Coal-to-Gas Bridge Incompatible with Paris Agreement Goals

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Abstract

Achieving the 1.5°C temperature target of the Paris Agreement requires rapid and significant reductions in emissions. There is strong evidence that electricity generation from coal must rapidly decrease to achieve this goal, but a large range of uncertainty over a potential bridging role of natural gas in the electricity sector. Using the integrated assessment model REMIND, we find that pathways that meet the 1.5°C temperature target with low overshoot show a marked ‘off-ramp’ characteristic for natural gas rather than a bridge. Natural gas electricity generation in 2030 decreases to 12–15 EJ (from 23 EJ currently) due to policy action implied by carbon prices above 250 USD/t; low carbon electricity generation reaches a median share of 80% and nearly 100% by 2050. This is driven by early and sustained investment in low carbon sources and storage capacity. The lack of a natural gas bridge globally has regional implications such as a coal-to-renewable switch for China, avoiding an intermediate natural gas stage, and the start of a natural gas phaseout in the USA.

Main

The COVID-19 pandemic led to an unprecedented drop in emissions in the first half of 2020, accompanied by significant stimulus and recovery packages that aim to ameliorate economic impacts stemming from the pandemic¹. Despite research indicating the need for a sustained shift toward low-carbon investment in the energy sector², and indicating this is feasible when compared to the overall size of stimulus packages³, several governments are including investments in natural gas generation in their recovery packages⁴.

Currently, approximately 40% (relatively stable between 2010 and 2019) of natural gas consumption globally is in the power sector. The International Energy Agency’s latest World Energy Outlook sees natural gas generation growing rapidly in several regions⁵. This growth is due, at least in part, to a belief that natural gas is a ‘bridging technology’ in the electricity system that can help achieve climate goals.

This ‘bridging role’ has been largely premised on the emissions reductions achieved by switching from coal to gas as well as the perceived need for gas to complement variable renewable energy (VRE) sources at high penetrations. The former argument has been investigated and criticized in the literature^{6–9}; the latter argument is being challenged by the rapidly declining costs of renewable energy and storage technologies¹⁰.

Recent research has attempted to estimate the difference between committed emissions from current and planned infrastructure and Integrated Assessment Model (IAM) scenarios (for varying climate targets) to assess the stranding risk that natural gas power generation faces¹¹. However, IAM models draw an ambiguous picture. Scenario results, despite reaching the same end of century warming, show a large range of future natural gas power generation (ranging from 2 EJ/y – 45 EJ/y in 2030; see Fig. 1a)¹². Natural gas consumption for electricity either increases, building a ‘natural gas bridge’, or

decreases with respect to current consumption levels, which we term an ‘off-ramp’ scenario. Similar (relative) scenario ranges also occur across different regions (Fig. 1b).

Each scenario underlying the Special Report on 1.5°C (SR1.5 henceforth) was designed to answer a different set of questions and it is uncertain whether the range of uncertainty for natural gas generation is due to differences in model structure or differences in the scenario design. The scenarios underpinning the SR1.5 assessment span a large range of futures from a technology and policy perspective that robust conclusions on the future of natural gas are absent from the report and subsequent literature, and require additional analysis to reduce such uncertainty. In this paper we demonstrate that this range of uncertainty can be significantly narrowed.

We analyze a dataset of 137 internally consistent 1.5°C scenarios from the REMIND v1.7 Integrated Assessment Model¹³ (further details in Methods). We further assess their climate impact to classify those that meet the definition of “no or low-overshoot pathways” as defined in the SR1.5 and assessed as consistent with the Long-Term Temperature Goal of the Paris Agreement (29 scenarios). These scenarios have at least a 33% probability of remaining below 1.5°C through the course of the century and at least a 50% chance of limiting warming below 1.5°C in 2100.

The scenarios vary along two dimensions: short term action to reduce emissions (represented by different levels of global carbon prices in 2030) and long-term availability of carbon dioxide removal (CDR) technologies (represented by an annual constraint on CDR availability). The combination of these two sets of parameters leads to different levels of overshoot beyond the 1.5°C warming limit. We find that natural gas plays a ‘bridging’ role only in the “Paris *incompatible*” scenarios that delay climate action and overshoot the Long-Term Temperature Goal (LTTG) of the Paris Agreement by a large margin.

