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The expansion of natural gas infrastructure puts energy transitions at risk

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Whether additional natural gas infrastructure is needed or would be detrimental to achieving climate protection goals is currently highly controversial. Here we combine five perspectives to argue why expansion of the natural gas infrastructure hinders a renewable energy future and is no bridge technology. We highlight that natural gas is a fossil fuel with a significantly underestimated climate impact that hinders decarbonization through carbon lock-in and stranded assets. We propose five ways to avoid common shortcomings for countries that are developing strategies for greenhouse gas reduction: manage methane emissions of the entire natural gas value chain, revise assumptions of scenario analyses with new research insights on greenhouse gas emissions related to natural gas, replace the 'bridge' narrative with unambiguous decarbonization criteria, avoid additional natural gas lock-ins and methane leakage, and take climate-related risks in energy infrastructure planning seriously.

Despite growing concerns about the negative impacts of natural gas, its production and consumption experienced a steep growth until the start of the COVID-19 pandemic[1]. Consequently, CO_2 emissions related to natural gas grew by 2.6% per year between 2009 and 2018[2]. Continuing investments in the natural gas infrastructure were justified by promoting them as beneficial for the transition to renewable energy sources and by presenting natural gas as a climate-friendly alternative to coal and oil[3–5]. Globally, a massive expansion of natural gas infrastructure is underway: almost 500 GW of natural gas-fired power plants are planned or under construction[6]. Meanwhile, new liquefied natural gas (LNG) import terminals with a capacity of 635 million tonnes of natural gas per year[7] as well as LNG export terminals with a capacity of 700 million tonnes per year are under development[7]. These figures are likely to increase in the future, as a new geopolitical order has been created after Russia entered war with Ukraine. The European Union is now going to great lengths to become independent of Russian gas supplies, which still accounted for more than 40% of the total gas imports to the European Union by February 2022. Germany is responding to this new situation with a draft law that approves up to 11 LNG terminals (seven offshore and four onshore units) under accelerated permitting procedures; these terminals can import fossil natural gas until 2043[8]. Although these expansion plans will create new material realities, political and scientific controversy is growing as to whether the use of natural gas and the related infrastructure should be expanded. In light of climate protection goals, and the fact that natural gas itself is one of the biggest causes of climate change, questions now arise as to whether a rapid decline in natural gas use might be necessary, instead of expansion.

In this Perspective, we argue why the expansion of natural gas infrastructure hinders a renewable energy future and why the natural gas 'bridge' narrative is misleading. Our aim is to stimulate critical discussion by challenging commonly held assumptions on natural gas. We highlight that the climate impact of natural gas has previously been underestimated and that new insights about this are not sufficiently incorporated into energy analyses. At the same time, the bridge narrative is problematic. Meanwhile, investments in natural gas make it harder to achieve climate targets due to lock-ins, and carry high economic risks. Based on these arguments, we put forth five recommendations to stimulate debate on the role of natural gas in decarbonization processes.

Methane emissions are much higher than previously estimated

In the public discourse, natural gas is often described as a climate-friendly alternative to coal that has a much lower negative climate impact than that of other fossil fuels[5,9]. In fact, several studies show that this is only true under certain conditions and that the differences in climate impacts are small and depend on various factors[10–13].

The extraction and use of fossil fuels accounts for about 15–22% of total methane emissions[14]. Along with natural and agricultural sources, it is one of the main sources of methane emissions that accumulate in the atmosphere. The latest research shows that the contribution of anthropogenic fossil fuel sources to total methane emissions has been underestimated in the range of 20–60% (refs. [14,15]). Natural gas consists largely of methane. The latest research on methane emissions related to natural gas production and transport has found that the actual methane leakage rates far exceed previous estimates[14,16]. However, there is no single, generally valid figure for fugitive methane emission rates related to the natural gas sector. This lack is because the rate depends heavily on the individual technical characteristics and process-related factors of the gas system. However, regional studies on upstream methane emissions related to the oil and gas sector in Canada and the United States show that previous studies underestimated methane emissions by 50–60% (refs. [16,17]).

