Achieving the 2°C target will not be facilitated by relying on a global abundance of natural gas

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Introduction

Owing to the benefits brought by the US shale gas boom - notably economic gains and reduced carbon emissions, natural gas has been touted as a bridge to a low-carbon future. Its lower carbon footprint compared to coal makes it indeed an attractive carbon mitigation option. As a result, several countries are seeking to replicate the North American development. This could lead to a “golden age of gas” that could bless the world with a global abundance of natural gas (IEA 2012). Regular upward revisions in natural gas resources support the possibility of such future global gas bonanza (Rogner 1997, BGR 2012). However, should the risks of dangerous climate change be reduced, this ”golden age of gas” would have to occur simultaneously with a global energy transition aiming at reducing greenhouse gas (GHG) emissions (IPCC 2014).

A global carbon pricing regime consistent with the 2°C target is widely seen as a comprehensive climate policy and an efficient means to incentivise this transition. But slow progress in international climate negotiations suggest that the implementation of such climate policy will be delayed by several years, despite a broad consensus on the 2°C target (IPCC 2014). In the context of delayed but stringent climate policies, could an abundance of natural gas act as a temporary substitute for a comprehensive climate policy by lowering the economic costs of climate policies and facilitating the near-term energy transition?

In this analysis we address this research question by investigating (i) the role of an abundance of natural gas under delayed climate policies and the associated economic costs as well as (ii) the subsequent impacts on energy markets.

The implications of using natural gas for climate change have been explored from various perspectives. Though a number of LCA studies have thoroughly demonstrated the advantage of using natural gas rather than coal in term of GHG emissions (Heath et al 2014, O'Donoughue et al 2014), several US modeling studies of the energy-economy system have emphasized the important role of energy market dynamics in an abundant gas world that can yield greater GHG emissions (Jacoby et al 2012, EMF26 2013, Shearer et al 2014). The reason is that an abundance of natural gas lead to a larger energy consumption and a preference for natural gas over low-carbon energy technologies. These findings are supported at the global level by a recent multi-model study in which the authors have investigated the implications of relying on abundant natural gas (McJeon et al 2014). This global analysis was however performed in the absence of climate policies.

The crucial role of climate policies to curb GHG emissions and avoid dangerous climate change has been extensively studied in the past. From an economic perspective, the most efficient and effective climate policy is an immediate global carbon pricing regime that aims to limit a rise of global average temperature to 2°C by 2100, in order to avoid dangerous climate change (IPCC 2014).

Despite a broad consensus on the 2°C target as well as various pledges and commitments to reduce carbon emissions, current and planned climate policies remain however fragmented and progress too slowly to avoid dangerous climate change (IPCC 2014). Delaying the adoption of comprehensive climate policies increase mitigation costs dramatically because GHG emitted during the delay need to be compensated later by quickly deploying a larger number of low-carbon and/or CDR capacities and retiring redundant power plants with a high carbon footprint (Luderer et al 2013, Riahi et al 2015).

By promoting the use of a particular low-carbon technology, a technology policy can however temporarily act as a carbon pricing substitute. When implemented optimally, technology policies can go a long way in reducing mitigation costs (Fischer and Newell 2008, Bauer et al 2011, Kalkhul 2013, Kriegler et al 2014, Bertram et al 2015). Nevertheless promoting natural gas can lead to a carbon lock-in (Schrag 2012). When this lock-in occur in conjunction with delayed climate policies, the unexpected introduction (being gradually phased-in or suddenly implemented) of a comprehensive global price regime later can result in stranded assets of power plants and lead to additional costs (Johnsson et al 2014, Bertram et al 2014). Low-carbon energy technologies such as renewables, CCS and nuclear are pivotal elements of the climate change mitigation portfolio (IPCC 2014). Therefore, should an abundance of gas help a transition towards a low-carbon energy system, it should not only alleviate the costs of policies but also promote the deployment of renewables, nuclear and CCS technologies and avoid natural gas lock-ins.

Methodology

With the help of an integrated model of the global energy-economy-climate system: REMIND, we investigate the role of a global abundance of natural gas under various climate policies and calculate a set of policy relevant metrics to evaluate to which degree it helps the implementation of climate policies. We first present the REMIND model and then provide a description of the scenarios.