Is there evidence of a natural gas bridge in 1.5°C scenarios?

We first investigate how the natural gas bridge responds to near-term carbon price signals. A bridge can be defined as a scenario in which natural gas generation grows above the generation in 2020 and the length of the bridge can be defined as the number of years until the generation falls below 2020 levels. In our full scenario set, gas used for electricity generation peaks at the latest in 2030 and falls below 2020 values by 2035 at the latest, indicating that the maximum length of a bridge is 15 years.

From our set of 137 scenarios, 78 can be characterized as ‘off-ramp’ scenarios (*i.e.*, with gas generation never increasing above 2020 values), and the rest of the scenarios either have a peak gas generation in 2025 ($n = 29$) or 2030 ($n = 30$) (Fig. 2a). We identify scenarios that **do not** exhibit a bridging role for natural gas in electricity generation and then further divide these scenarios into the two above-mentioned subsets: those that have a low overshoot and are therefore Paris Agreement compatible (lower left quadrant in Fig. 2a), and those with higher overshoot, implying higher levels of CDR deployment in compensation later in the century (lower right quadrant in Fig. 2a).

There is a strong relationship between the year of peak natural gas generation and the carbon price in 2030 (**Supplementary Information** Fig. 1). Low near-term carbon prices (in 2030) ranging from 10–50 US\$ 2005/tCO₂ allow natural gas generation to grow to 36–41 EJ in 2030 and moderate near-term carbon prices ranging from 70–126 US\$2005/tCO₂ allow natural gas generation to peak between 21–33 EJ in 2030. More stringent near-term carbon prices ranging from 146–1200 US\$2005/tCO₂ result in a marked “off-ramp” characteristic for natural gas generation, which falls to 12–20 EJ in 2030.

We observe that the off-ramp characteristic is a necessary, but not sufficient feature of low overshoot pathways (i.e., all low overshoot pathways are off-ramp pathways, the reverse is not necessarily true). Both the “bridge” and the “off-ramp” scenario sets contain scenarios that span different temperature categories, largely due to the differences in CDR deployment post-2030. Of the 29 pathways that can be classified as “Paris Compatible” pathways, the minimum carbon price is 250 US\$2005/tCO₂ with a range of natural gas generation in 2030 of 12–15 EJ (Fig. 2b).

The average yearly CDR deployment for these low-overshoot ‘off-ramp’ scenarios ranges from 6–12 GtCO₂ per annum. While CDR deployment does not affect the bridge, it can prolong the use of gas for electricity generation at low levels. If a higher CDR potential is postulated the model chooses to complement VRE with flexible natural gas, and compensate with CDR later. If the CDR option is reduced, the flexibility comes from storage instead of natural gas.

What does Paris compatibility require in addition to a gas power off-ramp?

Paris compatibility additionally requires a rapid low-carbon transformation in addition to reduced dependence on natural gas generation in the scenarios we assess. The emission intensity of electricity generation drops from a median of 459 gCO₂/kWh in 2020 to 119 gCO₂/kWh in 2030 and falls further to close to zero by 2040 (Fig. 3b). This is consistent with the requirement that the power sector decarbonize much more quickly than non-electric energy supply, and the need for low-carbon power to electrify hitherto non-electric energy demands in 1.5°C pathways¹⁴. For reference, the emission intensity of coal and gas generation are around 1000 and 400 gCO₂/kWh. Thus, while a switch from coal to natural gas generation can lead to a rapid emission drop, this is inconsistent with the rapid overall drop in the emission intensity of electricity generation in our Paris Agreement compatible set.

We find that this is largely due to economic dynamics within the modelling framework: while natural gas power generation equipped with carbon capture and storage (CCS) is an option represented in the REMIND model and could result in natural gas with CCS helping to meet the overall requirement for rapid decarbonisation of electricity generation, the model does not select this option as a transition to a renewable-based power system is identified as a more cost-effective option.