The greenhouse gas (GHG) emissions advantage of natural gas over coal becomes marginal if approximately 3.2% (ref. [11]) to 3.4% (ref. [18]) of the gas produced escapes into the atmosphere before being burned. The total global average leakage rate is estimated to be around 2.2% (ref. [14]). However, some studies that investigated

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individual gas fields even found fugitive emission rates of up to 6% of the total amount of natural gas produced[19]. Also, some measurements showed leakage rates of up to 17% for certain regions and circumstances[20].

These high numbers can be explained by a small number of 'superemitters', which have leakage rates far above the average[21]. In addition to overall fugitive emission, unintended processing conditions along the supply chain of natural gas release huge amounts of methane from point sources. They are caused by malfunctions and equipment failures, and lead to disproportional emissions effects[22]. According to a study by Zavala-Araiza et al.[23] on shale gas production sites in Texas, these superemitters account for approximately one-third of overall emissions released from shale gas production sites. As these emissions occur from point sources that are increasingly easy to detect due to improved detection methods (satellites and remote sensors), these superemitter events might be controlled cost-effectively, and so avoid large amounts of methane leaking into the atmosphere. Developing and implementing monitoring approaches that are able to detect superemitting events in a more timely manner, and thus reduce the frequency of large emission events, is a crucial first step to regulate methane emissions[23]. Nevertheless, given the limited GHG budget left, such regulations—as well as leakage control—cannot replace a strong reduction in natural gas consumption: natural gas is still a fossil fuel that emits large amounts of CO_2 during combustion, in addition to fugitive methane emissions.

Furthermore, recent studies found that methane has a greater impact on the climate than previously assumed[24–26]. According to the latest figures from the Intergovernmental Panel on Climate Change, the global warming potential (GWP) of methane is up to 87 times greater than that of CO_2 in the first 20 years after emission, and up to 36 times greater in the first 100 years[25]. Given the high global warming potential of methane, especially in the first 20 years, the use of natural gas as a (temporary) substitute for coal may even lead to an additional short-term temperature increase[27]. As a result, the world could reach climate tipping points that could lead to abrupt and irreversible climate change as early as the next decade and, in the worst case, trigger a cascade of global tipping points, leading to a 'hothouse' scenario[28]. Consequently, short-term reductions of methane emissions are a crucial component of climate mitigation efforts.

Emissions from natural gas are poorly treated in scenarios

From a methodological perspective, quantitative model-based scenario analyses are a valuable tool to assess energy systems transitions[29,30]. Importantly, however, the implications of a given scenario depend on the underlying assumptions and accuracy of the models. To avoid poorly designed energy policies, new research on the climate impact of methane (for example, via leakage), non-business as usual assumptions and non-economic factors[31] should be included in scenarios. In many of the scenarios referred to by natural gas proponents, these aspects remain largely unexamined. A representative example is the scenario analysis study by Eurogas that only covers CO_2 from energy use and process emissions, with methane emissions not covered at all[32]. Most importantly, the climate impacts of the use of natural gas have been systematically underestimated in energy system modelling and in the balance of national GHG inventories. This can be observed, for example, in the European Union's commonly used energy system model PRIMES (price-induced market equilibrium system)[33] and the linked GAINS (greenhouse gas and air pollution interactions and synergies) model (applied, for example, in the EU Reference Scenarios 2016 and 2020), which both use outdated GWP_{100} values. This is also the case, for example, in the German Environment Agency's National Greenhouse Gas Inventory Reporting[34].

The latest findings for fossil fuel methane emissions need to be applied to modelling exercises, emissions-budget balancing of the energy system in climate protection scenarios and climate policy derived from such models. Frequently, such calculations insufficiently account for methane emissions that result from leakage during the production, transport and use of natural gas. They also often employ outdated (and therefore lower) values for the global warming impact. Given that the world is quickly approaching several climate tipping points, to account for short-term warming impacts (for example, the 20-year time period) in addition to longer period warming (mostly calculated for 100 years) is of great importance.

Energy system models might find that when incorporating full-life cycle GHG emissions and the updated warming potentials of methane, results on natural gas change drastically. This might force scientists to discard natural gas as anything besides a marginally used fuel, and consider other options, such as energy efficiency and sufficiency in degrowth scenarios[35].