Model description

REMIND is a global multi-regional integrated assessment model that represents the macro-economic, energy and climate systems as well as their interactions over the 21th century. In its default configuration, this inter-temporal optimisation model computes a unique Pareto-optimal solution that corresponds to the market equilibrium in the absence of climate externalities. Each of its 11 world regions is represented by a Ramsey-type growth model which is hard linked to a detailed bottom-up energy model (Bauer et al 2008). Furthermore, regions engage in the trade of primary energy carriers such as coal, gas and oil as well as in final goods (Leimbach et al 2010).
The relatively detailed energy system comprises renewable and non-renewable primary energy carriers (e.g. coal, gas, oil, uranium, wind, solar…) which are transformed into secondary and end-use energies via a set of more than 50 technologies. The fossil fuel sector is also fairly detailed (Bauer et al 2013). Technically available amounts of oil, gas and coal and their associated production costs are represented as endowments of the various regions by cumulative extraction cost functions (Rogner 1997, BGR 2012, Rogner 2012, Bauer et al 2013). Each function is divided into 8 to 10 grades in a piecewise linear fashion to account for the different fossil fuel types (e.g. conventional oil and gas, deep-offshore oil, tight oil, shale gas, CBM, lignite, hard coal …). In addition the dynamics of the sector are captured by various constraints: (i) a maximum increase rate of extraction that is limited to 15% per year, (ii) a minimum decline rate ranging between 2% to 15% that accounts for the natural production decline of reservoirs (IEA 2008, 2009) and (iii) adjustment costs that represent fossil fuel supply and trade inertia via quadratic functions (Dahl and Duggan 1998, Krichene 2002, Askari and Krichene 2010). The inter-temporal nature of fossil fuel supply is fully represented in the model framework. The trade of coal, gas and oil is explicitly

modelled and transport costs are taken into account. Tax and subsidies are also applied. The prices of fossil fuels are endogenously determined to balance global demand and supply.

The model calculates energy related CO_2 and non-CO_2 GHG and aerosol emissions via time-dependent emission factors. In particular, CH4 leakage from fossil fuel extraction is taken into account.

For a more detailed description of the model, we refer the reader to the online documentation (Luderer et al 2013).

Scenario description

A summary of the scenarios performed in this analysis is shown in Table 1. We explore the effect of 4 different climate policies on two states of the world: a gas abundant world (Gas Abundance) and a world reluctant to use natural gas (Gas Reluctance). The climate policy cases are: no climate policy (Baseline), immediate and global carbon pricing regime to reach the 2°C target (Immediate CP), delayed climate policy with a smooth transition from a moderate carbon price to a high carbon price consistent with the 2°C target (Delayed CP (smooth)), and delayed climate policy with a smooth transition from a moderately increasing carbon price to a high carbon price consistent with the 2°C target (Delayed CP (shock)).

	Gas Abundance	**Gas Reluctance**
Baseline	GA-B	GR-B
Immediate CP	GA-iCP	GR-iCP
Delayed CP (smooth)	GA-dCPsm	GR-dCPsm
Delayed CP (shock)	GA-dCPsh	GR-dCPsh

Table 1: Scenarios generated with REMIND and explored in this analysis.

To construct the Gas Abundance and Gas Reluctance scenarios, we adopt the natural gas resources assumptions from Bauer et al (2015). These are displayed in Figure 1. The Gas Reluctance scenario represents a world that presents a certain averseness to the use of natural gas whereas the Gas Abundance scenario represents a world in a quest for global natural gas abundance, investing in the exploration, extraction and exploitation of natural gas.

