to a decrease in mitigation cost per ton (as the mitigation cost effect is negative). It also corresponds well to the differences in fuel production between both scenarios, as seen in Figure 8. Shale Gas mainly replaces other fossil fuels, while energy production from low-carbon technologies is hardly affected in most countries. This makes mitigation cheaper. However, the negative mitigation cost effect is more than offset by the increase in baseline emissions, which we discussed in detail in Section 4. Therefore, the additional supply of gas in the *Global Shale Gas* scenario causes an overall increase in compliance costs.

Similar to the baseline analysis, the largest changes occur in countries among the group of the biggest producers of shale gas, most notably in Argentina and in Mexico. In both countries, the baseline effect increases costs by over 10% and the total effect exceeds 5%. With an increase in total costs of

2.4% each, Russia and the EU face the biggest changes for any country outside the group of the biggest producers. For Russia, this can be traced back to the difference in baseline emissions (see Figure 4). The EU faces a relatively smaller increase in baseline emissions, but also a relatively smaller decrease in mitigation costs.

China, one of the biggest producers of shale gas, experiences almost no change in compliance costs. This is in line with the behavior of primary production of energy and country-wide GHG emissions in the baseline. In summary, while the Chinese reserves are big enough to make it the fourth-largest producer of shale gas in the *Global Shale Gas* scenario, its energy consumption, GHG emissions and compliance costs in the *mitigation case 2050* are so large, that the changes induced by variations in shale gas availability are hardly noticeable.

The effects for India and Japan differ from those observed for other countries, as their baseline effect is negative. However, this means that both countries already replaced a lot of coal and oil with gas in the baseline (see Figure 4). As a result, this option is no longer available in the mitigation case and for both countries the mitigation cost effect is positive. The absolute size of the effects still resembles those of all other countries, i.e. the total effect is negative.

5.2.3 The carbon market

International emissions trading allows each country to meet its GHG reduction target by either reducing GHG emissions domestically or by buying emission certificates from other countries, and thus decreases total compliance costs for each country (see Figure 10). In the *all trade* case, India, Mexico and Rest of the World are net-sellers of certificates. They enjoy substantial revenues on the international carbon market and are able to recoup much of their domestic compliance costs. India actually realizes a small profit in both scenarios. Major buyer countries are China, the EU, Russia and the USA, while Japan has the largest share of certificates used to reach its target.

In the *all trade* case, certificate prices on the international emissions trading market increase slightly from 406€/tCO_2e in the *US only* scenario to 412€/tCO_2e in the *Global Shale Gas* scenario, an increase of only 1.5%. This corresponds to the behavior of the total compliance costs on a global level, which also rise by a comparable amount.

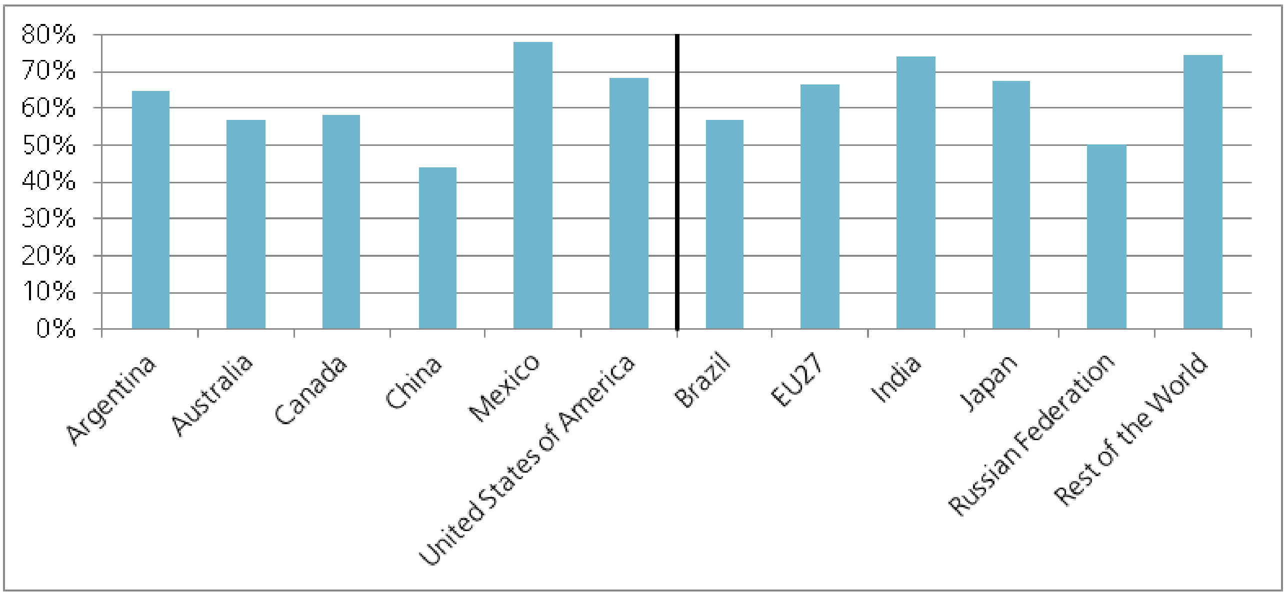
The amount of certificates bought or sold differs only slightly between both scenarios. Net-buyers of certificates account for a somewhat higher share of domestic reduction in the *Global Shale Gas* scenario, due to the higher price for certificates. Correspondingly, net-sellers of certificates also increase their domestic reduction amount in absolute numbers. While India sells the additional certificates on the market, for Mexico and Rest of the World the increase in baseline emissions offsets these additional emissions reductions and both countries sell slightly fewer certificates in the *Global Shale Gas* scenario than in the *US only* scenario.

