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Muez Ali, Abdalftah Hamid,
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ECONOMIC RESEARCH FORUM
منتدى البحوث الاقتصادية

Working Paper No. 1702
January 2024

HISTORICAL AND FUTURE GLOBAL EMISSIONS REDUCTIONS DUE TO QATAR'S LNG EXPORTS

Muez Ali, Abdalftah Hamid[1], Gonzalo Castro de la Mata[2] and Alex Amato[3]

Working Paper No. 1702

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Send correspondence to:
Muez Ali
Earthna: Center for a Sustainable Future, Qatar Foundation, Qatar
muezali@qf.org.qa

[1] Middle East Council for Global Affairs (MECGA), Qatar
[2] Earthna: Center for a Sustainable Future, Qatar Foundation, Qatar
[3] Earthna: Center for a Sustainable Future, Qatar Foundation, Qatar

First published in 2024 by
The Economic Research Forum (ERF)
21 Al-Sad Al-Aaly Street
Dokki, Giza
Egypt
www.erf.org.eg

Abstract

Qatar exports most of its LNG to South Korea, Japan, China and India. Most of Qatar's export markets have carbon-intensive economies where industry contributes, on average, 32% to total GDP. This paper attempts to estimate the reductions in carbon dioxide emissions due to Qatar's LNG displacing more carbon-intensive fuels in Qatar's main export markets. LNG emits almost 50% less carbon dioxide than coal and 30% less carbon dioxide than oil products. Therefore, LNG is a cleaner alternative to coal and oil products, particularly in the power sector and industry. Using data from the IEA, EIA and the World Bank, we estimate the reductions in carbon dioxide emissions due to Qatar's LNG replacing more carbon-intensive fuels in Qatar's export markets by assuming a hypothetical scenario where Qatar's LNG disappears from the global energy mix between 2005 and 2020. We estimate an upper bound where all of Qatar's LNG is replaced by coal and a lower bound where Qatar's LNG is replaced by all fuels in the energy mix in proportion to their existing shares. Finally, using a stochastic approach, we develop a 'most likely' scenario that considers the annual growth rate in coal consumption and the share of coal in the energy mix. The same analysis is conducted for a scenario that projects energy consumption and emissions to 2040. The results of the analysis show that between 2005 and 2020, in the 'most likely' scenario, by replacing coal and other carbon-intensive fuels, Qatar's LNG exports likely reduced global emissions by more than 600 MtCO2. During the same period, these emission reductions amounted to 40% of Qatar's annual local emissions on average. However, in the future scenario, emission reductions due to Qatar's LNG exports decrease significantly and the gap between Qatar's local emissions and how much it offsets by exporting LNG grows over time. This is mainly due to the phase out of coal from global energy systems. We conclude with policy recommendations on how Qatar can close the gap between its local emissions and how much it offsets through LNG exports.

Keywords: Exports, Liquefied Natural Gas (LNG), Qatar
JEL Classifications: Q5

ملخص

تصدر قطر معظم الغاز الطبيعي المسال إلى كوريا الجنوبية واليابان والصين والهند. معظم أسواق التصدير القطرية لديها اقتصادات كثيفة الكربون حيث تساهم الصناعة، في المتوسط، بنسبة 32٪ في إجمالي الناتج المحلي. تحاول هذه الورقة تقدير التخفيضات في انبعاثات ثاني أكسيد الكربون بسبب إزاحة الغاز الطبيعي المسال في قطر لمزيد من الوقود كثيف الكربون في أسواق التصدير الرئيسية في قطر. ينبعث من الغاز الطبيعي المسال ما يقرب من 50٪ أقل من ثاني أكسيد الكربون من الفحم و 30٪ أقل من ثاني أكسيد الكربون من المنتجات الزيتية. لذلك، فإن الغاز الطبيعي المسال هو بديل أنظف للفحم ومنتجات النفط، لا سيما في قطاع الطاقة والصناعة. باستخدام بيانات من وكالة الطاقة الدولية وإدارة معلومات الطاقة والبنك الدولي، نقدر التخفيضات في انبعاثات ثاني أكسيد الكربون بسبب استبدال الغاز الطبيعي المسال في قطر للوقود الأكثر كثافة للكربون في أسواق التصدير القطرية من خلال افتراض سيناريو افتراضي حيث يختفي الغاز الطبيعي المسال في قطر من مزيج الطاقة العالمي بين 2005 و 2020. نقدر الحد الأعلى حيث يتم استبدال جميع الغاز الطبيعي المسال في قطر بالفحم والحد الأدنى حيث يتم استبدال الغاز الطبيعي المسال في قطر بجميع أنواع الوقود في مزيج الطاقة بما يتناسب مع أسهمها الحالية. أخيرًا، باستخدام نهج عشوائي، نطور سيناريو «على الأرجح» يأخذ في الاعتبار معدل النمو السنوي في استهلاك الفحم وحصة الفحم في مزيج الطاقة. يتم إجراء نفس التحليل لسيناريو يتوقع استهلاك الطاقة والانبعاثات حتى عام 2040. تظهر نتائج التحليل أنه بين عامي 2005 و 2020، في السيناريو «الأكثر ترجيحًا»، من خلال استبدال الفحم وأنواع الوقود الأخرى كثيفة الكربون، من المحتمل أن تخفض صادرات قطر من الغاز الطبيعي المسال الانبعاثات العالمية بأكثر من 600 MtCO2. خلال نفس الفترة، بلغت تخفيضات الانبعاثات هذه 40٪ من الانبعاثات المحلية السنوية لقطر في المتوسط. ومع ذلك، في السيناريو المستقبلي، تنخفض تخفيضات الانبعاثات بسبب صادرات قطر من الغاز الطبيعي المسال بشكل كبير وتنمو الفجوة بين الانبعاثات المحلية لقطر ومقدار تعويضها عن طريق تصدير الغاز الطبيعي المسال بمرور الوقت. ويرجع ذلك أساسًا إلى التخلص التدريجي من الفحم من أنظمة الطاقة العالمية. نختتم بتوصيات سياسية حول كيفية سد قطر للفجوة بين انبعاثاتها المحلية ومقدار تعويضها من خلال صادرات الغاز الطبيعي المسال.

1 Introduction

Throughout human history, climate variability has been a recurring challenge, but the industrial revolution marked a significant shift toward the intensification of production processes that rely heavily on fossil fuel sources (Constantino et al, 2018). The IPCC AR 6 has identified anthropogenic greenhouse gas (GHG) emissions as the main cause of rising global temperatures (IPCC, 2023). The burning of fossil fuels and unsustainable land use has caused global warming of 1.1°C above pre-industrial levels, resulting in more frequent and intense extreme weather events with dangerous impacts on the planet. Every increment of warming leads to escalating hazards, including more intense heatwaves and heavier rainfall, increasing the risks for human health and ecosystems. Climate-driven food and water insecurity is expected to worsen with increased warming, and when combined with other adverse events, such as pandemics or conflicts, the risks become higher, and the impacts become more severe. Today, half of the global population faces water insecurity at least one month per year (IPCC, 2023), highlighting the urgent need to address this issue through sustainable practices and reducing GHG emissions.

Global GHG emissions have continued to rise over the years due to unsustainable energy use, land-use change, and consumption and production patterns across regions, countries, and individuals. Global net anthropogenic GHG emissions were estimated to be 59±6.6 GtCO2eq in 2019, which is about 12% higher than in 2010 and 54% higher than in 1990 (IPCC, 2023). For example, CO2 from fossil fuel combustion and industrial processes contributed the most to gross GHG emissions. The highest relative growth in GHG emissions occurred in fluorinated gases. The IPCC report stated that in 2019, 79% of global GHG emissions came from energy, industry, transport, and buildings, while 21% came from agriculture, forestry, and other land use. Despite improvements in the energy intensity of economic activity and carbon intensity of energy, net emissions are still positive in almost all sectors, including industry, energy, transport, agriculture and buildings.

Increases in GHG emissions and their direct contribution to climate change represents a significant global challenge, as it poses serious risks to the environment, economy, and society. The impacts of climate change are already being observed, and the most severe effects are yet to occur as global temperatures continue to rise. Changes in temperature and precipitation patterns, as well as extreme weather events such as hurricanes, floods, and droughts, are just some of the many environmental impacts caused by rising GHG emissions. These changes can lead to serious consequences such as an increased risk of wildfires, reduced crop yields, and water shortages, which can have significant impact on the natural environment and human wellbeing.

Climate change can lead to damage to infrastructure, property, and other assets, as well as increased costs associated with adapting to changing environmental conditions. Such costs can have a significant impact on a range of sectors including agriculture, forestry, fisheries, energy, and tourism. Moreover, the effects of climate change are not limited to local communities or national borders but have ripple effects across the global economy.

Low-income populations are at particular risk from the impacts of global GHG emissions. More frequent extreme climatic events can exacerbate poverty, food insecurity, and displacement, and can increase the risk of conflict and social instability. Moreover, air pollution caused by GHG emissions can lead to a range of health problems, including respiratory and cardiovascular diseases, cancer, and neurological disorders (IPCC, 2022). According to the World Health Organization (WHO), air pollution is responsible for around 6.7 million premature deaths each year, with the majority occurring in low- and middle-income countries (WHO, 2022).

International efforts are pushing for research to decrease greenhouse gas (GHG) emissions by exploring alternatives to fossil fuels. A shift towards a lower carbon future will demand substantial investment in cleaner technologies. It has been known for some time that enhancing the efficiency of fossil fuel combustion for energy generation can make a significant contribution (see, for example, Hardisty et al. (2012)). More data and information on the GHG intensity throughout a fuel's life cycle can empower decision-makers to make more informed decisions about technology selection, application and best practices. Various low-carbon or carbon-free alternative fuels are being considered globally to improve the environmental impact of economic activity (Al-Breiki and Bicer, 2021). Over the past couple of decades, there has been a growing interest in natural gas as a substitute for more carbon intensive fuels. This, coupled with lower prices, technological development and infrastructure expansion, has led to increased demand for natural gas. Natural gas (in its gaseous or liquid form as LNG), therefore, is expected to play a big role in the future. Although some studies have shown some potential negative effects of increased use of natural gas, most of the evidence suggests that LNG offers lower GHG emissions compared to other fossil fuel sources, such as coal and other heavy hydrocarbons (Al-Breiki and Bicer, 2021).

The transition from fossil fuels to renewable energy sources is an essential step in mitigating the impacts of global greenhouse gas emissions (IRENA, 2022). Globally, governments have created incentive schemes and various initiatives to promote the adoption of renewable energy sources, such as wind and solar power, with many countries setting ambitious targets for reducing their reliance on fossil fuels. While progress has been made, challenges – such as technological limitations, policy and regulatory barriers, and the high costs of infrastructure to absorb new renewable energy technologies – still exist. Having said that, the benefits of this transition extend beyond reductions in GHG emissions, and include job creation, improved energy security, and a reduction in air pollution and associated health problems.