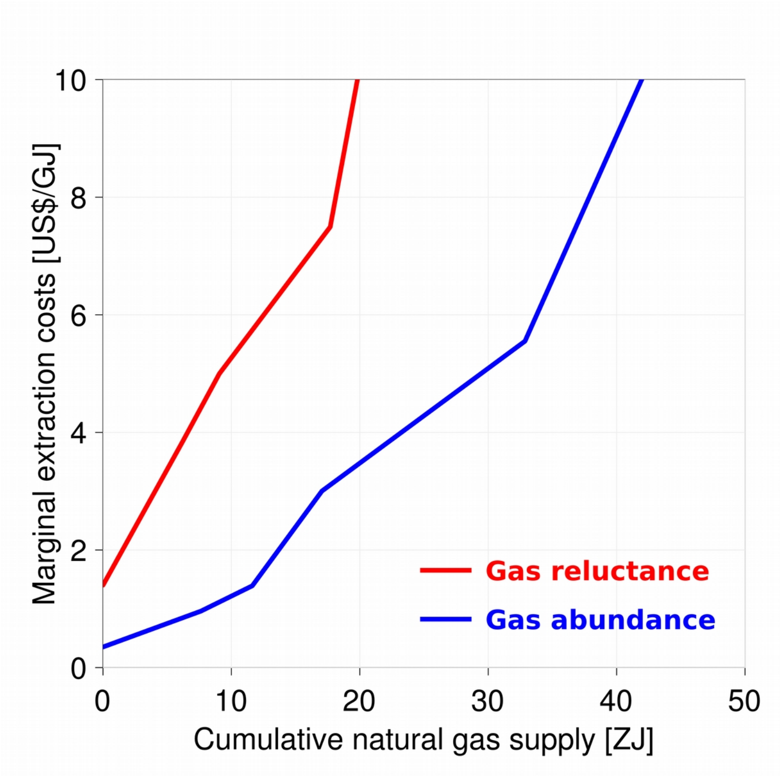

Figure 1: Cumulative supply cost curve of natural gas in the gas abundance and gas reluctance scenarios.

In addition we also consider 4 climate policy scenario cases: no climate policy, immediate climate policy, and 2 delayed climate policies. As in the RCP scenario, a radiative forcing target in 2100 is chosen; we opt for a 2.6 $W.m^{-2}$ target for all climate policies scenarios which is consistent with a 66% probability of limiting a rise in global average temperature to 2°C by 2100. In the delayed climate policy case with smooth transition, the Cancún pledges are followed by world regions until 2020, then countries transition linearly to a global carbon pricing regime that become binding in 2040. In the delayed climate policy case with a shock, a moderate global carbon price is applied between 2015 and 2030 which is followed by a stringent climate policy. In the immediate climate policy case, countries agree on a global carbon price in 2015 to reach the target of 2.6 $W.m^{-2}$ in 2100.

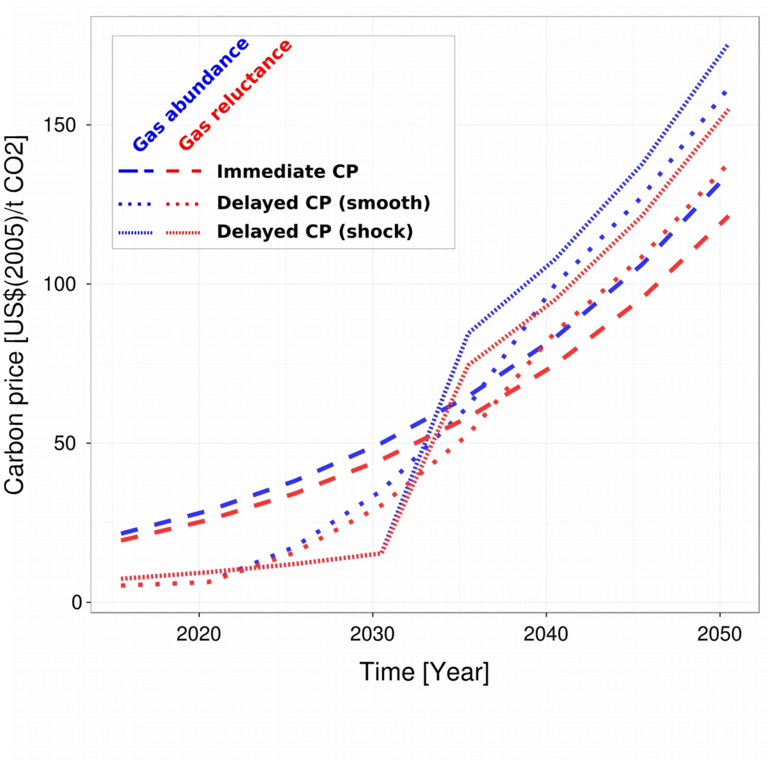

Figure 2: Global carbon prices computed endogenously by REMIND in the different climate policy scenarios.