The breakdown of compliance costs for individual countries and the decomposition of the total effect in baseline effect and mitigation cost effect leads to similar results as in the *no trade* case. In essence, the effects of shale gas are “spread out” over all countries by the introduction of international emissions trading. Countries with small changes in baseline emissions, such as China, are now affected by the higher certificate price in the *Global Shale Gas* scenario, which leads to a higher baseline effect in money terms. The opposite holds for countries with big changes in baseline emissions, such as Argentina, such that the baseline effects for all countries tend to align in the *all trade* case. The same dynamic applies for the mitigation cost and total effects. For net-sellers of certificates, another effect takes place: they profit from the higher certificate prices and are able to create higher revenues from the international emissions trading market. This allows India to increase profits in the *Global Shale Gas* scenario.

5.3 The Medium-term perspective

For the medium-term perspective in 2030, emission reduction targets are based on the C&C approach. Figure 12 shows the emission targets, relative to the *US only* baseline.

Figure 12: Emission targets in the *mitigation case 2030* in % of *US only* baseline emissions



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5.3.1 The energy market

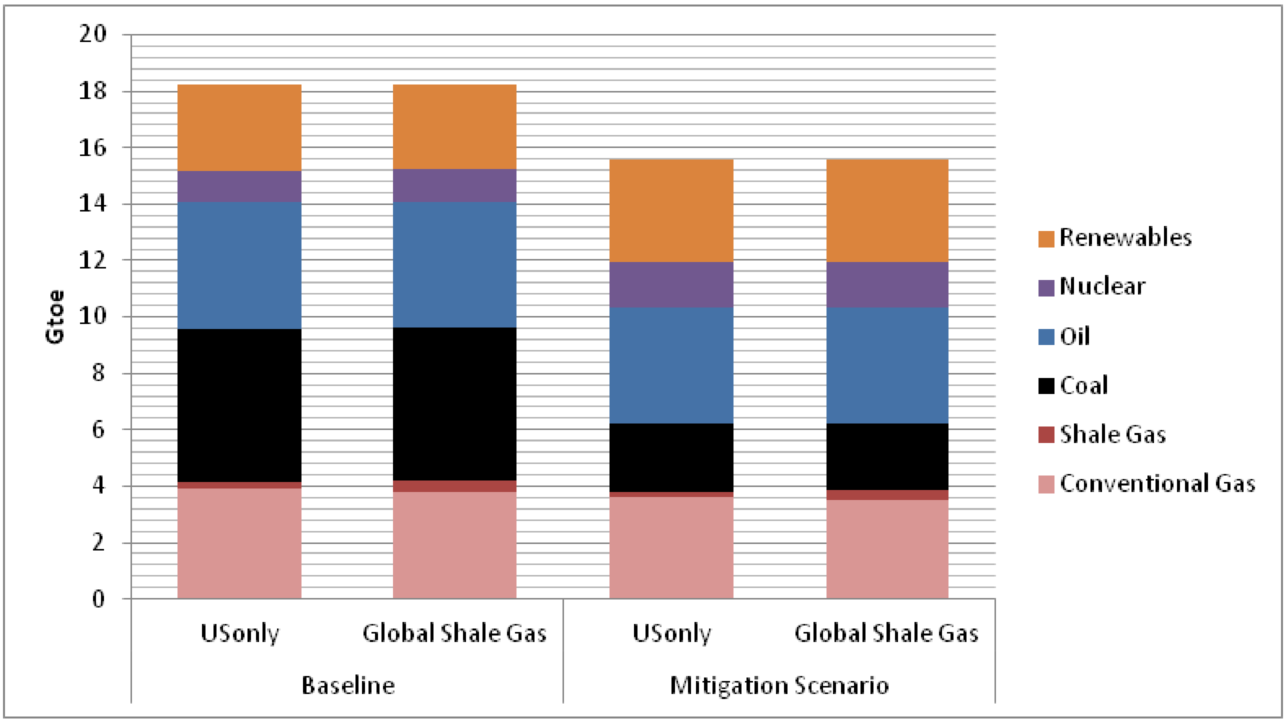
The change of global energy production in the *mitigation case 2030*, compared to the baseline case, is similar to the long-term perspective. Figure 13 shows the results. Energy efficiency measures achieve a 15% decline of total production. Coal is affected most and loses 56% of production. Gas and oil production also decline, but only by 9%. The remaining gap is filled by nuclear (+41%) and renewable (+20%) energy.

As in the long-term analysis, production of shale gas decreases more than total production when mitigation targets are in place in the *Global Shale Gas* scenario (-24%). In the US, it remains a relevant energy source, representing 13% of production. That is, shale gas can present a “bridge fuel” to some extent in the US. Still, under ambitious mitigation targets even in the US shale gas production peaks by 2025. On a global level, the ambitious mitigation targets prevent shale gas from playing a major role in the energy mix. The competition with other low-carbon energy sources limits the increase in global production. It peaks by 2030, at less than 2% of total energy production.

On a country level, the effects of shale gas availability in the mitigation case are very similar to the long-term perspective. As in the baseline case, the USA remains the biggest developer of shale gas, producing 74% of global supply. Canada and Mexico start the exploitation of their shale gas reserves when this is allowed, but, contrary to the long-term case, do not also increase their conventional gas production. Therefore, the North-American gas market does not experience a major shift in the *Global Shale Gas* scenario.