Qatar has benefited from the global increase in demand for LNG in the last two decades and, as a result, experienced a 10-fold increase in GDP between 2000 and 2020. Most of Qatar's LNG is exported to countries in Asia, mainly South Korea, Japan, India, China and Pakistan. Most of the LNG imports from Qatar are used in industry and power generation and have arguably replaced coal and other more carbon intensive fuels in those sectors. Given the size of the country, and its heavy reliance on fossil fuel exports, Qatar has the highest per capita CO2 emissions in the world.[4] However, countries with similar characteristics – such as Norway – have much lower per capita CO2 emissions. Norway, which is similarly reliant on fossil fuel production and exports, has per capita CO2 emissions five times lower than Qatar. One factor is Norway's exploitation of its hydropower resources for electricity generation. Qatar does not have a similar geographic advantage and, in parallel, must consume a lot of energy for cooling. Given the above, this paper makes two contributions to the existing literature. First, it provides an estimate of the amount of CO2 emissions offset through LNG substitution of coal and other more carbon intensive fuels for Qatar

[4] The figures for emissions per capita are currently calculated using the production-based approach – where the emissions associated with fossil fuel production are attributed to the source country. While this approach is hotly debated among researchers and policymakers, it is the one currently used by the IPCC and for which data is most readily available.

LNG exports. Second, it provides a potential pathway for offsetting Qatar's local emissions – in addition to local policies aimed at emission reductions – by targeting LNG exports to countries with a high carbon intensity energy mix. While several studies have attempted to estimate the reductions in CO2 emissions due to coal-gas substitution, to the best of our knowledge, no studies have attempted to make similar estimates for Qatar's LNG exports. Qatar's case is particularly interesting because of its high per capita CO2 emissions, the dominance of the fossil fuel sector in the economy, and the economic structure of its export markets.

This paper presents an analysis of the reductions in CO2 emissions due to Qatar's LNG replacing more carbon-intensive fuels in Qatar's main export markets. The paper is structured as follows: Section 2 provides a background on fuel emissions and LNG as a cleaner alternative, Section 3 provides a detailed methodology, Section 4 presents the results of the analysis and discussion and Section 5 concludes with policy recommendations.

2 Background

2.1 Fuel-based emissions

It is equally important to promote an analysis that allows for the assessment of all socioeconomic and environmental impacts caused by natural gas and other fuels and technologies. For example, life cycle assessment (LCA) is a powerful analytical tool that helps to evaluate the environmental impact of a product or process throughout its entire life cycle, from the extraction of raw materials to the disposal of waste (Korre et al., 2012). The assessment considers the emissions generated from all stages involved in the fuel supply chain. For LNG, this includes production, processing, midstream infrastructure operations, liquefaction, transport, regasification, and end-use. Several studies have investigated the life cycle GHG emissions associated with natural gas delivery pathways from different production regions to consumers around the world (see, for example, Coleman et al., 2015; Hardisty, 2012; Jaramillo et al., 2007; Nie et al., 2020).

Some studies have assessed the lifecycle emissions of various Australian hydrocarbon exports, including Northwest Shelf gas (conventional gas), coal seam gas (CSG), and Australian black coal. The studies find that LNG has lower overall lifecycle GHG emissions than coal, especially when comparing power generation technologies with similar efficiency or application. In addition, the variations in emissions intensity are partly due to production location and delivery pathways. One study compared the life cycle GHG intensities of various energy sources, including coal, conventional LNG, coal seam gas LNG, nuclear and renewables, found that LNG is less GHG intensive than black coal, but the gap narrows depending on combustion technology (Hardisty et al., 2012).[5]

In a similar study, Coleman et al. (2015) discuss the impact of LNG exports from Canada on global GHG emissions. The results show that the net impact of LNG depends on the import market and the type of electricity generation technology displaced by LNG. Assuming that LNG displaces a representative cross-section of an importer's power sector, the results showed that Canadian LNG could lower global greenhouse gas emissions if it displaces coal in China, India, and Taiwan, but raise emissions if it displaces low-carbon

[5] The study shows that conventional LNG is less GHG intensive than black coal, but the gap narrows when comparing OCGT LNG combustion with ultra-supercritical coal power.

sources, such as nuclear and renewables in European and South American countries. Similarly, Nie et al. (2020) find that LNG exports from Canada to China results in lower life cycle GHG emissions than coal imported from Asian markets. The study found that emissions from coal in Chinese power production are almost double the GHG emissions from imported Canadian LNG. The study emphasizes that total emissions are dominated by end-use emissions, not just the LNG supply chain's upstream and liquefaction stages. The conclusion was that understanding end use consumption is critical when considering the climate benefits and drawbacks of using LNG. On the other hand, Di Lullo et al. (2020) find that the operation phase in pipeline transportation of natural gas represents between 78% and 95% of the GHG emission intensities of three large-scale pipelines in Canada.

Additionally, Gibon et al. (2021) argue that fossil fuel extraction and transportation are not uniform across regions, and methane leakage rates vary at different stages. There are different GHG emissions associated with different energy generation technologies. For example, coal used in power generation has the highest GHG emissions (751 to 1095 gCO2eq/kWh), while natural gas emits significantly less (403 to 513 gCO2eq/kWh, and 49 to 220 gCO2eq/kWh in combined cycle plants). There are also regional differences for certain technologies. For example, concentrated solar power (CSP) is responsible for more GHGs in regions with lower solar irradiation, but wind turbines offer consistently low emissions regardless of location and most of the associated emissions are embodied in infrastructure. Hydropower and nuclear haver lower GHG emissions than solar due to the absence of operational emissions, long asset lifetime and high load factors. Table 1 below shows the mean emissions of the different power generation technologies. The range of emissions for each technology depend on end use technology and geographical location.

Table 1: Emission factors of the different fuels and technologies

Technology	Tons of CO2e per GWh		
	Mean	Low	High
Lignite	1,054	790	1,372
Coal	888	756	1,310
Oil	733	547	935
Natural gas	499	362	891
Solar PV	85	13	731
Biomass	45	10	101
Nuclear	29	2	130
Hydroelectric	26	2	237
Wind	26	6	124

Moreover, Littlefield et al. (2022) emphasize the need to understand how GHG emissions vary across the natural gas supply chain based on where it is produced and delivered. They provide a detailed life cycle perspective by disaggregating transmission and distribution infrastructure into six regions and balancing natural gas supply and demand locations. The study incorporates new data on distribution meters and estimates the transmission distance for US natural gas to range from 45 to 3000 km across different production-to-delivery pairings. The results show significant differences in emissions in the delivery of one megajoule (MJ) of natural gas across the US, where natural gas delivered to the Pacific region has the highest mean life cycle GHG emissions (13 g CO2e/MJ) and delivery of natural gas to the Northeast US has the lowest mean life cycle GHG emissions (8.1 g CO2e/MJ). In another study, Abrahams et al. (2015) investigate the difference in emissions between exported LNG and natural gas consumed in the US. The study finds that exported LNG has mean precombustion emissions of 37 gCO2eq/MJ when regasified in Europe and Asia. Shipping emissions of exported LNG from US ports to these markets account for only 3.5% to 5.5% of precombustion life cycle emissions, which indicates that shipping distance is not a major factor in lifecycle GHG emissions. The study's scenario-based analysis shows that LNG imports from the US used in electricity generation have mean emissions 11% higher that natural gas used the US for the same purpose.

The literature shows that emission intensities vary significantly across regions and technologies. On a lifecycle basis, coal-fired power plants have the highest GHG emission intensities. While natural gas and oil have lower GHG emissions. Additionally, biomass, nuclear, hydroelectric, wind, and solar PV have significantly lower GHG emission intensities than fossil fuel-based generation. The relative magnitude of GHG emission intensities of the different electricity generation technologies and fuels remains consistent across various studies. However, the absolute emission intensity varies across studies due to differences in scope. The definition of 'lifecycle' affects the results, with some studies including waste management and treatment while others exclude waste. The period during which a study is conducted also affects the results, particularly for solar power, which has seen rapid advances in technology and manufacturing processes over the past decade. Recent studies estimate lower lifecycle emissions for solar photovoltaic panels compared to fossil fuel generation methods, while older studies estimate comparable emissions.

2.2 LNG as a cleaner alternative

Liquefied Natural Gas (LNG) and coal are the most widely used fossil fuels worldwide. Coal has been the dominant fuel for power generation for many years, but the concern about its environmental impact has led to a growing interest in substituting it with cleaner alternatives. LNG is a fossil fuel primarily composed of methane and is produced by cooling natural gas to a temperature of -162 degrees Celsius, at which point it becomes a liquid (Al-Breiki and Bicer, 2021). In combustion, LNG has lower GHG emissions than coal. This is due to several factors. One major factor is that LNG has a lower carbon intensity than coal, which means it releases fewer GHG per unit of energy produced. Interest in substituting coal with LNG is driven by concerns about the environmental impact of coal and the need to reduce global GHG emissions.

A study of the lifecycle GHG emissions of various energy sources in Australia, including coal, conventional LNG, coal seam LNG, nuclear and renewables, found that the emission intensity of fossil fuels exported to China depends on the technology used in combustion for generating electricity (Hardisty et al., 2012). Natural gas exported as LNG is generally less GHG intensive than black coal, but the gap narrows considerably when comparing open cycle gas turbine plant OCGT combustion to ultra-supercritical coal-fired power. On average, conventional LNG burned in a conventional OCGT plant is approximately 38% less GHG intensive over its life cycle than black coal burned in a sub-critical plant per MWh of electricity produced. And coal seam LNG is approximately 13% to 20% more GHG intensive across its life cycle than conventional LNG. Coal seam LNG is more GHG intensive than conventional LNG, and fugitive methane emissions from coal seam LNG are uncertain but could potentially be managed through best practice technologies.

A study comparing three independent LCAs of the same planned LNG supply chain from Canada to China finds that GHG emissions of Canadian LNG are 34% to 62% lower than emissions from coal power generation in China (Nie et al., 2020). Moreover, Roman-White et al. (2019) show that for natural gas scenarios, a significant proportion of the life cycle emissions, around 34% to 45%, are from the natural gas supply chain before reaching the power plant, compared to 2% for coal on a 100-year basis. On a 20-year basis, the upstream share in natural gas scenarios increases to 42% to 64% due to the high global warming potential of methane. In a review, Al-Yafei et al. (2021) find that natural gas releases 50% to 60% less CO2 than a typical new coal plant when combusted in a new efficient natural gas power plant. Finally, the lifecycle emissions of natural gas in the US decreased significantly between 2005 and 2015, with 86% of annual emissions attributed to power generation (Tavakkoli et al., 2022). Despite concerns about methane leaks, the study finds that natural gas has a greenhouse gas benefit relative to coal due to efficiency improvements. Methane leaks would have to be 4.4 times the Environmental Protection Agency (EPA) value in 2015 to reverse these benefits over a 20-year time horizon. The study concludes that, with retiring coal plants and increasing scrutiny of supply chain emissions, natural gas can provide a lower emissions option to coal in a decarbonized power sector.