Even though this paper focuses on fossil natural gas, it should not be ignored that the development and expansion of a global hydrogen economy is also associated with climate-damaging emissions. On the one hand, the production of hydrogen from methane (steam reformation) leads to additional methane leakage from natural gas production while CO_2 continues to be emitted, because not all the CO_2 from the reformation process is stored in a final repository[36]. The latest research on the climate impact of so-called 'blue hydrogen' even showed that burning blue hydrogen is related to a 20% greater GHG footprint than burning the fossil natural gas itself[37]. On the other hand, although not yet widely discussed, hydrogen leakage also has a negative impact on the climate. Hydrogen, as a potent indirect GHG, increases the lifetime and amounts of other GHGs, such as methane, ozone and water, which results in additional warming effects in the atmosphere[38,39]. Given these circumstances, ambitions to limit leakage rates should focus on both methane and hydrogen, especially when the goal is to plan climate-neutral 100% renewable energy systems.

Research on the feasibility and transition pathways to 100% renewable energy systems has grown substantially since the 2000s. Several publications for a variety of jurisdictions have shown that 100% renewables are technically feasible[40]. A cross-sectoral perspective of the entire energy system, which includes fluctuating and dispatchable renewables, and various sources of flexibility (for example, energy storage options, demand response and sector coupling) enable 100% renewable energy systems[40,41]. Nevertheless, the economic and political feasibility of the transition are still contested[31,42]. This highlights the planning and governance challenges of restructuring global energy systems and, in particular, those with very high shares of renewables[43–45]. Although natural gas might help with the final small percentage of energy provision to ease technical difficulties[46], it is important to acknowledge the required drastic reduction in absolute natural gas use. This reduction will most probably result in very low shares of capacity utilization of the natural gas infrastructure[47].

Misleading narratives prevent a direct shift to renewables

Agenda setting and the decision-making process at the political level do not take place in a purely objective and fact-based manner but are influenced, for example, by public discourse. For their own interests to be taken into account at the political level, actors feed them into discourses, for example, in the form of narratives[48]. Narratives are easy to convey stories that, at the same time, offer a suitable solution proposal, and can influence the interpretation and understanding of an issue[49]. How successfully a narrative sticks does not mainly depend on whether it is based on facts, but on whether it is coherent in and of itself and if it addresses the concerns of the audience in line with their core beliefs[49].

Advocates of natural gas often use the 'bridge technology' or 'transition fuel' narratives to legitimize investments in natural gas infrastructure and natural gas usage in line with their own economic interests or beliefs.

The bridge technology narrative has been widely used since the 1970s in public discourses around energy transitions[50] (for examples, see Wilson[51] and Delborne et al.[52]). Besides framing the current dominant energy technology (mix) as the problem, this narrative also claims that renewable energy technologies are too technologically immature or unreliable to replace fossil fuels. The solution the narrative presents is that gas is a bridge technology that, although it has its own drawbacks, is still better than the old technology and will help to buy time until renewable energy technologies are mature enough. The bridge narrative seems coherent as long as it is convincing that the bridge technology offers sufficient advantages over the old technology to make the necessary additional investments viable. It is easy for several diverse actors to agree on the bridge technology narrative. This unifying effect is possible because the narrative remains imprecise at crucial points—for example, no information is given about what system the bridge leads to, or until which year the bridge should last[52].

When the bridge technology narrative became popular in the public discourse, coal ('ready' for carbon capture, transport and storage) was considered to be the bridge[51]. This shifted, especially since the shale gas revolution in 2008, and natural gas became the new bridge technology. The long coal bridge since the 1970s, and the ease with which the bridge technology narrative has moved from coal to gas, suggests that the narrative mainly serves to legitimize the continued use of fossil fuels, instead of accelerating the transition to renewables[52,53]. Now, fossil natural gas is often presented as a necessary intermediate step for sustainable system transformations[54], and as an enabler of a hydrogen economy[55,56].

Natural gas lock-ins delay renewable energy transitions

Another argument that proponents of natural gas use is that it is needed to meet national and international climate targets because of its low emissions. This argument is misleading because natural gas causes more emissions than often attributed to it (see above). Furthermore, the ongoing use of natural gas creates carbon lock-ins, which will probably delay the energy transition to renewables[57]. The term carbon lock-in describes the interaction of fossil fuel-based technological systems and related institutions that create barriers to the phase-out of fossil fuels[58], and thus hinder the use of renewable technologies. Carbon lock-in mechanisms can, for instance, be of an infrastructural, institutional or behavioural nature[59].