The detailed changes in energy production on a country level caused by the availability of shale gas can be found in Figure A4 in the Annex.

Figure 13: Global production of different fuel types in 2030.



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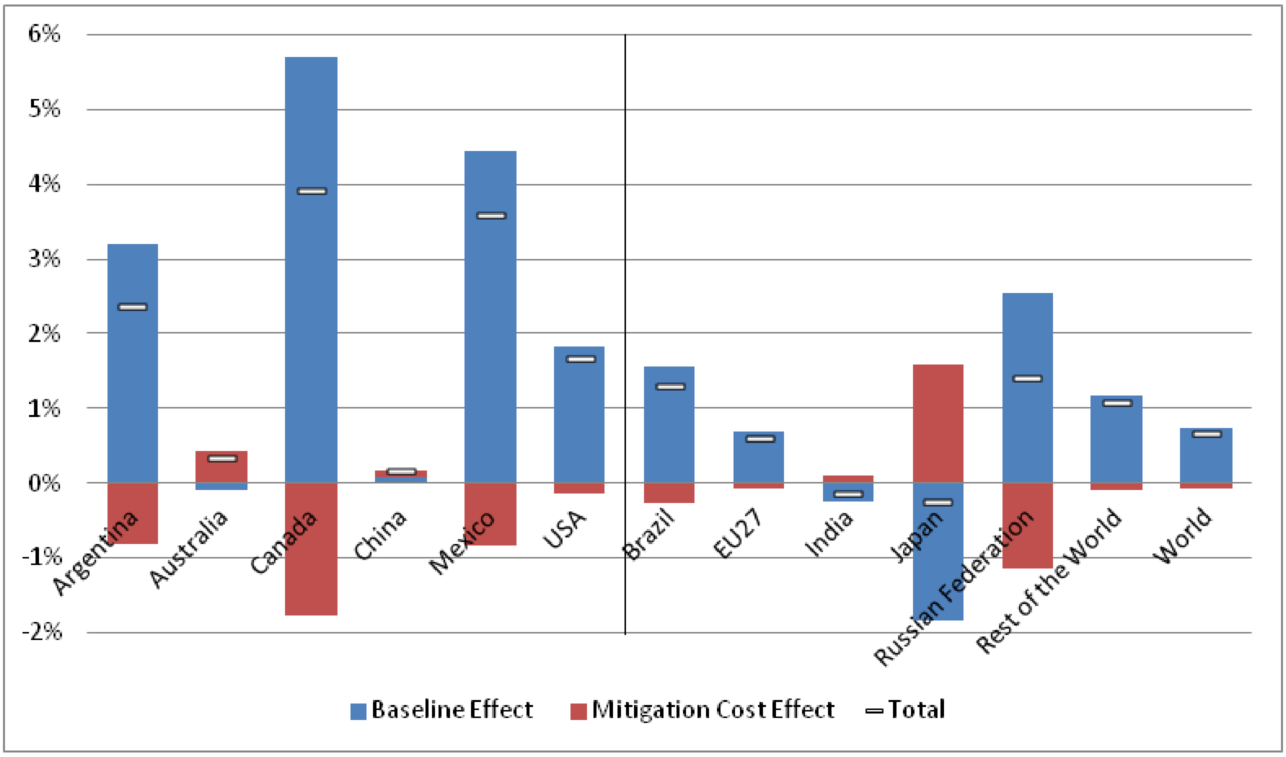
5.3.2 Cost of compliance

In the *mitigation case 2050*, the change in compliance costs caused by the availability of shale gas, and its decomposition in baseline effect and mitigation cost effect, is relatively homogeneous among all countries. In the *mitigation case 2030*, these changes are more diverse. Figure 14 shows the changes between the *US only* scenario and the *Global Shale Gas* scenario in the *no trade* case. Compliance costs as a share of GDP can be found in Figure A5 in the Annex.

Figure 14: Change in compliance costs induced by global availability of shale gas in 2030, decomposed in *baseline effect* and *mitigation cost effect*. (*no trade* case)



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In the baseline for 2030, the difference between the *US only* scenario and the *Global Shale Gas* scenario, measured in total gas production and in GHG emissions, is very small (less than 0.1%, see section 4). Therefore, the effects of additional shale gas in the *mitigation case 2030* are smaller than in the *mitigation case 2050*. In 2030, the difference in compliance costs on the global level between the *US only* scenario and the *Global Shale Gas* scenario is 0.7% in the *no trade* case and 0.8% in the *all trade* case, both less than half of the relative increases in 2050. On a country level, the largest relative total effects in the *mitigation scenario 2030* are around 4% in Canada and Mexico. At the moment, Canada has the most advanced shale gas industry outside of the USA and already extracted a small amount in 2012. Therefore, it is able to react relatively quickly to the availability of shale gas and, accordingly, sees a big effect in its compliance costs in 2030.

For the countries with the largest effects (Argentina, Canada, Mexico, USA, Brazil, Russia), the decomposition shows a positive baseline effect and a smaller, negative mitigation cost effect. This is similar to the *mitigation case 2050*. However, unlike in the long-term perspective, other countries show different patterns. For China the baseline effect and the mitigation cost effect are both positive, illustrating that baseline and mitigation effects may have the same sign. Furthermore, Australia shows that the absolute size of the mitigation cost effect can be greater than the baseline effect. This leads to a positive total effect despite fewer baseline emissions in the *Global Shale Gas* scenario.