On the other hand, a study looking at the emissions intensity of natural gas imports into Europe found that piped gas from Norway produces approximately 7kg of carbon per barrel. In contrast, the average emissions from LNG imports into Europe are over 70kg, ten times higher than piped gas. The study considers LNG as a more carbon-intensive alternative to piped gas because of its production process. To make it smaller and more transportable, natural gas is cooled to extremely low temperatures, typically around -160°C. The emissions associated with combustion of natural gas is the same it's imported through pipelines or as LNG. Thus, the research suggests that the unaccounted emissions produced during the liquefaction process contribute to a higher carbon footprint.

The process of liquefying natural gas to produce LNG consumes a considerable amount of energy and generates significant emissions (IEA, 2019). This is because natural gas is frequently used to provide the energy required for the liquefying process. Similarly, emissions occur during pipeline transportation due to the utilization of natural gas in compressor stations along the pipeline. However, when compared to pipeline transport, the emissions intensity of LNG transport is generally higher. Based on IEA estimates, importing LNG to China results in lower emissions than pipeline imports. This is due to the methane emissions that occur along the value chains. However, this is not always the case. In Europe, the emissions intensity of pipeline gas is currently lower than that of LNG.

Switching from coal to natural gas reduces global CO2 emissions but leads to an increase in emissions of radioactive substances, such as methane, sulfur dioxide, a sulfate aerosol precursor, and black carbon (BC) particles. These substances have varying impacts on changes in global temperatures (Jain et al., 2000). Methane, for example, which has a significantly higher global warming potential than CO2. Some experts still insist that there may be a balancing-out effect because of the higher emissions of methane associated with natural gas, mainly in production and transportation (Jain et al., 2000). Some earlier studies predicted that, despite the reduction in carbon dioxide emissions due to switching from coal to natural gas, emissions of other substances would lead to an initial increase in global temperatures (see, for example, Hayhoe et al. (2002)).

2.3 Industrial decarbonization

Innovations in industrial decarbonization will create financial and environmental benefits. There are certainly behavioral, economic, political and technical barriers to industrial decarbonization. Therefore, there is equally an urgent need for policy innovations to help governments, and industry, overcome these barriers. The level of decarbonization required and the barriers associated with it vary significantly across industries. And some industries are more energy intensive than others. For example, the chemical industry has high energy inputs as feedstock and generally requires high temperatures and pressure during the production process. However, the industry also has relatively high investment in research and development, which is good for innovation efforts, and can accommodate carbon capture and storage solutions in different ways.

There are several decarbonization opportunities for the chemical industry. For example, hydrogen, which is an essential feedstock in many industrial processes can also be used as a fuel to replace hydrocarbons. More specifically, hydrogen could replace coking coal in steel manufacturing (Butler et al., 2020). And the production of hydrogen can be done through low carbon technologies. There are also energy efficiency approaches that can be adopted, such as insulation improvements and enhanced heat management. But the barriers to industrial decarbonization remain significant, most of which are yet to be overcome. Broader socio technical transitions will be required in the future for significant decarbonization of industry to be achieved (Chung et al., 2023).

While decarbonization technologies and strategies must be tailored to each industry, there are solutions that could be adopted across the industrial sector. For example, carbon capture and storage could be adopted in hydrocarbon production (Butler et al., 2020), and in cement and steel manufacturing. And electrification technologies, such as molten oxide electrolysis for melting iron ore, can be used in steel production and cement manufacturing. Substituting certain inputs can also reduce emissions in certain industries, such as replacing clinker with fly-ash and limestone in cement manufacturing (Williams and Bell, 2022).

Other solutions include reuse and recycling programmes and incentives for industry to reduce emissions. More broadly, most experts think the solution is through strong government policy, an important mechanism to incentivize industry to decarbonize and implement strong emissions regulations (Naimoli and Ladislaw, 2020). For example, the EU's recent update of the Carbon Border Adjustment Mechanism targets imports of certain carbon intensive goods, including cement, iron, steel, fertilisers, electricity and hydrogen.[6]

2.4 Qatar's commitments

Qatar launched its National Climate Change Action Plan (NCCAP), which targets a 25% reduction in GHG emissions by 2030. In addition, Qatar Energy, a state-owned energy company which operates all oil and gas exploration, production, refining, transport and storage in the country, recently upgraded its Sustainability Strategy. The strategy outlines numerous initiatives to reduce GHG emissions, including deployment of carbon capture to capture over 11 Mt per year of CO2 by 2035 (Qatar Energy, 2021), strengthening its commitment to deliver cleaner LNG.

In its 2021 sustainability report, Qatar Energy committed to driving the energy transition by expanding to 126 Mt per annum of LNG production capacity in 2027 (Qatar Energy, 2021). The company is focused on

[6] See the EU's Carbon Border Adjustment Mechanism at: https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en#latest-developments (Accessed 14 May 2023).

achieving zero routines flaring by 2030 through investments in innovative technologies and maintenance procedures. They claim to have reduced flaring intensity at Ras Laffan Industrial City and the Al-Shaheen oil field by 72% (Qatar Gas, 2021). Qatar Energy places a strong emphasis on reducing methane emissions. They have expanded their smart Leak Detection and Repair (LDAR) program, utilizing advanced technologies to quickly and efficiently detect and repair methane leaks. Their goal is to achieve near-zero methane emissions and report accurate data. Regarding carbon capture and sequestration (CCS), Qatar Energy has successfully captured around 4 MtCO2eq. They plan to further increase their CCS capacity to approximately 6 Mt per annum by 2028. The company is actively investing in renewable energy, particularly in solar PV projects, with an existing capacity of 850 MW (Qatar Energy, 2021). They aim to double their installed solar PV capacity by 2024 and aim to surpass 5 gigawatts (GW) of installed capacity by 2035. Qatar Energy is also exploring the potential of alternative energy sources such as hydrogen and ammonia. Leveraging their expertise in large-scale hydrogen production, they have plans to utilize these energy vectors in their operations.

Due to its harsh climate, over 90% of GHG emissions in Qatar are due to energy use. The overwhelming majority of energy is used in climate control for buildings and in the hydrocarbon sector. Reductions in GHG emissions in the LNG supply chain in Qatar will have a significant impact on the country's total emissions. Some estimates show that LNG production accounts for almost half of total emissions (Mohammed, 2021).

3 Methodology

3.1 Research question

This research exercise seeks to determine the reductions in global carbon dioxide emissions that are due to Qatar's LNG exports around the world. The exercise assumes a hypothetical scenario where Qatar's LNG disappears from the global fuel mix during the period 2005 to 2020, and asks the following questions:

- What fuels would have replaced Qatar's LNG in the global energy mix?
- How much more carbon dioxide would have been emitted by this replacement?

To answer these questions, an analysis is conducted using data on global flows of natural gas from the IEA's database. The following sub-sections provide details on the methodology, including the assumptions made, the data used and the empirical approach.

This paper also entails an outlook to 2040 based on the historical analysis, looking at how much more future reductions in global carbon dioxide emissions, if any, will be due to Qatar's LNG exports. Policy recommendations are provided based on the findings of both the historical analysis and future projections.

3.2 Assumptions

The research exercise on historical emission reductions due to Qatar's LNG exports makes several assumptions about decarbonization, emission factors and developments in the global LNG market. The future projections make the same assumptions about LNG substitution and emission factors as the historical analysis and makes additional assumptions about Qatar's CO2 emissions and the global energy mix in the future.

3.2.1 Historical analysis

Assumption 1: Decarbonisation of industry

As highlighted in the Background section, there are several decarbonization opportunities and potential approaches for the industrial sector. Hydrogen could be used as a replacement fuel for hydrocarbons (Butler et al., 2020) and green hydrogen could potentially replace dirtier hydrogen currently used as an input in many industrial processes. Energy efficiency measures, such as improvements in insulation and enhanced heat management, could potentially play a significant role in reducing carbon emissions in the industrial sector. Technologies such as carbon capture and storage, and electrification of certain industrial processes, could play a significant role in making hydrocarbon use in industry less carbon intensive. And in certain industries, replacing certain inputs with lower carbon intensive ones are also likely to reduce emissions (William and Bell, 2022). More importantly, government policy will play a significant role in forcing industry to decarbonize (Naimoli and Ladislaw, 2020).

What is clear from the literature is that significant decarbonization of industry is yet to happen. And considering that many of the broader socio-technical issues have yet to be addressed (Chung et al., 2023), this exercise assumes that no significant industrial decarbonization occurred in Qatar's export markets between 2005 and 2020.

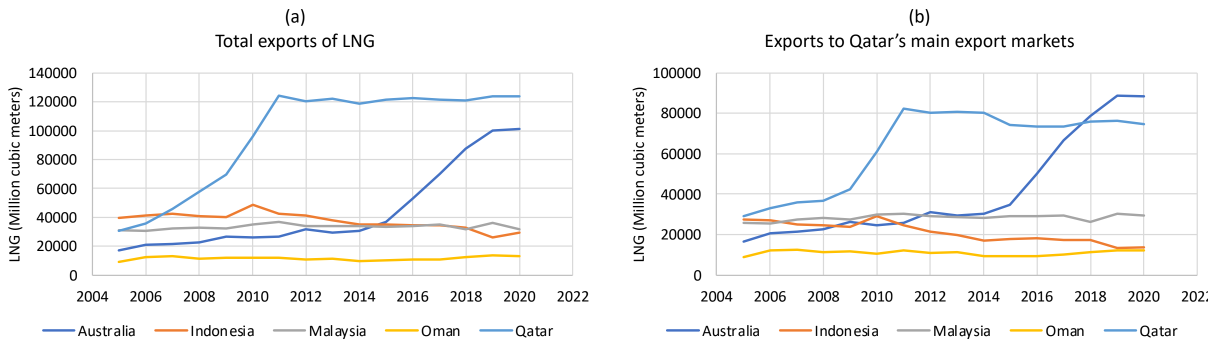
Assumption 2: Emission factors are constant

This exercise assumes that all the fuels and technologies used for energy generation have consistent emissions factors across their multiple end-uses in all the sectors considered. And that embodied emissions for all fuels and technologies are negligible, unless otherwise stated. Despite the evidence of variations in emission factors across technology end use and region, several country level studies have used mean emission factors as highlighted in Table 1 for convenience.

Assumption 3: Replacement of Qatar's LNG exports

In 2020, Qatar was largest exporter of LNG in the world. Qatar's exports of LNG increased significantly from 30 billion cubic meters 2005 to over 120 billion cubic meters by 2011 and remained at that level until 2020. During this period, a significant proportion of Qatar's LNG exports went to countries in Asia. Qatar exported, on average, over the period 2005 to 2020, 66% of its LNG to South Kore, Japan, China, India, the UK, Spain, Italy and Pakistan.

Figure 1: LNG exports of Qatar's main competitors: (a) Total LNG exports; (b) Exports to Qatar's main export markets.