As gas pipelines, LNG terminals and gas-fired power plants have a technical lifetime of several decades, they pose a particularly great risk for carbon lock-ins. Tong et al.[60] noted that if the currently existing energy infrastructure continues to operate as it has historically, approximately 658 $GtCO_2$ will be released. These emissions would exceed the entire remaining carbon budget to limit global warming to 1.5 °C (420–580 $GtCO_2$). From a climate target perspective, this means that the operation time of the infrastructure must be curtailed. However, the global use of natural gas is still growing[2], which will require even lower utilization rates, or earlier decommissioning of the existing infrastructure. Owing to institutional lock-in mechanisms, such as the legal protection of property and opposition from asset owners, the decommissioning of privately owned infrastructure after only a fraction of its lifespan is very challenging[61].

To circumvent the redundancy of natural gas infrastructure or even to justify the construction of new infrastructure, incumbent actors, particularly in Europe, have proposed the use of synthetic gases and e-fuels in all sectors[62]. Regardless of whether a repurposing of the infrastructure is at all technically possible or economically viable, this idea poses a danger of carbon lock-in. If, for example, as envisaged in the EU hydrogen strategy[63], synthetic gases are first produced by steam methane reforming (SMR) with carbon capture, transport and storage facilities, it will be necessary to construct comprehensive new infrastructure. This would create an additional potential for infrastructural and technological carbon lock-in. Hydrogen production from SMR, and thus of all its derivatives, still causes methane emissions from upstream and midstream natural gas value chains[37,64], and SMR itself emits a substantial amount of GHGs[65]. Today, SMR (without carbon capture, transport and storage) is responsible for around three-quarters of global hydrogen production[66]; an expansion of this process would lead to a significant increase in emissions compared with those from the direct use of natural gas[37]. Besides that, there is a risk that the production of renewable synthetic gases would not be sufficient to replace fossil fuel-based gases and fuels in the medium to long term[67].

Investments in gas infrastructure imply economic risks

It is often argued that investments in natural gas are preferable to those in renewable energy technologies, which are supposedly still technologically immature and comparatively expensive. This argument is misleading, as investments in natural gas infrastructure pose serious economic risks.

One major economic risk is energy asset stranding, which results in a key challenge of the transition to renewable energy sources[68]. Stranded assets are "assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities"[69]. The risk of asset stranding applies to existing and new natural gas infrastructures, due to their long technical lifespans and amortization periods. Smith et al.[70] show that the use of existing and planned fossil fuel infrastructures is not compatible with the 1.5 °C target and that investments in new fossil fuel infrastructure are highly risky. Owing to the diffusion of low-emission technologies and stricter climate policy, the demand for fossil fuels will decline[71]. Hence, the operation of the new infrastructure needs to end before their technical lifetime, and so cause massive financial losses[72].

The financial sector[73,74], academics[75], governments[76] and non-governmental organizations[77] have warned about the carbon bubble and cited stranded assets as a key climate-related financial risk. These risks are so-called 'sustainability risks' and result from the physical impact of climate change (physical risks) as well as changes in climate policy that accompanies the net-zero transition (transition risk)[78].

Although estimates on global gas infrastructure stranding are not yet available to our knowledge, calculations for fossil fuel assets and the gas sector provide some insights. According to Mercure et al., global fossil fuel assets might cause a discounted loss in global wealth of US$7–11 trillion[79]. Current gas and oil projects worth at least US$2.3 trillion are not aligned with the Paris Agreement[80]. In 2030, up to US$90 billion of today's coal and gas power plants could become stranded (with US$400 billion of stranded assets by 2050)[81].

Besides the lack of research on gas infrastructure stranding, the economic losses from stranded gas assets are a source of great uncertainty and could thus be much higher. This uncertainty is due to the immature calculation approaches of asset stranding[82], the timing of climate policies[83] and the expectations of investors[71]. Confidence in the continuation of fossil fuel consumption is still high[71]. Consequently, investors rarely adjust their investment behaviour, as they expect compensation in case of losses[72]. Ignoring the risk of asset stranding and further investments in fossil fuel infrastructure will amplify the economic risks[68].