Overall, only India and Japan experience lower costs in the *Global Shale Gas* scenario. Both countries produce almost no shale gas themselves, but use a substantial amount of imported gas for electricity generation and therefore profit from the lower gas price in the *Global Shale Gas* scenario. In addition, these countries have a negative baseline effect, as the GHG benefit of the switch from coal to gas outweighs the harm of additional fossil fuels. This negative baseline effect is large enough to exceed the positive mitigation cost effect.

5.3.3 The carbon market

In the *mitigation case 2030*, the emission certificate price increases from 100.49€/tCO_2e in the *US only* scenario to 100.99€/tCO_2e in the *Global Shale Gas* scenario, an increase of less than 0.5%. The distribution of net-sellers and buyers of certificates is similar to the *mitigation case 2050*, with one exception: the USA joins Mexico, India and Rest of the World as a net-seller of certificates. These countries face a relatively lenient emission target under the C&C approach, mainly due to strong population growth in the period up to 2030. The USA also had high per capita emissions at the beginning of the convergence period, meaning that per capita emissions in 2030 are still high, relative to other countries. The impact of global shale gas production on the pattern of emission reductions is small – the difference in domestic reduction between the *US only* scenario and the *Global Shale Gas* scenario is less than 2% for each country.

The decomposition of compliance costs in the *all trade* case is similar to the decomposition in the long-term perspective. The effects of the *no trade* case are spread out over all countries and net-sellers of certificates profit from the higher certificate price in the *Global Shale Gas* scenario.

Box 3: The impact of shale gas in Europe

In the *Global Shale Gas* baseline in 2050, the EU accounts for 4% of global shale gas production. France is the biggest single producer of shale gas in the EU. It produces 17.2 Mtoe, i.e. more than a third of total EU shale gas production. 28% of the additional gas in electricity generation is used to replace coal or oil, while the remaining 72% replace low-carbon technologies or increase overall electricity generation. The resulting GHG emissions in France are 1.4% higher than in the *US only* baseline, a slightly larger increase than the EU average of 1.2%.

Poland produces roughly a quarter of all EU shale gas, making it the second biggest producer. Poland's electricity production is relatively coal-intensive, and this situation is projected to persist in 2050 relative to other EU countries, although not in absolute terms. Therefore, Poland uses a larger share than France (34%) of the additional gas in the *Global Shale Gas* baseline to replace other fossil fuels, while only 66% replace low-carbon technologies or increase overall electricity generation. As a result, GHG emissions in Poland increase only by 1.1%.

Of the other big EU countries, Italy and Spain produce no shale gas, while Germany (1.6 Mtoe) and the UK (0.8 Mtoe) produce only small amounts. Germany uses a relatively large share of the additional gas to replace fossil fuels (39%) and consequently increases GHG emissions only slightly. In the UK, this share is lower (16%) and GHG emissions rise more than the EU average.

In addition to the big producers of shale gas, Romania, the Netherlands and Hungary are projected to have substantial shares of shale gas production, relative to their total energy production, at 11.8%, 11.5% and 8.5%, respectively. EU-wide, 5.7% of total energy produced is shale gas.

In terms of GHG emissions, Estonia sees the largest difference between Global Shale Gas scenario and US only scenario of all EU countries, at 4.8%, although it produces no shale gas itself. However, lower fossil fuel prices mean that Estonia uses more gas in its electricity production. This additional gas mostly replaces low-carbon energy technologies, as less than 10% replaces coal or oil. Similar changes are projected in Hungary and Latvia, where GHG emissions also rise by more than 2%.

In the mitigation case for 2050, the EU-wide share of shale gas in total energy production falls to 1.1%. All individual countries follow this trend and the countries with the highest share of shale gas production are the same as in the baseline case. The cost of compliance with the mitigation targets changes similarly to the EU-wide increase of 2.4% in all countries. As it largely depends on the change in baseline GHG emissions, the highest relative increases in costs are observed in Estonia (6.2%) and other eastern European countries. The UK sees the largest increase in compliance costs of the big EU countries (3.7%). On the other hand, only negligible changes in costs are observed in Belgium, Luxemburg and Slovenia.

Overall, the impact of shale gas availability in the EU is twofold. First, significant shale gas production is limited to a few countries. France and Poland together produce over half of all EU shale gas, while the Netherlands and Hungary also produce sizable amounts, relative to the size of their total energy production. Second, the lower prize of fossil fuels mostly affects some eastern European countries, who replace low-carbon energy in electricity production. GHG emissions of these countries rise significantly more than the EU average.

The price effects of shale gas are mostly caused by production outside of the EU. In 2050, shale gas production in the EU covers only 6% of EU gas demand. Therefore, an EU-wide shale gas ban would only have a small impact on gas prices on the European Market.

6 Conclusion

This report considers the impacts of global availability of shale gas on GHG emissions and the costs of meeting GHG reduction targets. We find that, in the baseline development without additional measures to reduce GHG emissions, shale gas availability only produces modest changes to the energy landscape on a global scale. Production of shale gas outside of the USA does not have an impact before 2030 and only realizes most of its potential in the long-term period up to the middle of the century. In 2050, shale gas accounts for 18.5% of total global gas production and for 4.8% of global energy production. As part of this additional production is offset by a decrease in conventional gas supply, the share of gas in total production of energy increases only by two percentage points, when global shale gas reserves are available. However, the impact on single countries varies considerably, as in some countries, most notably Argentina, Australia, Canada, Mexico, and the USA, shale gas accounts for a significant part of total energy production.