Paris-agreement compatible scenarios thus employ significant ramping up of low-carbon energy sources in the power sector. The alternative to natural gas is a strong, and sustained growth in wind and solar electricity generation, with the median of our Paris Agreement compatible set growing from 11 EJ in 2020

to 60 EJ in 2030 (*range: 55–68 EJ*) and 164 EJ (*range: 83–200 EJ*) in 2040 (Fig. 3c). Renewable electricity generation from wind and solar energy grows to account for a median share of 79% (*range: 50–81%*) of total electricity generation by mid-century, with low carbon sources including nuclear energy (*median share of 7% with a range from 6–28%*) and hydropower (*median share of 10% with a range from 9–19%*) making up the balance.

While the relative shares of these technology options vary as a function of the discontinuity in carbon prices post-2030 and represent alternative perspectives on the electricity mix all pathways show a strong tendency to a 100% low carbon electricity system. Our results generated using the REMIND model are consistent with other lines of evidence from bottom-up energy system models that do not take into account whole-economy feedbacks and find that 100% renewable electricity systems are technoeconomically feasible by 2050^{15–19}.

The transformation to renewables is supported by a sustained shift (and growth) in investments in short-term battery storage, and longer-term storage using, for example, hydrogen, and grid infrastructure (Fig. 3d-f). In addition to the storage of energy, batteries can also provide other services such as frequency stabilization and grid inertia, at least as effectively and quickly as traditional thermal generators. Although storage needs in REMIND are rather coarsely modeled due to the lack of high time resolution, parameterization of storage in the model does allow for rough estimates²⁰. The median of the Paris Compatible pathways shows a rapid increase in investments in storage, from 7 billion US\$2005 in 2020 to around 350 billion US\$2005 in 2030 with grid investments doubling to around 780 billion US\$2005 in 2030 compared to 2020. These estimates also take into account that some degree of curtailment of variable renewable energy can actually be part of a cost-optimal system²⁰. Investments in gas collapse to zero from current levels.

Expressed differently, model outputs show that the renewable energy pathway is economically favorable; were actual investments in fossil fuel infrastructure to continue or increase as in the bridge narrative, the likely result would be a stranding of those assets in a world consistent with the Paris Agreement. A rapid increase in storage and grid investments is consistent with the observation by McCollum et al. (2018), who note that “... the models exhibiting the largest increase in supply-side investments in the 2°C and 1.5°C pathways (AIM/CGE and REMIND-MAgPIE) are also the ones with the most rapid upscaling of renewable electricity capacity”².

While the primary area of investigation of this paper is future natural gas use for electricity generation, a similar lack of a bridging role is observed for total gas for primary energy (Fig. 3a) for the Paris Compatible scenarios. The median of total gas for primary energy in our Paris Compatible set is more than halved from 150 EJ in 2020 to 61 EJ in 2030 (*range: 60–67 EJ*) and 25 EJ by 2040 (*range: 1–50 EJ*).

No Gas Bridge To Net-zero Visions For Major Economies

Our analysis highlights the lack of a role for a natural gas bridge in Paris Agreement compatible energy system transformations globally. To examine the regional implications, we look into the cases of China and the United States of America, which have recently announced their intention to achieve net-zero emissions. China has relatively low levels of natural gas generation (~ 1 EJ in 2019, representing less than 3% of total electricity generation) and the US has relatively higher levels of natural gas generation (~ 6 EJ in 2019, representing 38% of total electricity generation).

We use the national target quantification provided by the Climate Action Tracker²¹, which reports emissions in total GHG emissions excluding Land Use, Land Use Change and Forestry emissions (LULUCF) and international bunker emissions and compare this to the emission band of our Paris Agreement compatible set of scenarios.