Methane leakage regulations might be a cause for additional stranded assets. In particular, the Global Methane Pledge launched at COP26 has the potential to create a new momentum to regulate methane leakages. As the industry has hardly addressed leakages since at least the 1990s[84,85], it is crucial to leave the related duties not solely to the industry. However, attempts to minimize leakages via regulation have proved difficult too[86]. As these regulations and leakage controls cannot replace a strong reduction in natural gas consumption, leakage control technologies might also strand in the long run.

The underestimation of climate-related asset stranding[87] has two main implications. First, it leads to a misallocation of capital towards emission-intensive technologies[88]. In other words, investment in natural gas infrastructure locks up capital, which is then no longer available for investments in renewable energies, in turn delaying the energy transition[89]. In the light of the green energy financing gap, large investments are necessary to enable an energy system transformation[90]. Second, widespread climate-related asset stranding could cause a cascading effect on coupled sectors, in particular the financial sector[91]. If, therefore, financial institutions were struggling to provide credits, this would also restrict possibilities to make necessary investments in the renewable energy transition. Fossil divestment might be a powerful measure for international authorities and financial institutions to reduce climate-related financial risk and to avoid delaying energy transitions.

Outlook

In summary, a fossil fuel with a high climate impact, often hidden under a misleading narrative, which hinders decarbonization via infrastructure expansion, and so creates carbon lock-in effects and bears high economic risk, cannot be a solution towards a zero-emission future.

The potentially detrimental impacts of fossil natural gas call for research on how to achieve a 100% renewable energy supply while strictly minimizing natural gas use during the transitional period. Based on the five different perspectives discussed here, we propose five recommendations to further stimulate the debate on the risks related to natural gas use.

First, the management of GHG emissions, especially methane leakage along the entire natural gas value chain, requires considerable improvement. Taking a climate science perspective, the latest research on methane emissions from natural gas infrastructure shows a higher climate impact than was previously assumed. This means that countries attempting to develop decarbonization strategies need to carefully assess whether natural gas can play a role in them. To do so, it is crucial to improve the measurement, accounting and reduction of GHG emissions along the value chain (this requires accurate and transparent GHG inventories), especially to minimize methane leakage. Eventually, as regulation cannot reduce methane emissions to zero and natural gas causes significant CO_2 emissions when it is burned, an end of natural gas use is needed.

Second, to avoid misleading policies, the assumptions of scenario analyses need to be revised to include new research insights on GHG emissions related to natural gas. From a methodological perspective, scenario analyses need to incorporate the latest findings on methane emissions that result along the whole chain of natural gas production and use. Doing so reveals the much smaller role that natural gas can play in global energy systems and highlights the importance of planning the phase-out of natural gas. Consequently, such scenario analyses would also demonstrate the increasing importance of immediate investment in energy efficiency measures and the massive expansion of renewable energy sources.

Third, narratives that present gas as climate friendly need to be replaced with unambiguous criteria. From a discursive perspective, the bridge technology or transition fuel narratives lack clarity regarding aspects such as the time horizon and the target system, and are utilized to legitimize natural gas use. Clearer concepts are needed, with unambiguous criteria and limits for GHG emissions from energy production in various years and for various applications, accompanied by a narrative based on a 100% renewable energy system.

Fourth, to meet climate targets, further lock-ins must be avoided. Additional expansions of natural gas infrastructure and consumption aggravate infrastructural and institutional lock-in effects, which slow down the transition to renewable energy systems. To effectively govern the transition, these lock-in effects need to be taken into account in energy infrastructure planning, even and especially if the expansion is legitimized with plans to replace natural gas with synthetic gases or e-fuels in the long term.

Finally, climate-related risks, such as asset stranding, need to be taken seriously in energy infrastructure planning. From an economic perspective, investments in additional natural gas energy infrastructure are a poor fit for climate targets and would cause massive economic losses from asset stranding. Additionally, they can delay the needed investments in a renewable energy-based system. Consequently, investment decisions by the private sector and state actors need to take climate-related risk from asset stranding seriously.

The five different perspectives and related recommendations demonstrate the need for a more holistic assessment of all GHG emissions related to natural gas and infrastructure expansion, as well as its impact on energy transitions. Political and scientific debates should focus more on how to reduce the production and use of natural gas to accelerate the shift towards renewable energy systems. Meeting the Paris Agreement and longer-term climate mitigation targets inevitably implies a fossil natural gas exit. The earlier such a gas exit is planned for, the more of the emission budget remains for those sectors that are harder to decarbonize.

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Additional information

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