The research exercise assumes that, had Qatar's LNG exports disappeared, then its main competitors in Qatar's main export markets in Asia, namely Australia, Indonesia, Malaysia and Oman, would not have been able to replace it. Figure 1 shows that between 2005 and 2020, exports from Indonesia, Malaysia and Oman were constant, and that LNG exports from Australia, despite experiencing significant growth between 2015 and 2019, are still lower than LNG exports from Qatar.

A large proportion of LNG exports from Qatar's main competitors also goes to Qatar's main export markets in Asia (Table 2). But the increase in production required from the main competitors to replace Qatar's LNG – 79.2 % on average – is significantly higher than the average growth in their respective total LNG exports for the period 2005 to 2020: 13.5% for Australia, -1.5% for Indonesia, 0.4% for Malaysia and 3% for Oman (Table 2). The same is true for exports to Qatar's main export markets.

Therefore, it's unlikely that, had Qatar's LNG exports disappeared, they would be replaced by other LNG exporting countries.

Table 2: Necessary increases from Qatar's main competitors to replace Qatar's LNG

	Australia	Indonesia	Malaysia	Oman
Share of total exports that go to Qatar's main export markets (%)	95.6%	54.7%	84.9%	94.6%
Average growth in Total LNG exports (2005-2020) (%)	13.5%	-1.5%	0.4%	3.0%
Required increases in production to cover Qatar's export needs (%)	79.2%			
Average growth in LNG exports to Qatar's main export markets (2005-2020) (%)	12.7%	-3.9%	1.1%	2.8%
Required increases in production to cover Qatar's exports (%)	64.5%			

3.2.2 Future projections

Assumption 1: Global energy mix 2020 to 2040

The projections for future energy demand up to 2040 are based on growth trends between 2015 and 2020. The justification for the choice of period is two-fold: first, to reflect realistic future demand by looking at the most recent demand trends; and to avoid demand dynamics following shocks, such as the 2008 global financial crisis, after which there was a significant increase in demand for coal during the economic recover.

Under this scenario, power sector coal demand increases on average by 0.9% per year to 2040 and coal demand across sectors has an average growth rate of -5.2%. So, coal demand in the power sector in 2040 is 1.2 times higher than in 2020, and 50% less across all sectors. On the other hand, energy from renewables increases on average by 6% per year in the power sector and, therefore, total consumption of renewables is 3.2 times higher in 2040. Natural gas demand increases by an average of 1.6% per year in the power sector, 2.2% per year in industry and 1.9% per year across all sectors up to 2040. Natural gas demand in 2040 is, on average, 1.5 times higher than in 2020. The average growth rates of all the fuels and technologies for the different sectors is provided in Table A1 in the Appendix.

Assumption 2: Qatar emissions to 2040

The future projections of Qatar's CO2 emissions assume a business-as-usual scenario based on the growth rate of emissions between 2005 and 2020. The projections assume an average growth rate of 2.9% per year from 2020 to 2040, resulting in total CO2 emissions of 178 MtCO2 in 2040 compared to 100 MtCO2 in 2020. The projects make use of the

3.2 Data

This research exercise makes use of several databases. The estimation of reductions in global CO2 emissions due to Qatar's LNG exports uses the IEA Natural Gas Information database, the IEA Energy Balance database and the EIA's Carbon Dioxide Emissions Coefficients. Analysis of Qatar's CO2 emissions in a global context uses the World Bank's World Development Indicators database and the UN Human Development Index. Table 1 provides a summary of the data.

Table 1: Data and data sources used in the analysis.

Data	**Units**	**Source**
Total final consumption (TFC)	Mtoe (Million tons of oil equivalent)	IEA Sankey Tool
Emissions	kgCO2/toe (kilogram of CO2 per ton of oil equivalent)	EIA Carbon Dioxide Emissions Coefficients
Natural gas imports	Mtoe (Million tons of oil equivalent)	IEA Sankey Tool
Qatar share of natural gas imports	Percentage share	IEA Natural Gas Information – World Imports by Origin
Total population	Persons	World Bank World Development Indicators
Country CO2 emissions	MtCO2 (Million tons of CO2)	World Bank World Development Indicators
Country CO2 emissions per capita	tCO2 per capita (tons of CO2 per capita)	World Bank World Development Indicators
Country GHG emissions	MtCO2e (Million tons of CO2 equivalent)	World Bank World Development Indicators

3.3 Empirical analysis

3.3.1 Scenario development

This exercise is based on the hypothetical scenario that Qatar's LNG disappears from the energy mix of Qatar's export markets. To that end, the following sub-section highlights the methodology of the empirical exercise to calculate the emissions reductions (or increases) of different scenarios modelling how the deficit is covered by other fuels (the calculations are conducted for three sectors: power, industry and other).

The analysis initially considers four different scenarios:

- Scenario 1: Qatar's LNG is replaced by LNG from other exporters.
- Scenario 2: Qatar's LNG is replaced by coal.
- Scenario 3: Qatar's LNG is replaced by all fuels proportionally.
- Scenario 4: Qatar's LNG is replaced by all fuels, except for nuclear (coal replaces the share of nuclear).

Under Scenario 1, there will be no change in global CO2 emissions – assuming negligible differences in CO2 emissions during LNG production and transportation across regions – because Qatar's LNG would be replaced by LNG from another exporting country. Based on the assumptions highlighted in Section 0, it is not realistic that Qatar's LNG is replaced by LNG from other countries, so Scenario 1 is not considered in the analysis.

Scenario 2 assumes that all of Qatar's LNG is replaced by coal. This scenario provides the highest possible reductions in global CO2 emissions due to Qatar's LNG exports because coal has the highest emissions factor of all the fuels and technologies being considered. Therefore, this is considered the Upper Bound. Scenario 3 assumes that all of Qatar's LNG is replaced by all fuels in the existing fuel mix in proportion to the existing share of each fuel in the sector. This is considered the Lower Bound. Scenario 4 assumes that all of Qatar's LNG is replaced by all fuels in the existing fuel mix in proportion to the existing share of each fuel in the sector, except for the share of nuclear energy, which is taken up by coal. Scenario 4 is within the range between the Upper Bound and Lower Bound.

A scenario where all of Qatar's LNG is replaced by renewables is not considered. Consumption of renewable energy during the period 2005 to 2020 grew, on average, by 22% per year in the power sector, where renewable energy adoption was highest. The growth rate peaked in 2011 at 33% and then saw a gradual decline through to 2020, when renewable energy consumption was 14% higher than in 2019. So, during this period, given the global push for renewables energy adoption and the various policies implemented across the globe to increase renewable energy us in the power sector, it is unlikely that the growth rate in renewables would have been sufficient to cover the gap left by Qatar's LNG. In fact, on average, a growth rate of 82% per year would have been required for renewables to replace Qatar's LNG in the power sector between 2005 and 2020.

3.3.2 Emission reductions calculation

The first step in the empirical exercise is to calculate the total LNG imports from Qatar. This is calculated by multiplying Qatar's share of LNG imports by total LNG imports globally. Then to estimate the total emissions due to LNG imported from Qatar, total LNG imports from Qatar is multiplied by the emissions factor of LNG. These two steps are implemented for each of the three final consumption sectors where natural gas is mostly used: power sector, industry and other.[7]

For the Upper Bound (Scenario 2), the emissions due to coal replacing LNG imports from Qatar is calculated by multiplying total final consumption of LNG imports from Qatar by the emissions factor of coal. The difference in emissions is calculated by subtracting the emissions due to Qatar's LNG from the emissions due to coal for the same final consumption. This calculation is repeated for all three sectors.

For the Lower Bound (Scenario 3), the emissions due to all fuels replacing LNG imports from Qatar proportional to their respective share in the energy mix is calculated by taking the sum of total final consumption of LNG imports from Qatar multiplied by the emissions factor of each fuel multiplied by the share of each fuel in the energy mix. The difference in emission is calculated by subtracting the emissions due to Qatar's LNG from the emissions due to all fuels replacing LNG imports from Qatar. This calculation is repeated for all three sectors.

3.3.3 Developing a 'most likely' scenario

The Upper Bound and Lower Bound calculated using the aforementioned method represent the maximum and minimum possible reductions of global CO2 emissions due to Qatar's LNG exports. This exercise assumes that the true amount is within this range. The following empirical exercise is used to determine the most likely reductions in global CO2 emissions due to Qatar's LNG exports between 2005 and 2020.

The 'most likely' scenario was developed based on the following assumptions and stochastic approach. First, the higher the growth rate of coal consumption the more likely it is for coal to replace Qatar's LNG imports. Based on this assumption, in the 'most likely' scenario the probability of coal replacing Qatar's LNG is highest when the increase in coal consumption is higher than the increase in total energy consumption in any given year. Second, the larger the share of the coal in the energy mix, the more likely it is for coal to replace Qatar's LNG imports. Similarly, the probability of coal replacing Qatar's LNG imports is highest when the share of coal is more than half of total energy consumption, lowest when the share of coal is less than a fifth of total energy consumption.

A more detailed methodology is provided in the Appendix.

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[7] Other (sector) includes residential, commercial and public services, agriculture/forestry, fishing and non-specified consumption (see IEA (2021)).

3.4 Limitations

The methodology outlined in this section has several limitations. First, the reliance on aggregate data means that seasonal fluctuations and prices cannot be incorporated into the analysis. For example, the demand for LNG in Europe is much higher in the winter than it is in the summer. This has an impact on prices and on subsequent demand, and hence has a similar impact on consumption and investment on exploration and extraction. Second, the analysis – on both historical and future projections – does incorporate the introduction of new policies on decarbonisation of industry and the power sector. The electrification of industry, while still at its early stages, will have an impact on LNG demand in most of Qatar's export markets in the future. Third, the analysis assumes emission factors are constant across countries and contexts. While this assumption is used in similar studies, it compromises the accuracy of the calculations. As an alternative, an LCA approach would provide much more accurate estimates, especially in incorporating the embedded emissions in transport. Finally, the assumptions about the future energy mix and Qatar's future emissions relies heavily on historical data. Given the urgency of climate change and the pressure to decarbonise, it is likely that the future energy mix in Qatar's export markets and Qatar's own CO2 emissions diverge significantly from their historical path, or at least that of the years used as the base for the future projections.