China's net-zero vision until 2060 lies within the emission band of our Paris Agreement compatible scenario set. However, a large emission gap (*range: 7.8–9.7 GtCO₂eq*) can be observed between the NDC emission level in 2030 and the emission band of our Paris Agreement compatible scenario set (Fig. 4a). Aligning short-term policies with a trajectory consistent with our Paris Agreement scenario set required electricity generation from coal to reduce from 14.6 EJ in 2020 to a median level of 4.93 EJ in 2030 (*range: 4.93–4.96 EJ*) and close to zero by 2040 (Fig. 4b). Generation from wind and solar grows from 3.6 EJ in 2020 to a median level of 16.8 EJ in 2030 (*range: 15.9–18.7 EJ*) and to a median level of 41.8 EJ in 2040 (*range: 30–46.8 EJ*). Closing the emission gap in 2030 requires China to **avoid phasing in** gas for electricity to substitute for coal, with gas generation following coal in being phased out by 2040.

US President Biden's announcement of a net-zero power sector by 2035 is a key element of his administration's intent to achieve net-zero emissions by 2050²². The median emission intensity of electricity generation in our Paris Agreement compatible scenarios for the US drop from 405 gCO₂/kWh to 50.6 gCO₂/kWh in 2030 and further down to 9.5 gCO₂/kWh by 2035. This rapid decline leaves little space for either coal or natural gas generation, with coal generation falling from a median level of 4.56 EJ in 2020 to 0 EJ (*range: 0–0.5 EJ*) by 2030 and gas generation falling from a median level of 6 EJ in 2020 to 2.3 EJ in 2030 (*range: 2.2–3.5 EJ*) and phased out by 2040. Closing the emission gap in 2030 (*range: 1.2–3.2 GtCO₂eq*) will require a phaseout of both coal and gas, with electricity generation from wind and solar growing from 1.5 EJ in 2020 to a median level of 10.5 EJ in 2030 (*range: 9.4–12.5 EJ*).

Conclusion

While the rapid decrease of coal in electricity systems is reflected in virtually all analyses of 1.5°C and 2°C transformation pathways, a key open question has been that of the future development of natural gas. By analyzing a broad and consistent set of 1.5°C mitigation pathways generated by the Integrated Assessment Model REMIND, we find that for Paris compatible scenarios the role of natural gas is better described as an off-ramp toward a renewable energy-based system rather than a bridge. This result has significant implications for both climate policy and investment decisions in the near-term. We show that a bridging role for natural gas in the power sector is risking large overshoots of the 1.5°C guardrail, while

relying on substantial and uncertain amounts of CDR. In contrast, Paris compatible scenarios require large near-term investments in renewable energy (primarily wind and solar PV) accompanied by battery storage, but not in natural gas infrastructure. Given the rapid cost decreases in renewable energy and storage, near-term investments in natural gas infrastructure may well lead to natural gas becoming the new coal within the current decade – with stranded assets abandoned for newer, cheaper, cleaner technologies.

Integrated Assessment Models provide information on technological transformations that are consistent with desired climate change outcomes, relying on input assumptions; the value in using IAMs lies not in the results from a single particular scenario, but in examining the trends and outputs from a wide variety of scenarios in which many technological parameters can be varied. The potential downside of this approach is that the large range of output trajectories may give the appearance that all results are equal, thus providing little guidance for policymakers. Here we have presented a generally applicable methodology and results for down-selecting from a larger parameter space of potential scenarios those pathways meeting the Paris Agreement long-term temperature goal.

Our approach, while focused on a large number of scenarios from the IAM REMIND to gain a deeper understanding of parameter and scenario construction dependencies, is generalizable to any IAM. Further investigations with other IAMs should be carried out, but the model flexibility to incorporate large penetrations of variable renewable energy may be one key characteristic of interest. IAMs have historically underestimated the rate of increase in renewable energy production and have been catching up to actual technological advances only very recently²³. Thus, it can be anticipated that IAMs will continue to converge toward the results shown by bottom-up energy system models that demonstrate transitions to 100% renewable energy systems. An important feature not present in most energy models, however, is the important role played by political will and locally-based constraints on energy system transformation, independent of the availability and economic advantages of renewable technologies.

Methods

REMIND Scenario Design

In this study, we evaluate the amount of natural gas used for electricity at the global and regional level in Paris Agreement compatible scenarios by varying levels of near-term action and sustained CDR deployment. To achieve this, we use 137 scenarios generated using the global, multi-regional integrated energy-economy-climate model REMIND²⁴ that are consistent with a 400 GtCO₂ carbon budget between 2010 and 2100 (consistent with a 50% chance of keeping warming below 1.5°C in 2100). We provide a description of the model in the Supplementary Information that accompanies this article. These scenarios have previously been used in Strefler et al. (2018) to assess the minimum CDR requirements (global) necessary for meeting end-of-century temperature targets²⁵.