The additional supply of shale gas causes opposing effects on the amount of GHGs emitted. It replaces coal and oil, but also crowds out renewable and nuclear power and leads to an increase in the total consumption of energy due to lower energy prices. Overall, the availability of shale gas induces an increase of GHG emissions in almost all countries. The increase is especially large in countries in which much of the additional gas replaces nuclear power and renewable energy sources.

When GHG reduction targets consistent with the 2°C-target are introduced, shale gas plays a smaller role, as global reduction targets limit the overall use of fossil fuels. In 2050, shale gas contributes less than 1% to global energy production. However, it can cause a substantial change in the costs of meeting the climate targets. The main driver behind this change is the higher baseline GHG emission level, which requires a larger reduction to meet the specific target and therefore induces higher costs of meeting the target. The effect that the availability of shale gas also reduces the costs of abating a fixed amount of GHG emissions is found in most countries. However, this effect is not enough to offset the increased costs caused by higher baseline emissions. Overall, for most countries the costs of meeting the GHG reduction target is therefore higher when shale gas is available. Particularly large increases are found in Mexico and Argentina with up to 9% increase. A slight reduction in mitigation costs is found in Japan and India, countries in which the baseline emissions are lower when shale gas is available.

An international emission trading scheme results in effects from shale gas that affect all countries, not only due to changes in energy prices but also due to changes in certificate prices on the international emission trading market. The global increase in baseline emissions, and hence higher emission reductions and mitigation costs to meet the reduction targets when shale gas is available result in higher certificate prices in the scheme. As a result, all net-buyers of certificates face higher costs, while net-sellers increase their revenue.

The impact of increased availability of shale gas on medium-term GHG reduction targets in 2030 is limited. While the share of shale gas in total energy production on a global scale is actually higher than in the long-term mitigation case, most of the shale gas supply is still produced in the US. Therefore, the effect of non-US shale gas production on the costs of meeting GHG reduction targets is smaller than in 2050. The signs of the considered effects are similar to the long-term analysis in most countries.

While effects differ significantly across countries and regions, the EU's affectedness as well as its role in shale gas production is limited in the long term. In total, the EU27 account for 4% of global shale gas production in the *Global Shale Gas* baseline and even less in the mitigation scenarios. At the same time, mitigation costs in the mitigation scenarios increase by 2.4% in the *Global Shale Gas* case compared to the *US only* case. Highest effects are found in Eastern European countries and are around 6%

increase in mitigation costs. For France, the largest producer within the EU27, increased availability of shale gas in the Global Shale Gas case results in an increase of mitigation costs of 2.6%. In the medium-term effects are even lower, i.e. no significant differences can be found in the EU27 as a whole.

To conclude, this analysis indicates that the effects of the availability of shale gas on either global GHG emissions or on mitigation costs for meeting ambitious climate targets are limited. In total, our results show a slight increase in global GHG emissions and as a result an increase in mitigation costs due to lower energy prices rather than – as often discussed – a reduction in global GHG emissions and lower mitigation costs due to a switch from coal to gas. Lower energy prices reduce the profitability of energy efficiency measures and renewable energy sources compared to fossil fuels and hence have a negative impact on meeting the EU's energy and climate targets. Finally, it should be noted that the results in this report were reached without consideration of the environmental side effects or the fugitive emissions of shale gas production. Therefore, the results should be considered to be biased towards a positive result for shale gas development.

7 Annex

Figure A1: Primary production of energy by fuel and country in 2012 and 2050 in both baselines