4 Results and discussion

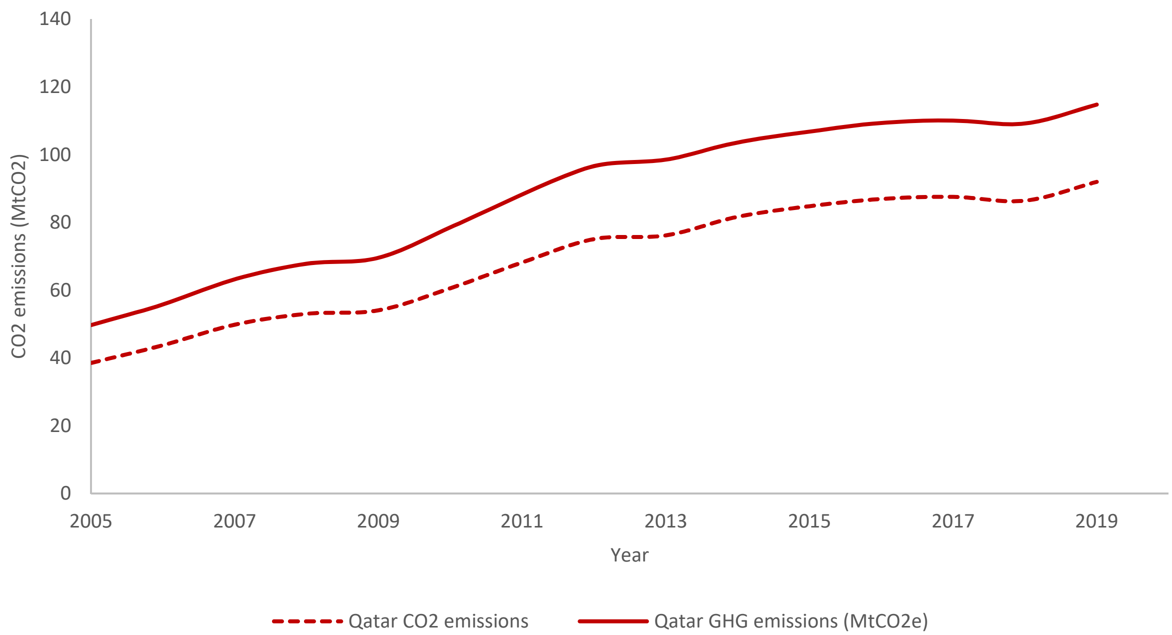
This research exercise set out to estimate the reductions in global CO2 emissions due to Qatar's LNG exports to the world. Over the past two decades, in Qatar's main export markets – namely, South Korea, Japan, China and India – coal has been a dominant fuel in both power generation and industry.

4.1 CO2 and GHG emissions in Qatar

In 2019, Qatar's total CO2 emissions (red dotted line in Figure 2) were 92 MtCO2 and total GHG emissions (red solid line in Figure 2) were 115 MtCO2e. Between 2005 and 2019, Qatar's CO2 and GHG emissions grew by 138% and 131%, respectively. The average year-on-year growth of CO2 and GHG emissions for the same period were 6.5% and 6.3%, respectively.

A large percentage of Qatar's total GHG emissions come are fugitive emissions from the LNG production process, and they represent a significant portion of total GHG emissions. However, between 2005 to 2019, Qatar's GHG emissions (not including CO2) as a percentage of total emissions decreased from 22.5% to 19.9%.

Figure 2: Qatar's historical CO2 and GHG emissions, 2005 to 2020



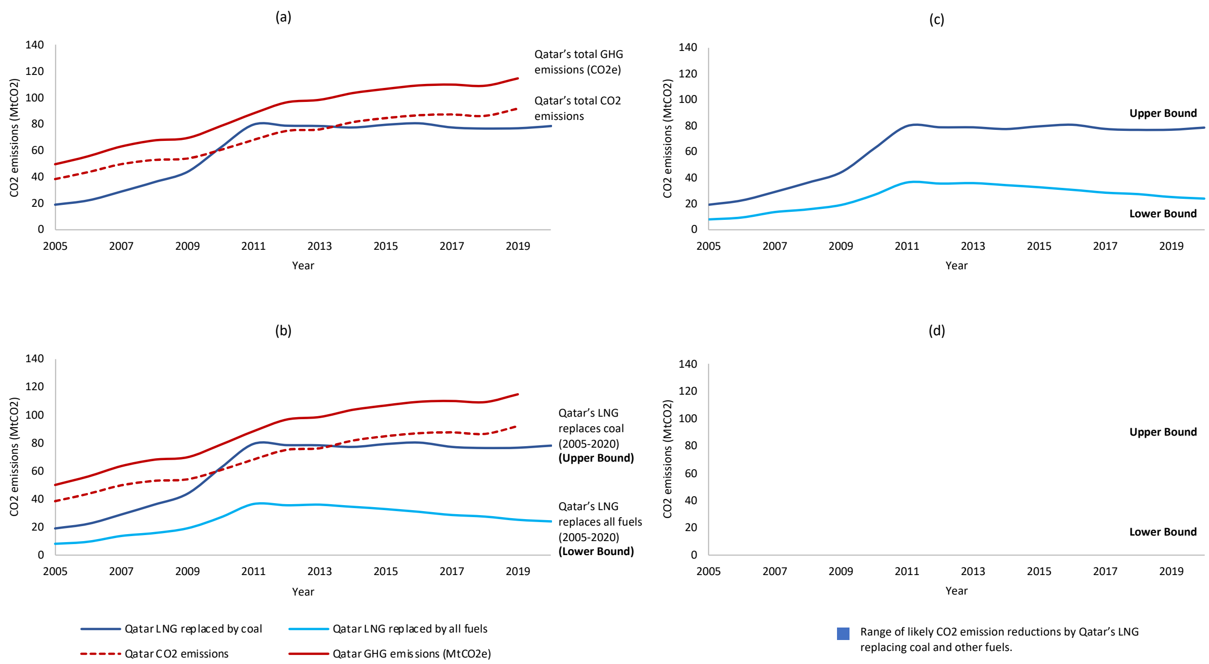
4.2 CO2 emission reductions due to Qatar's LNG exports

Scenario 2 models the reductions in global CO2 emissions due to Qatar's LNG exports by assuming that, if Qatar's LNG exports disappeared from international markets between 2005 and 2020, they would have been replaced by coal (blue line in Figure 3 (a)). The model shows that more CO2 would have been emitted by coal for the same total final consumption than would have been emitted by Qatar's LNG. Between 2005 and 2020, under Scenario 2, for the same total final consumption, the difference in CO2 emitted between coal and Qatar's LNG is, on average, equivalent to 88% of Qatar's total CO2 emissions (Figure 3 (a)). There was a significant increase in coal consumption during the economy recovery following the global financial crisis in 2008. Therefore, Scenario 1 predicts that in 2011, had coal replaced all of Qatar's LNG exports, the difference in emissions is equivalent to 117% of Qatar's local CO2 emissions of that year, which would have meant that Qatar was carbon negative. Having said that, since it's more likely that Qatar's LNG would have been replaced by a mixture of fuels, Scenario 2 serves as the highest possible emissions difference (Upper Bound).

Scenario 3 models the reductions in global CO2 emissions due to Qatar's LNG exports by assuming that Qatar's LNG exports would have been replaced by all fuels and technologies proportional to their share in the energy mix (light blue line in Figure 3 (b)). Given the high share of coal in both the power and industrial sectors in Qatar's export markets, the model shows that the difference in CO2 emissions is positive under Scenario 3 (the light blue line is above the x-axis for the period 2005 to 2020). Between 2005 and 2020, if Qatar's LNG exports were replaced by all fuels proportional to their share in the energy mix, the difference in emissions is, on average, equivalent to 36% of Qatar's total CO2 emissions for that period. Like Scenario 1, emission differences peak in 2011 and are equivalent to 53% of Qatar's local CO2 emissions for that year. Since it is assumed that Qatar's LNG would not have been replaced by LNG from other countries, and that a renewable energy scenario was not likely, Scenario 3 serves as the lowest possible emissions difference (Lower Bound).

Therefore, the Upper Bound is the highest possible emission reductions due to Qatar's LNG exports and the Lower Bound is the lowest possible emission reductions due to Qatar's LNG exports (Figure 3 (c)). The actual reductions in global CO2 emissions due to Qatar's LNG exports replacing more carbon intensive fuels in Qatar's export markets lies somewhere in the shaded area between the Upper Bound and Lower Bound (Figure 3 (d)). While it is virtually impossible to estimate the actual reductions because of a lack of a counterfactual, the next sub-section presents the results of an estimation based on a 'most likely' scenario.

Figure 3: Results of historical analysis



Notes: (a) total reductions in global CO2 emissions due to Qatar's LNG exports if it was replaced by coal relative to Qatar's emissions; (b) total reductions in global CO2 emissions by Qatar's LNG exports if it was replaced by coal (dark blue line) and if it was replaced by all fuels proportionally (light blue line); (c) the identified Upper Bound and Lower Bound of global CO2 emission reductions due to Qatar's LNG exports; (d) the range of likely global CO2 emission reductions due to Qatar's LNG exports replacing coal and other fuels.

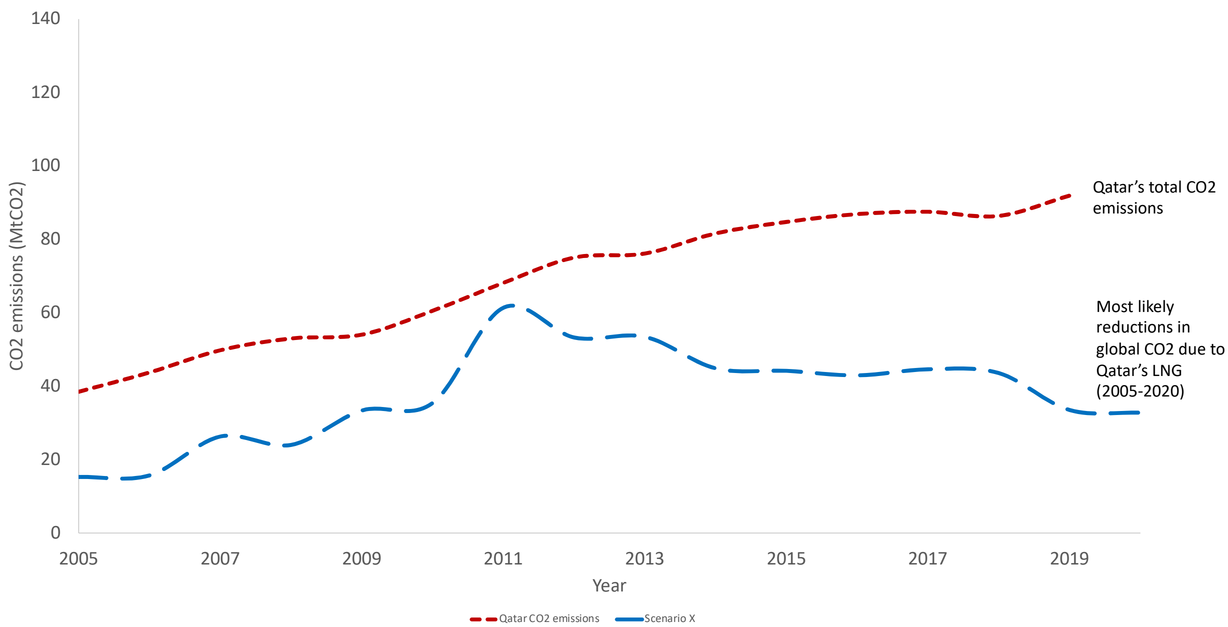
4.3 The 'most likely' scenario

Scenario 2 presents the highest possible reductions in global CO2 emissions due to Qatar's LNG substituting coal in Qatar's export markets. This scenario, while plausible, is unlikely for several reasons. First, the urgent need for low-carbon growth strategies and global commitments to meet National Determined Contributions targets have resulted in a push towards cleaner energy and policies to incentivise non-hydrocarbon alternatives. Second, fluctuations in global energy market prices and suitability of certain fuels and technologies for certain regions mean that coal is never the only option. Finally, concerns around the health impacts of carbon-intensive fuels and energy technologies have forced governments away from coal, especially in China and India.