This approach enables us to explore the impacts of an abundance of natural gas along the whole natural gas chain, from resource extraction to end-use consumers.

Results

Since most effects induced by change in natural gas supply occur to the global electricity system, we analyse changes in cumulative electricity generation potential between 2011 and 2050 (Fig. 3). To gain insights on the effects that happen before and after the implementation of stringent climate policies in delayed scenarios, we further split this time frame into the time ranges 2011-2030 and 2031-2050.

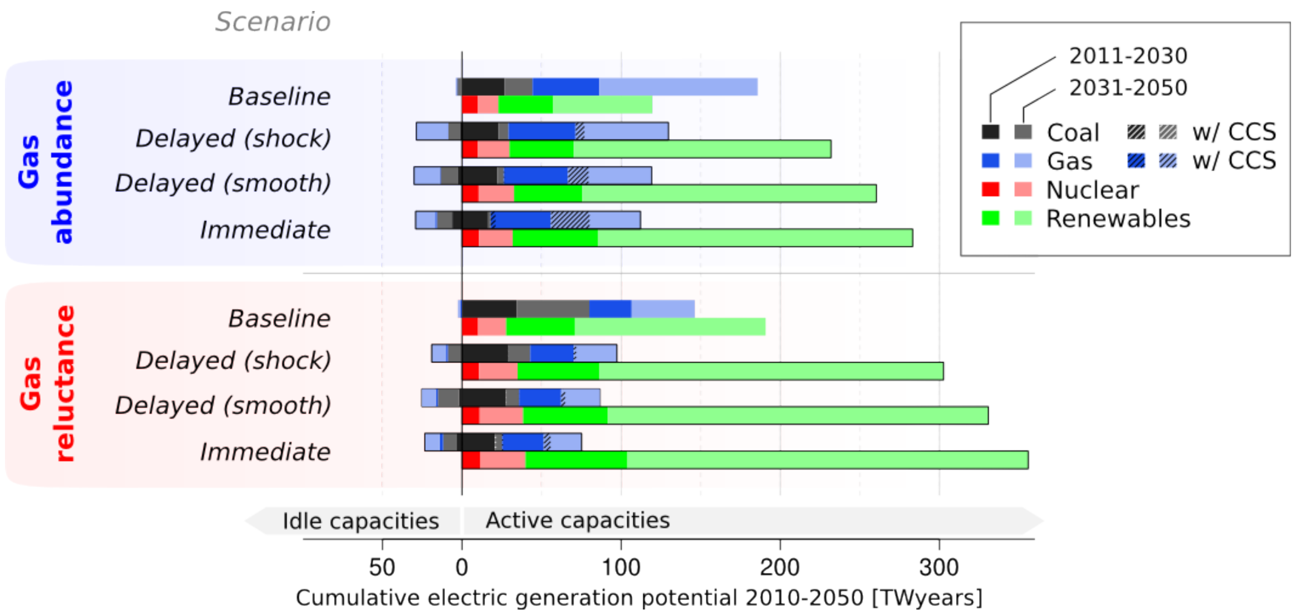

Figure 3: Cumulative electricity generation potential between 2011-2050 in the different scenarios.

By first looking at differences between the gas abundance and reluctance cases across all scenarios, one can observe a robust feature that was already shown in previous studies: a world relying on a global abundance of gas substitutes coal, nuclear and renewable capacities for natural gas ones. This substitution is more pronounced between 2031-2050 because of the inertia of the system.

In addition, there are two important effects on the electricity sector resulting from the implementation of climate policies in a gas abundant world, compared to a gas reluctant world.

First the deployment of low-carbon technologies such as nuclear and renewables is substituted by a larger deployment of gas capacities, including those fitted with CCS technologies. In case of delayed climate policies, the deployment of gas with CCS and other low-carbon technologies is lessened because of false expectations about the future establishment of a stringent carbon price regime and system inertia.

Second a world relying on abundant gas has a larger amount of idle capacities than a world reluctant on using natural gas. This amount is dominated by gas capacities without CCS, particularly in the delayed climate policy cases. In the immediate climate policy case, a larger amount of coal capacities are retired in the first period (2011-2030). A reluctance to use natural gas implies that a larger number of coal capacities are idle than gas capacities.