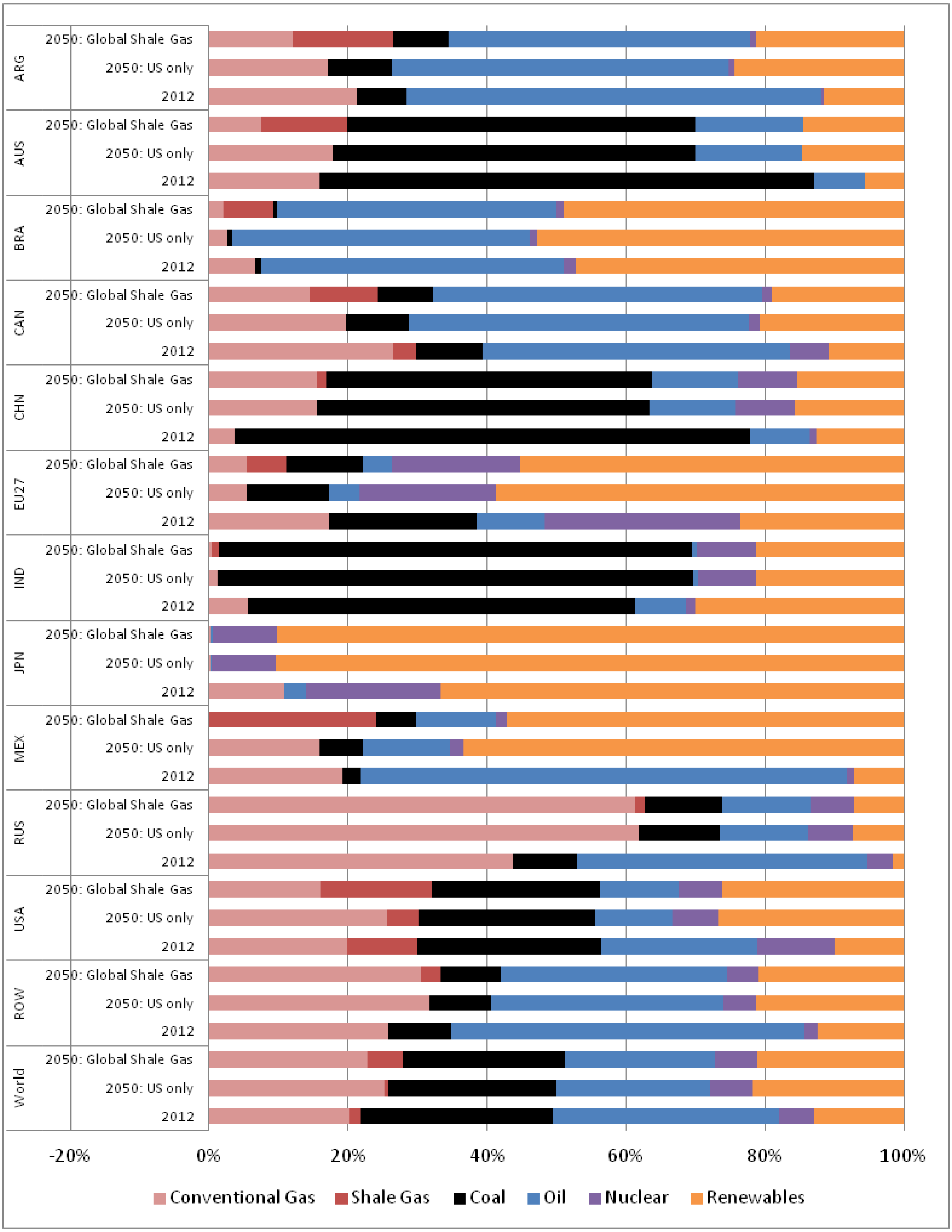

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Figure A2: Changes in primary production of energy as share of total production (*Global Shale Gas* baseline versus *US only* baseline) in 2030

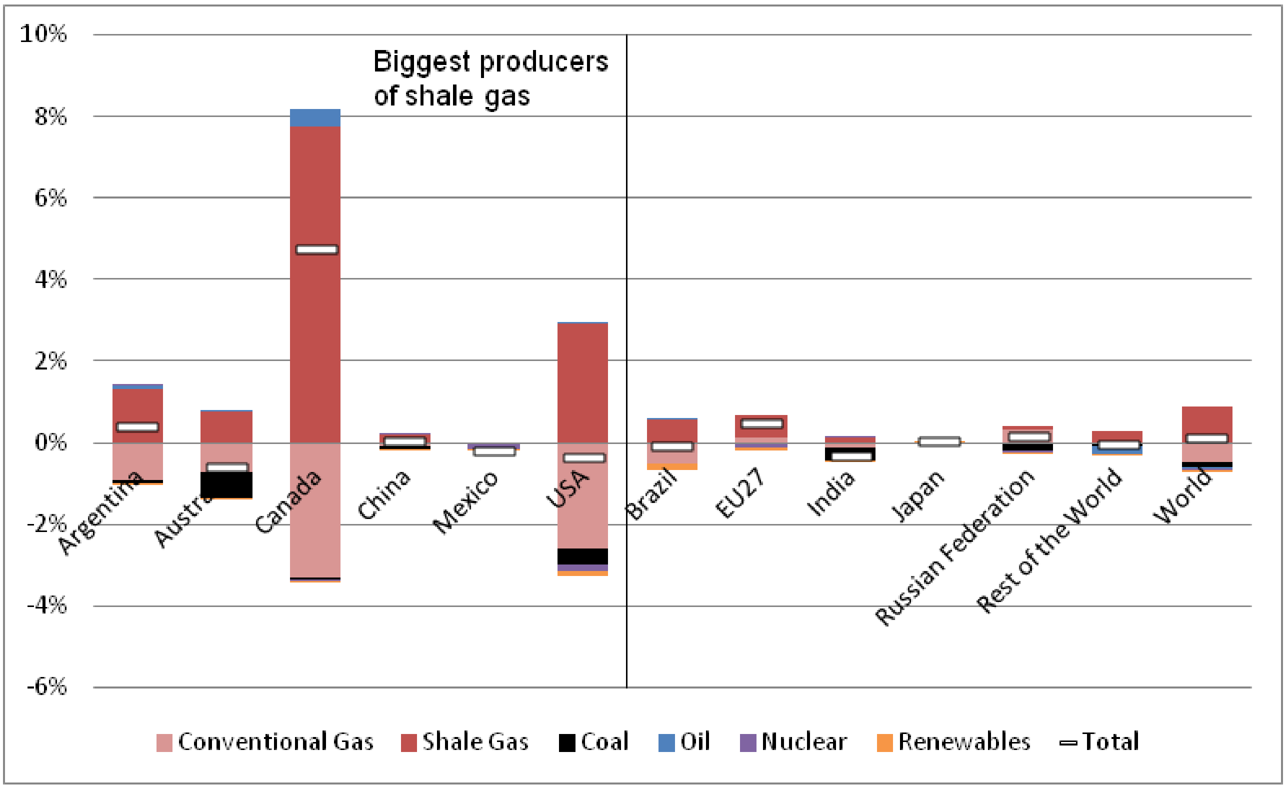


Figure A3: Difference in GHG emissions between *Global Shale Gas* baseline and *US only* baseline (blue) and share of fossil fuel replacement (red) by country in 2030.