Scenario 3, on the other hand, presents the lowest possible reductions in global CO2 emissions due to Qatar's LNG substituting all other fuels in proportion to their respective shares in the energy mix. This scenario is considered the Lower Bound for several reasons. First, a scenario where renewables replace Qatar's LNG exports is much less likely. Second, it is more plausible that each fuel and technology expands at a rate commensurate to their relative shares.

The 'most likely' scenario makes use of the Upper Bound and Lower Bound. Under the 'most likely' scenario, whether coal replaces Qatar's LNG (Scenario 2) or all fuels replace Qatar's LNG proportionally (Scenario 2) depends on the share of coal in the energy mix and the growth rate of coal relative to the growth rate of total consumption. As a result, the most likely reductions in global CO2 emissions due to Qatar's LNG exports lie somewhere within the limits of the Upper Bound and Lower Bound. Figure 4 shows the reductions in CO2 emissions under this scenario (dotted blue line) relative to Qatar's local CO2 emissions.

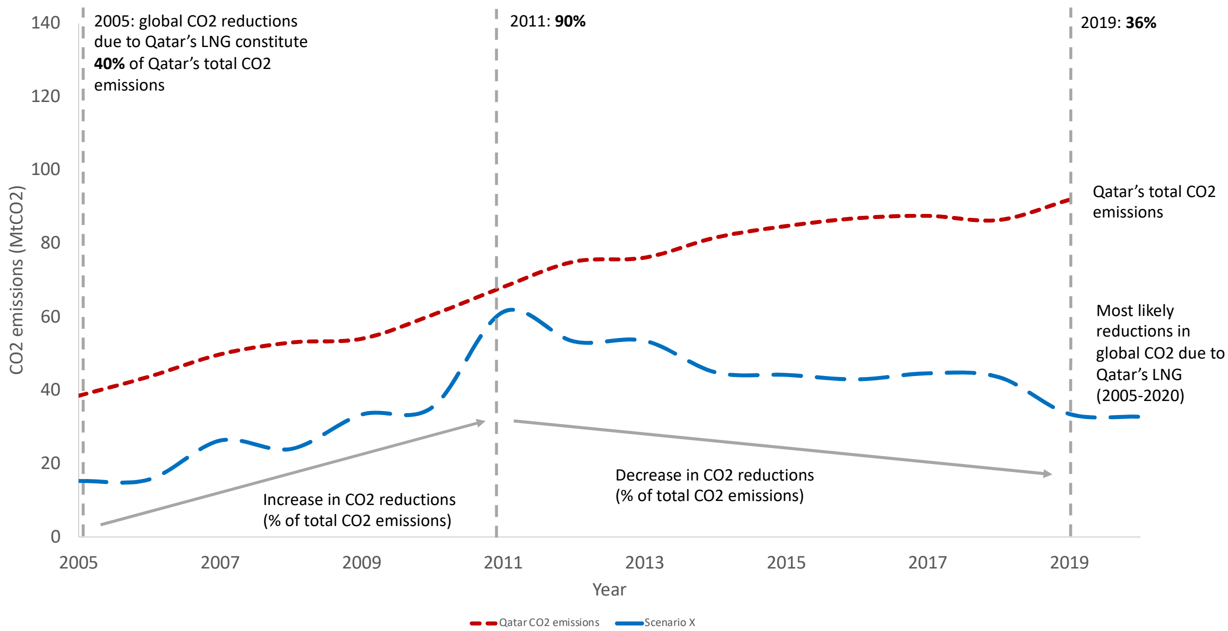
Figure 4: The most like reductions in global CO2 emissions due to Qatar's LNG exports, 2005 to 2020



Under this scenario, global CO2 reductions due to Qatar's LNG exports represented 40% of Qatar's local CO2 emissions in 2005 (Figure 5). Like Scenarios 2 and 3, the reductions in emissions as a percentage of Qatar's local emissions peak at 90% in 2011, when both coal consumption and growth rate were high. Reductions in CO2 emissions then decrease gradually after 2011 in parallel to increase in local CO2 emissions in Qatar. As a result, in 2019, reductions in global CO2 emissions due to Qatar's LNG were equivalent to 36% of local emissions. Between 2005 and 2020, this scenario predicts that the cumulative reductions in global CO2 emissions due to Qatar's LNG exports amount to 605 MtCO2.

There is a clear split under this scenario: an increase in global CO2 reductions and a parallel increase in reductions relative to local consumption between 2005 and 2011; and a decrease in global CO2 reductions and a parallel decrease in reductions relative to local consumption after 2011. Between 2005 and 2011 the increase in reductions can be attributed to increase in coal consumption globally. During this time, there was more coal to be displaced by Qatar's LNG exports. After 2011, the decrease in absolute reductions and reductions relative to local emissions can be attributed to two factors: a reduction in global coal consumption, and, therefore, less coal to be displaced; and an increase in local CO2 emissions in Qatar.

Figure 5: The trend in reductions in global CO2 emissions due to Qatar's LNG exports as a share of local emissions before 2011 (increasing) and after 2011 (decreasing)



4.4 Future CO2 reductions due to Qatar's LNG exports

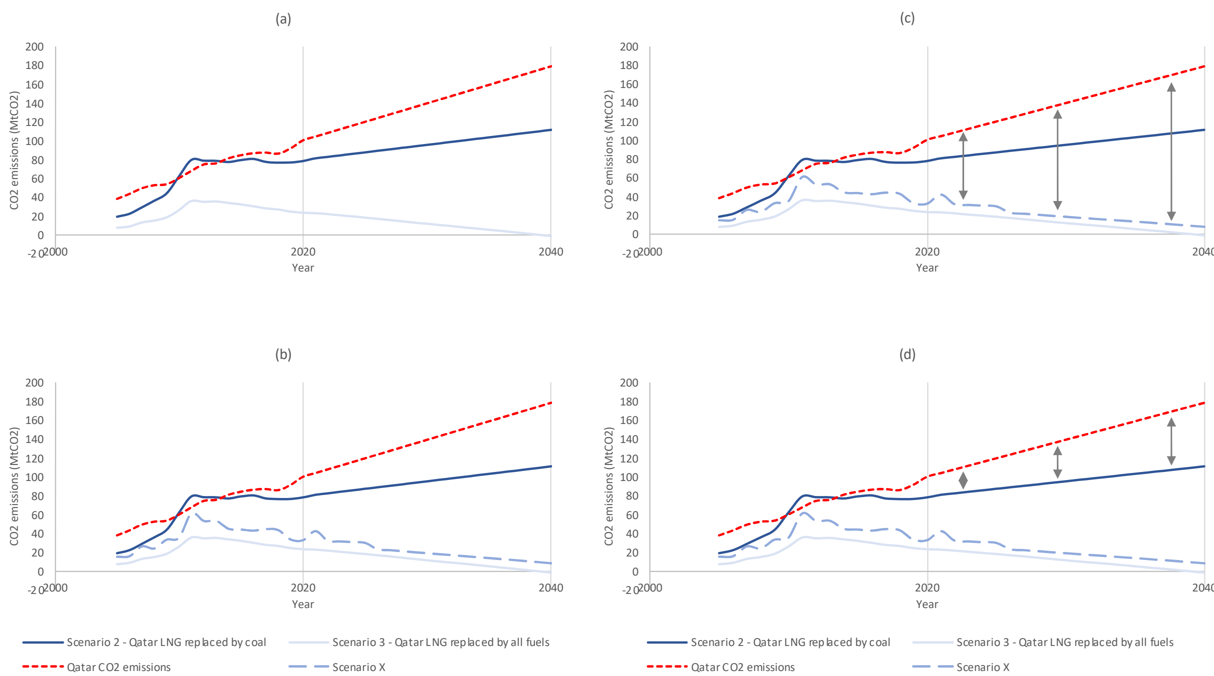
The previous sub-sections provided the outputs of the modelling exercise looking at historical CO2 reductions due to Qatar's LNG exports for the period 2005 to 2020. The same modelling exercise was conducted to estimate potential reductions in global CO2 emissions between 2020 and 2040. A business-as-usual scenario for Qatar's local CO2 emissions shows an increase in local emissions, resulting in 178 MtCO2 in 2040. An extension of Scenarios 2 and 3 for the period 2020 to 2040 based on projections of global total final consumption (see, Section 0), provides an Upper Bound (blue line in Figure 6 (a)) and Lower Bound (light blue line in Figure 6 (a)) for possible reductions in the future.

Similarly, an extension of the 'most likely' scenario for future reductions in global CO2 emissions for the period 2020 to 2040 shows that future reductions beyond 2020 are likely to decrease through to 2040 (dotted light blue line in Figure 6 (b)). Assuming a business-as-usual scenario for Qatar's local emissions between 2020 and 2040, the reductions in global CO2 emissions as a percentage of local emissions decreases at a higher rate than for the period between 2011 and 2020. The higher rate of decrease is primarily due to a consistent decline in global coal consumption in the future consumption scenario, where global coal consumption across sectors decreases, on average, by 5.2% on annual basis between 2020 and 2040. Lower coal consumption globally means that Qatar's LNG will more likely take the place of less carbon intensive fuels and technologies.

The 'most likely' scenario is closer to the Lower Bound in the period 2020 to 2040. And the gap between this scenario and Qatar's local CO2 emissions increases over time (Figure 6(c)). Even considering the best-case reductions, Scenario 2 (blue line in Figure 6(d)), the gap between reductions in global CO2 emissions due to Qatar's LNG exports and local CO2 emissions increases over time.

After 2040, given the increase in the adoption of renewable energy globally, it's likely that Qatar's LNG exports will increase global CO2 emissions. This can be seen in the future projection of the Lower Bound and 'most likely' scenario in Figure 6. When the Lower Bound crosses the x-axis, a negative reduction value means a net increase in global CO2 emissions.

Figure 6: Future projections, 2020 to 2040



Notes: (a) Qatar's future CO2 emissions under a business-as-usual scenario (dotted red line) and potential reductions in global CO2 emissions due to Qatar's LNG exports replacing coal (blue line) and replacing other fuels proportionally (light blue line); (b) the most likely future reductions in global CO2 emissions due to Qatar's LNG exports (dotted light blue line); (c) widening gap between the most likely future reductions in global CO2 emissions due to Qatar's LNG exports and Qatar's future CO2 emissions under a business-as-usual scenario; (d) widening gap between potential reductions in global CO2 emissions due to Qatar's LNG exports replacing coal and Qatar's future CO2 emissions under a business-as-usual scenario.