It is also interesting to look at the amount of electricity produced over the time period 2011-2050 (Table 2). An abundance of gas lead to a larger global electricity production as shown in previous studies. This yields a slightly larger global GDP and lower electricity prices. However these advantages remain rather small.

Gas case	Gas abundance				Gas reluctance			
Climate policy	Baseline	Immediate	Delayed (smooth)	Delayed (shock)	Baseline	Immediate	Delayed (smooth)	Delayed (shock)
GDP 2030 [Trilion US$/yr]	144.0	141.6	142.8	143.2	143.2	141.0	141.9	142.2
GDP 2050 [Trilion US$/yr]	233.8	228.2	227.4	226.8	232.2	228.0	227.3	227.0
Cum elec produced 2011-2050 [EJ]	5920	5670	5670	5590	5620	5450	5450	5420
Elec. Price in 2030 [US$/GJ]	19	24	22	20	21	26	25	23
Elec. Price in 2050 [US$/GJ]	20	23	24	26	22	23	24	25

Table 2: Global cumulative electricity produced between 2011-2050 and global electricity price in 2030 and 2050 in the different scenarios.

From a climate change perspective, all abundant gas scenarios exhibit systematically larger GHG emissions which result in larger cumulative GHG emissions in 2050 (Fig. 4a). The immediate climate policy scenario has the smallest emissions whereas the delayed climate policy with instantaneous transition to a stringent climate policy has the largest (after the baseline case). Compared to the baseline case, differences in emissions between the abundant and reluctance gas cases are gradually reduced over 2010-2050.

To better understand the effects of relying on an abundance of natural gas from an economic and GHG emission perspective, it is interesting to look at the amount of energy produced per unit of GDP (energy intensity) as well as the amount of carbon emitted per unit of energy produced (carbon intensity) (Fig. 4b). The two metrics provide an indication of the levers actioned by the model to mitigate carbon emissions by either restructuring the energy supply sector or reducing energy demand.

One can first observe the clear separation between baseline and climate policy scenarios. Climate policy scenarios have a much larger reduction in both energy and carbon intensities. A second important observation is the gradual convergence of energy and carbon intensities in delayed climate policy scenarios towards those in immediate climate policy scenarios between 2020 and 2050, which explains the emission convergence noticed earlier.

In addition the effects of abundant gas under climate policies are well depicted on this figure. During the convergence phase, an abundance of gas allows a larger production of energy per unit of GDP, especially in the delayed climate policy scenarios. However the initial carbon intensity advantage of a global energy system relying on abundant gas progressively disappears and vanishes after 2030. These 2 dynamic effects result in larger emissions in an abundant gas case.

From a climate mitigation perspective, abundant gas can thus only bring short-term benefits and push some of the near-term emission reduction efforts into the future .