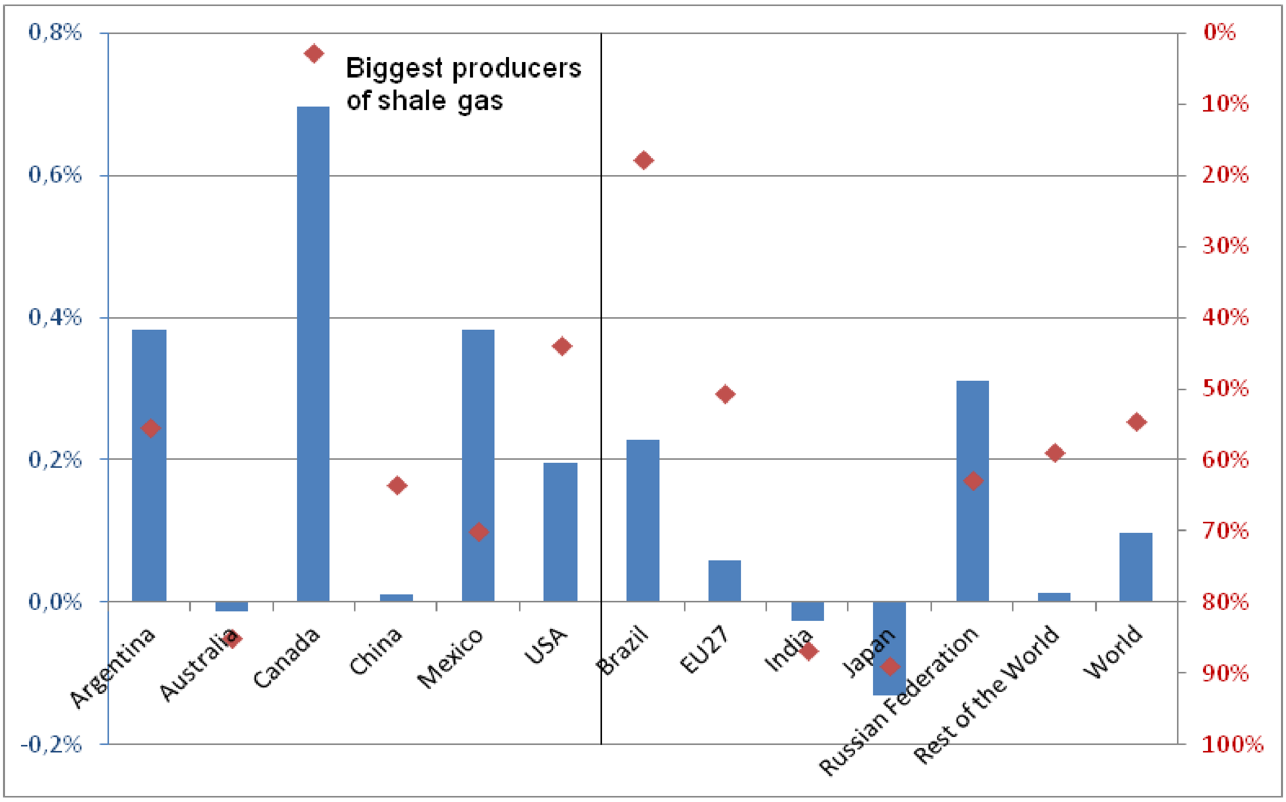


Figure A4: Changes in production of different fuel types as share of total primary production of energy (*Global Shale Gas* scenario versus *US only* scenario) in the *mitigation case 2030*.