4.5 Qatar in a global context

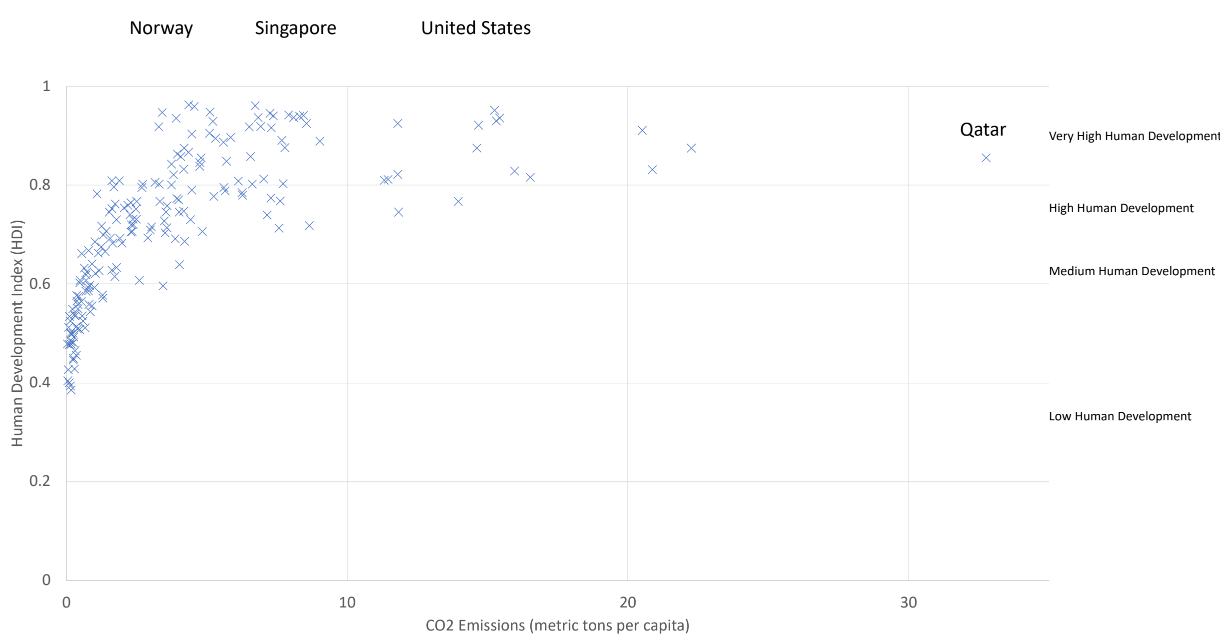
Qatar has received a lot of criticism in recent years over its carbon footprint. Qatar has the highest CO2 emissions per capita (Table 4). The top ten countries with the highest CO2 emissions per capita, except for Luxembourg, are net exporters of hydrocarbons. Four of the other five members of the GCC, Bahrain, Kuwait, the United Arab Emirates and Oman, have the second, third, fourth and fifth highest emissions. A common response to this criticism is that the current carbon accounting system, which assigns the emissions due to hydrocarbon production to the producer, is flawed. And that a consumption-based approach, which assigns the emission in hydrocarbon production to the end user, is more suitable.

Table 4: Qatar's ranking in CO2 emissions per capita, human development index and energy intensity of the economy

Rank	Country	CO2 emissions* (metric tons per capita)	Human Development Index* (Rank)	Emissions per GDP (tCO2e per million $GDP)
1	**Qatar**	**32.8**	**0.86 (43)**	**652.6**
2	Bahrain	22.3	0.88 (37)	1,407.5
3	Kuwait	20.9	0.83 (50)	1,003.6
4	United Arab Emirates	20.5	0.91 (26)	583.7
5	Oman	16.5	0.82 (54)	1,138.7
6	Brunei Darussalam	16.0	0.83 (51)	715.3
7	Canada	15.4	0.94 (15)	444.5
8	Luxembourg	15.3	0.93 (17)	145.4
9	Australia	15.3	0.95 (5)	437.2
10	**United States**	**14.7**	**0.92 (21)**	**270.0**
:	:			
22	**Singapore**	**8.3**	**0.94 (12)**	**179.2**
:	:			
38	**Norway**	**6.7**	**0.96 (2)**	**66.6**

Notes: * Data is for 2019.

Figure 7: Human development index vs CO2 emissions per capita: where Qatar is and where it should aim to be

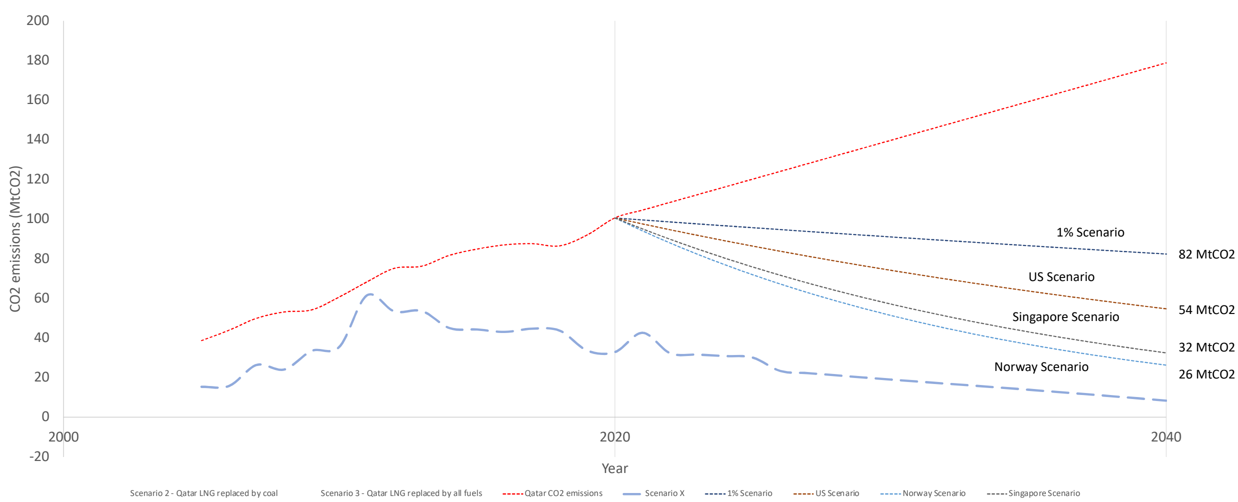


Using a consumption-based approach, recent accounting efforts have estimated that Qatar's local emissions are in fact 50% lower than estimates used in Table 4 (Mohammed, 2021). The consumption-based approach does not account for emissions due to the production of hydrocarbons. This would make Qatar's per capita CO2 emissions around 16 MtCO2 per capita, which would place it 6th on the ranking. However, it's equally likely that a consumption-based approach applied to the other members of the GCC and Brunei Darussalam – who are also net exporters of hydrocarbons and have fossil fuel-based economies – would reduce their emissions too. So, even considering the carbon accounting method used, Qatar's per capita emissions are one of the highest worldwide.

Having said that, over the past two decades, Qatar has experienced unprecedented economic growth and has invested heavily in infrastructure, education, and health. It performs well in almost all economic and wellbeing indicators and has a very high Human Development Index (HDI) of 0.86 (Table 4). However, it ranks lower than Bahrain and the United Arab Emirates, who have an HDI of 0.88 and 0.91, respectively. More importantly, when likened to Singapore, which has a similarly small area with low natural capital, and Norway, which has similar fossil fuel resources and a small population, Qatar compares poorly. Singapore and Norway rank much higher than Qatar in human development and rank much lower in CO2 emissions per capita (Figure 7). Norway, which has the second highest HDI and is one of the largest exporters of fossil fuels in the world, emits 80% less CO2 than Qatar on a per capita basis.

Given that Norway and Singapore are at different stages in their development process, the difference in per capita emissions between them and Qatar is understandable. However, there is a lot of room for improvement. There are several ways in which Qatar can reduce its local – production and consumption – emissions. And in doing so, Qatar could reduce the gap between its local emissions and emission reductions due to Qatar's LNG exports to global markets, therefore, continuing to offset its emission as it had done between 2005 and 2020.

Figure 8: Potential emission reductions scenarios



Notes: (1% scenario, US scenario, Singapore scenario and Norway scenario) and projected most likely reductions in global CO2 emissions due to Qatar's LNG exports (light blue dotted line) (Note: the different country scenarios are based on their 2020 CO2 per capita emissions highlighted in Table 4).

5 Conclusion

The results of the analysis in this paper have shown that the substitution of coal and other carbon-intensive fuels by Qatar's LNG exports quite possibly contributed to reductions in global CO2 emissions. The reductions in CO2 emissions due to Qatar's LNG exports between 2005 and 2020 amounted to 605 MtCO2, which is the equivalent to more than three years' worth of emissions of a middle-income country such as Peru. The reductions in emissions peaked when coal demand was highest in 2011 and declined after that. It is likely that reductions in CO2 emissions will continue to decline to 2040 as the world moves away from coal and other hydrocarbons towards cleaner fuels and technologies. It is, therefore, unlikely that reductions due to Qatar's LNG exports will increase again.

In 2011, the reductions in CO2 emissions were equivalent to 90% of Qatar's local CO2 emissions. With the reduction in global coal consumption, the reductions in CO2 emissions relative to Qatar's local emissions decreased to 36% in 2019. The government could adopt several strategies to ensure that Qatar continues to offset its own local emissions by exporting LNG.

First, Qatar must prioritise reducing local emissions. Many studies have been conducted in the past and have produced several policy recommendations on how local emissions could be reduced. The policy recommendations, in one way or another, address the following issues: energy efficiency measures that increase building energy efficiency and increase awareness about efficient energy use; fossil fuel subsidy reform and promotion of electric transport to reduce consumption of fossil fuels in the transport sector; import regulations on energy intensive goods and services; circular economy policies to enhance and encourage sustainable production and consumption.

The findings also indicate that a more targeted export strategy could ensure that Qatar's LNG continues to displace coal and other carbon intensive fuels in its export markets. Exporting to countries with a high share of coal and other carbon intensive fuels in their energy mix could ensure LNG has a net positive impact on global GHG emissions.

Finally, the government could diversify its energy services to include renewable energy in previously untapped markets. Many developing countries, especially in Sub-Saharan Africa, do not possess the necessary infrastructure to import LNG. Most of these countries will continue to rely on their existing infrastructure, which was designed around, and continues to cater to, more carbon-intensive fossil fuels. These same countries, however, need, and can accommodate, decentralised energy solutions. Unlike hydrocarbons, renewable energy is not heavily dependent on a specific type of infrastructure. While most developing countries lack the financial capacity to expand existing grid networks to increase supply of electricity, Qatar is in a unique position to support the expansion of energy access. Providing other types of energy services in parallel with financial support for infrastructure development would help Qatar diversify its income sources and support development around the world.

References

Abrahams, L. S., Samaras, C., Griffin, W. M., and Matthews, H. S. (2015), Life cycle greenhouse gas emissions from US liquefied natural gas exports: implications for end uses, Environmental Science and Technology, vol. 49, issue 5, pp. 3237-3245.