All scenarios follow policies consistent with current policies until 2020. After 2020, it is assumed that global cooperative mitigation starts, represented by a globally uniform carbon price increasing exponentially at 5% per year. Our focus is on scenarios derived using the middle-of-the-road Shared Socioeconomic Pathway (SSP2) as a background for developments that drive energy consumption and technological choices²⁶. The scenarios are varied along two dimensions: Along the policy dimension, we consider different levels of short-term policy ambition from 2021–2030, i.e. different levels of a carbon price, which result in different levels of 2030 emissions. In a second scenario dimension, we vary the maximal annual CDR availability between 0 and 20 Gt CO₂/yr.

Climate Assessment of Scenarios

We further perform a diagnostic assessment of the climate impact of each scenario for this study to ensure that the climate assessment is consistent with the assessment performed for the SR1.5. The emissions from the scenario set are harmonized to the historical dataset used in the Representative Concentration Pathway (RCP) database using 2010 as the base year and using an automated harmonization routine and software that was published after the Special Report was published and missing emission species are infilled using the corresponding trajectories from RCP2.6^{27,28}. An illustration of the effect of harmonization on different emissions species is presented in Supplementary Information.

The harmonized emission pathways are used as an input to the reduced complexity carbon cycle and climate model MAGICC6 in its probabilistic setup using the parameter set from the 5th Assessment Report (and subsequently, the SR1.5)^{29–31}. The harmonized emissions are only used for the climate assessment, while all further insights on emissions presented in this study use raw model outputs.

Declarations

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Author Contributions

G.G. and R.J.B designed this study. J.S. provided output from REMIND. J.S., G.L., F.U. contributed interpretations and background on REMIND. M.J.G. contributed to the conception of the study and assisted in interpreting IAM results. G.G. and R.J.B analyzed data and provided visualizations. G.G. and R.J.B. drafted the manuscript, and all authors contributed to writing the manuscript.

Code Availability

The data and code used for the analysis and creation of plots can be found at :

https://gitlab.com/gaurav-ganti/natural_gas_bridge_paper

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Figures

Figure 1

(a) Evolution of natural gas electricity generation in pathways underlying the Special Report on 1.5°C. The red markers indicate the scenarios used in this study generated using the REMIND model (b) Regional variation in natural gas generation in the SR1.5 pathways.

Figure 2

(a) Comparison between natural gas generation in 2025 against median peak warming in our scenario set. Scenarios below the generation in 2020 are classified as “off-ramp” scenarios and those with generation in 2025 above 2020 generation are classified as “bridge” scenarios. (b) Natural gas generation over time in our scenario set. Scenario results in (a) are further sorted by the carbon price in 2030 according to the color scale at the right.

Figure 3

Energy system transformation characteristics of the Paris Agreement compatible scenarios in this study set. (a) Primary energy demand for natural gas. (b) Emission intensity of electricity generation. (c) Electricity generation from wind and solar. (d) Investments in natural gas for electricity generation. (e) Investments in battery storage. (f) Investments in the electricity grid.

Figure 4

Evaluating the net-zero visions of China and the United States of America. Panel a-d is for China and Panel e-h is for the USA. Panel (a) and (e) represent total greenhouse gas emissions (excluding land use, land-use change and forestry emissions, and bunker emissions), with the 2030 and long-term national targets represented by the triangular markers (according to the Climate Action Tracker²¹). Panel (b) and (f) represent electricity generation from coal. Panel (c) and (g) represent electricity generation from gas. Panel (d) and (h) represent electricity generation from wind and solar. In panels (b-d) and (f-h) the boxplots represent our Paris Agreement compatible scenario set, the dots represent the projections under

stated policies from the World Energy Outlook and the dashes represent the values from the non-Paris-compatible scenarios in our study set.

Supplementary Files

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