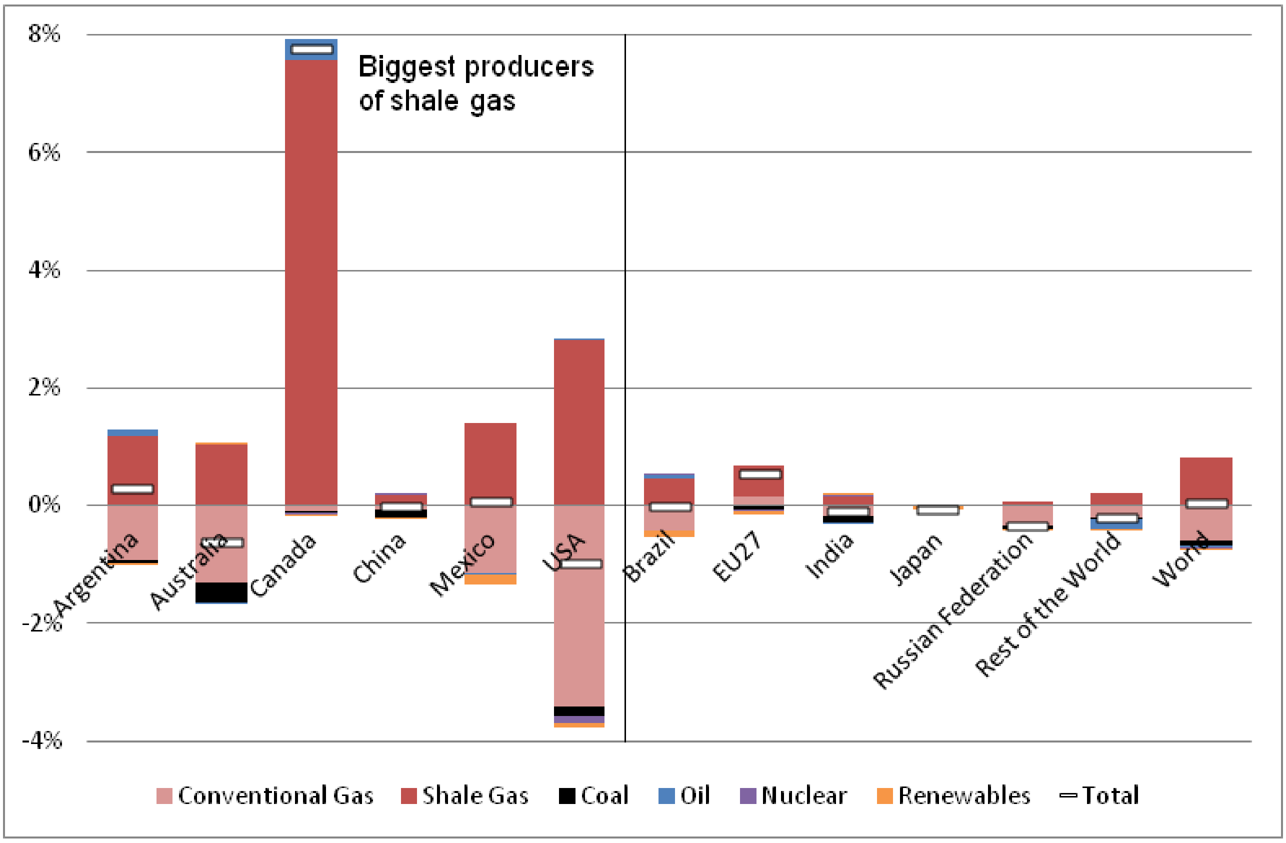
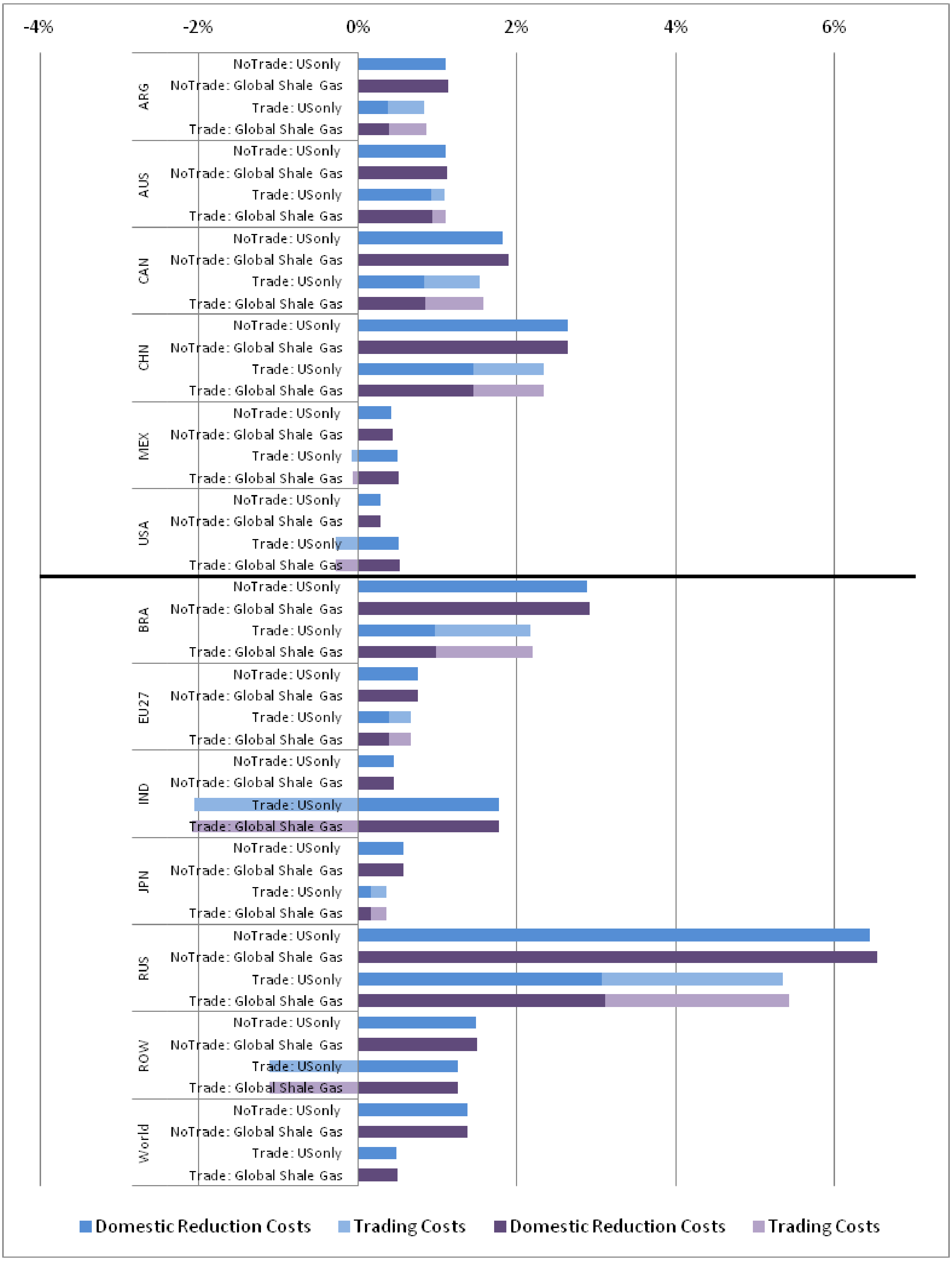


Figure A5: Compliance costs per GDP for the *mitigation case 2030* in *US only* and *Global Shale Gas* scenarios. (*all trade* case)



Note: Negative bars indicate earnings from the sale of emission certificates.

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