Al-Breiki, M. and Bicer, Y. (2021), Comparative life cycle assessment of sustainable energy carriers including production, storage, overseas transport and utilisation, Journal of Cleaner Production, vol. 279, 123481.

Al-Yafei, H., Aseel, S., Kucukvar, M., Onat, N. C., Al-Sulaiti, A. and Al-Hajri, A. (2021), A systematic review for sustainability of the global liquified natural gas industry: A 10-year update, Energy Strategy Reviews, vol. 38, 100768.

Butler, C., Denis-Ryan, A., Graham, P., Kelly, R., Reedman, L., Stewart, I. and Yankos, T. (2020), Decarbonisation Futures: Solutions, actions and benchmarks for a net zero emissions Australia, ClimateWorks Australia, March 2020.

Chung, C., Kim, J., Sovacool, B., Griffiths, S., Bazilian, M. and Yang, M. (2023), Decarbonizing the chemical industry: A systematic review of sociotechnical systems, technological innovations and policy options, Energy Research & Social Science, vol. 96, 102955.

Coleman, J. W., Kasumu, A., Liendo, J., Li, V. and Jordaan, S. M. (2015), Calibrating Liquefied Natural Gas Export Life Cycle Assessment: Accounting for Legal Boundaries and Post-Export Markets (June 1, 2015). Canadian Institute of Resources Law, Occasional Paper No. 49

Constantino, G., Freitas, M., Fidelis, N. and Pereira, M. G. (2018), Adoption of photovoltaic systems along a sure path: A life-cycle assessment (LCA) study applied to the analysis of GHG emission impacts, Energies, vol. 11, issue 10, 2806.

Di Lullo, G., Oni, A. O., Gemechu, E. and Kumar, A. (2020), Developing a greenhouse gas life cycle assessment framework for natural gas transmission pipelines, Journal of Natural Gas Science and Engineering, vol. 75, 103136.

Gibon, T., Menacho, A. H. and Guiton, M. (2021), Life Cycle Assessment of Electricity Generation Options, United Nations Economic Commission for Europe (UNECE), Geneva.

Hardisty, P. E., Clark, T. S. and Hynes, R. G. (2012), Life Cycle Greenhouse Gas Emissions from Electricity Generation: A Comparative Analysis of Australian Energy Sources, Energies, vol. 5, issue 4, pp. 872-897.

Hayhoe, K., Kheshgi, H., Jain, A. and Wuebbles, D. (2002), Substitution of natural gas for coal: climatic effects of utility sector emissions, Climate Change, vol. 54, pp. 107-139.

IEA (2019), The Role of Gas in Today's Energy Transitions, International Energy Agency, Paris.

International Energy Agency (2021), Statistics Report: Key World Energy Statistics 2021, IEA, September 2021, Paris.

IPCC (2023), Climate Change 2023: Synthesis Report of the IPCC Sixth Assessment Report (AR6), Summary for Policymakers.

IPCC (2022), Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)], Cambridge University Press, Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3056, doi:10.1017/9781009325844.

IRENA (2022), World Energy Transitions Outlook 2022: 1.5oC Pathway, International Renewable Energy Agency, Abu Dhabi.

Jain, A. K., Briegleb, B. P., Minschwaner, K. and Wuebbles, D. J. (2000), Radiative forcings and global warming potentials of 39 greenhouse gases, Journal of Geophysical Research, vol. 105, pp. 20773-20790.

Jaramillo, P., Griffin, W. M. and Matthews, H. S. (2007), Comparative life-cycle air emissions of coal, domestic natural gas, LNG, and SNG for electricity generation, Environmental Science & Technology, vol. 41, issue 17, pp. 6290-6296.

Korre, A., Nie, Z. and Durucan, S. (2012), Life Cycle Assessment of the natural gas supply chain and power generation options with CO2 capture and storage: Assessment of Qatar natural gas production, LNG transport and power generation in the UK, Sustainable Technologies, Systems and Policies, vol. 2012, issue 2.

Littlefield, J., Rai, S. and Skone, T. J. (2022), Life Cycle GHG Perspective on U.S. Natural Gas Delivery Pathways, Environmental Science and Technology, vol. 56, issue 22, pp. 16033-16042.

Mohammed, S. (2021), Qatar’s National Emission Inventory Report 2019: Emission Inventories 1998-2019, Arab Youth Climate Movement Qatar.

Naimoli, S. and Ladislaw, S. (2020), Climate Solutions Series: Decarbonizing Heavy Industry, CSIS Briefs, October 2020.

Nie, Y., Zhang, S., Liu, R. E., Roda-Stuart, D. J., Ravikumar, A. P., Bradley, A., Masnadi, M. S., Brandt, A., Bergerson, J. and Bi, X. T. (2020), Greenhouse-gas emissions of Canadian liquified natural gas for use in China: Comparison and synthesis of three independent life cycle assessments, Journal of Cleaner Production, vol. 258, 120701.

Qatar Energy (2021), Your Energy Transition Partner: Sustainability Report 2021, Qatar Energy.

Qatar Gas (2021), 2021 Sustainability Report: Drive Sustainability Through Cleaner Energy, Qatar Gas.

Roman-White, S., Rai, S., Littlefield, J., Cooney, G. and Skone, T. J. (2019), Life Cycle Greenhouse Gas Perspective on Exporting Liquefied Natural Gas from the United States: 2019 Update, National Energy Technology Laboratory, Pittsburgh.

Tavakkoli, S., Feng, L., Miller, S. M. and Jordaan, S. M. (2022), Implications of generation efficiencies and supply chain leaks for the life cycle greenhouse gas emissions of natural gas-fired electricity in the United States, Environmental Science and Technology, vol. 56, issue 4, pp. 2540-2550.

WHO (2022), Ambient (outdoor) air pollution, WHO Fact Sheet (Accessed on 8 May 2023): https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.

Williams, M. and Bell, A. (2022), The Pathway to Industrial Decarbonization, Center for American Progress, (Accessed on 14 May 2023): https://www.americanprogress.org/article/the-pathway-to-industrial-decarbonization/

Appendices

Appendix I: Growth rate of different technologies

Table A1: Average change in energy consumption between 2020 to 2040

Fuel/technology	**Growth rate (%)**
Power sector	
Oil products	-9.8%
Oil	-14.2%
Coal	0.9%
Natural gas	1.6%
Biofuels and waste	3.8%
Solar/tide/wind	6.0%
Geothermal	3.2%
Hydro	1.6%
Nuclear	1.2%
Industry	
Oil products	0.4%
Oil	-12.6%
Coal	-5.2%
Natural gas	2.2%
Biofuels and waste	2.1%
Heat	2.3%
Electricity	2.1%
Other	
Oil products	-0.1%
Oil	0.0%
Coal	-12.4%
Natural gas	2.1%
Biofuels and waste	0.3%
Geothermal	6.1%
Solar/tide/wind	2.2%
Heat	1.8%
Electricity	2.1%

Appendix II: Emissions calculations

The following equation is used to calculate total LNG imports from Qatar

$$TFC^{Q}_{LNG,j,t} = a^{Q}_{j,t} \times TFC^{T}_{LNG,t}$$

where $TFC^{Q}_{LNG,j,t}$ is the total final consumption of Qatar's LNG imports, $a^{Q}_{j,t}$ is the share of Qatar's LNG imports and $TFC^{T}_{LNG,t}$ is the total final consumption of total LNG imports, in sector j for year t. Then, to calculate the emissions due to LNG imports from Qatar, the following equation makes use of the emissions factor of LNG as

$$E^{Q}_{LNG,j,t} = TFC^{Q}_{LNG,j,t} \times \varepsilon_{LNG}$$

where $E^{Q}_{LNG,j,t}$ is the emissions due to LNG imports from Qatar and ε_{LNG} is the emissions factor for LNG.

For Scenario 2, where coal replaces all LNG imports from Qatar, the emissions difference is calculated using the following equation

$$E_{2,j,t} = \left(TFC^{Q}_{LNG,j,t} \times \varepsilon_{coal}\right) - E^{Q}_{LNG,j,t}$$

where $E_{2,j,t}$ is the emissions due to Qatar's LNG for Scenario 2 and ε_{coal} is the emissions factor for coal.

For Scenario 3, where Qatar's LNG is replaced by all fuels proportional to their share of the energy mix, the emissions difference is calculated using the following equation

$$E_{3,j,t} = \sum_{f=1}^{9} \left(i_{f,j,t} \times TFC^{Q}_{LNG,j,t} \times \varepsilon_{f}\right) - E^{Q}_{LNG,j,t}$$

where $E_{3,j,t}$ is the emissions due to Qatar's LNG for Scenario 3, $i_{f,j,t}$ is the share of fuel f in the energy mix and ε_f is the emissions factor for fuel f.

A 'most-likely' scenario was developed based on the following assumption: the higher the growth rate of coal consumption and the larger the share of coal in the energy mix, the more likely it is for coal to replace Qatar's LNG. To that end, the follow probabilities are assigned to determine the most likely emissions differences between the real and hypothetical counterfactual: the probability of coal replacing Qatar's LNG is highest – equal to 1 – when the increase in coal consumption is higher than the increase in total energy consumption, and the probability of coal replacing Qatar's LNG is highest when the share of coal is more than half of total energy consumption, lowest when the share of coal is less than a fifth of total energy consumption.

Therefore, the emissions difference based on the 'most likely' scenario is calculated using the following equation

$$E_{x,j,t} = E_{2,j,t}\big(p(coal)\big) + E_{3,j,t}\big(1 - p(coal)\big)$$

where $E_{x,j,t}$ is the emissions reductions in the 'most likely' scenario and $p(coal)$ is the weighted sum of the probability of coal replacing Qatar's LNG, which takes the form

$$p(coal) = \sum_{k=r,i} \omega_k p_k(coal)$$

with $\forall \omega_k > 0$ and $\sum_k \omega = 1$, where $\omega_1 = \omega_2 = \cdots = \omega_n = n^{-1}$, r is the growth rate and i is the share of the energy mix. Therefore, $p_r(coal)$ is the probability of coal replacing Qatar's LNG given coal has a higher growth rate than total energy consumption and $p_i(coal)$ is the probability of coal replacing Qatar's LNG given that coal has a certain share of the energy mix, for sector j in year t, where

$$p_r(coal) = \begin{cases} 1 & if\ r_{coal} > r_{Tot} \\ 0 & otherwise \end{cases}$$

and

$$p_i(coal) = \begin{cases} 1 & if\ i_{coal} > 0.5 \\ 0.5 & if\ 0.5 > i_{coal} > 0.2 \\ 0 & otherwise \end{cases}$$

The logic being that a large increase in coal consumption in sector j in year t means that, for that year, coal was a more feasible option, both economically and logistically. Moreover, a higher share of coal in the energy mix means that the infrastructure available is more conducive to coal consumption and it would therefore be easier to consume more coal than switch to alternative fuel. This is especially true when considering technologies with very high adoption and expansion barriers, such as nuclear. This is also the reason why Scenario 4 makes sense.