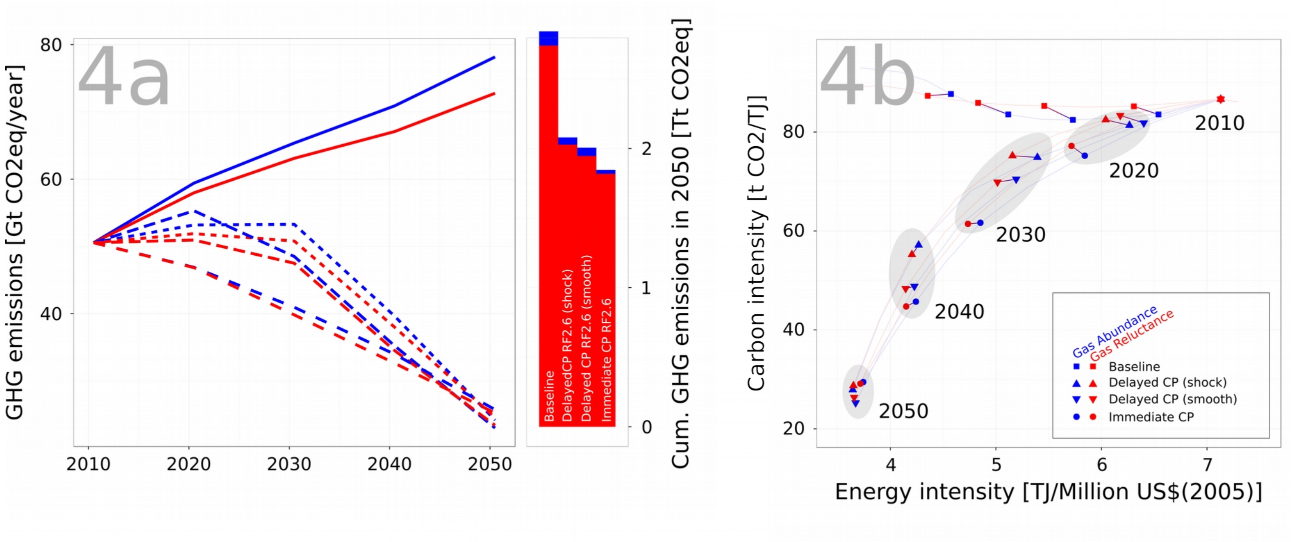

Figure 4: Greenhouse gas emissions between 2010 and 2050 in the different scenarios (panel 4a). Cumulative GHG emissions in 2050 are indicated in the bar plot on the right. Energy intensity and carbon intensity are displayed in the panel 4b.

Larger GHG emissions over the first half of the 21st century will necessary increase mitigation costs, at least in the medium and long term. We compute these costs and present them in Table 3. In the short-term, differences are small with a tiny cost advantage in an abundant gas world. However, as comprehensive climate policies are phasing-in, this advantage is gradually lost.

Gas case	**Gas abundance**			**Gas reluctance**		
Climate policy	Immediate	Delayed (smooth)	Delayed (shock)	Immediate	Delayed (smooth)	Delayed (shock)
Mitigation costs 2011 – 2030 [%]	0.25	0.08	0.03	0.25	0.08	0.06
Mitigation costs 2011 – 2050 [%]	0.82	0.72	0.64	0.70	0.58	0.52
Mitigation costs 2011 – 2100 [%]	1.65	1.71	1.79	1.36	1.38	1.45
GDP growth reduction 2011-2030 [pp per dec.]	0.87	0.43	0.29	0.80	0.47	0.36
GDP growth reduction 2031-2050 [pp per dec.]	0.38	0.99	1.27	0.16	0.65	0.82

Table 3: Cumulative GDP, mitigation costs and GDP growth reduction in the different scenarios.

Because of the larger reduction in energy intensity in the abundant gas scenarios, the effect of climate policies on GDP growth rate are larger, especially in the delayed cases. This is noticeable after the period of short-term benefits 2015-2030. In other words, the opportunity costs are greater in the abundant gas scenarios.

It is worthwhile to note that at the regional level, it is important to note that policy costs increase proportionally across the majority of model regions (except LAM), suggesting that an abundant gas world is unlikely to yield a fairer distribution of policy costs.

Discussion and conclusions

As claimed by some natural gas proponents, an abundance of gas is shown to bring some benefits, such as a larger GDP and a more rapid modernization of energy by expanding the electricity system associated with a decline in electricity prices.

Our results also reveal (see supplementary material) that an abundance of gas yields a decrease in total natural gas and coal trade, thus improving overall energy security (Jewell 2014, Cherp and Jewell 2014). At the regional level, the picture is mixed. While some regions like Europe, the USA and Southern Asia decrease their imports of gas, others like China, India and Japan increase them.

Nevertheless these benefits are marginal and of short-term nature. More importantly, relying on an abundance of gas produces greater GHG emissions. When comprehensive climate policies consistent with the 2°C target are delayed, as it is currently the case, mitigation costs after the implementation of the stringent climate policy are increased because of the atmospheric carbon disposal space is reduced and more electric capacities relying on fossil fuels need to be retired. As a result the opportunity costs of implementing a comprehensive climate policy after period of weak climate policies are higher in a gas abundant world. This outcome could lead to an even greater resistance to the implementation of climate policies.

In light of these results, an abundant-gas world seems unlikely to facilitate the implementation of stringent climate policies. Natural gas has indeed the potential to play a crucial role as an option to comply with climate policies, but the policy interference needs to be stronger rather than weaker. Particularly, timely implementation of global emissions pricing is more urgently needed because delaying the policy lead to higher social costs if gas is abundant. Therefore, the abundance of natural gas is socially desirable, but also increases the challenge to achieve climate change stabilisation.

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