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Strategic Planning for Qatar's Hydrogen Industry Development: Insights from Bayesian Belief Networks Analysis#

Carlos Méndez[1*], Marcello Contestabile[1]

1 Qatar Environment and Energy Research Center (QEERI), Doha, Qatar

(*Corresponding Author: cmendezdelgado@hnku.edu.qa)

ABSTRACT

Fossil fuel exporters such as Qatar are seeking ways to adapt to a world that aims to shift away from unabated fossil fuels. In this regard, clean hydrogen production is viable for harnessing the nation's natural resources while addressing environmental concerns. Nonetheless, uncertainties surrounding the hydrogen market add complexity to hydrogen strategy development. Hence, the present study accounts for said uncertainties while deploying a probabilistic approach via a Bayesian Belief Network (BBN) to obtain evidence that can support decision-makers in generating Qatar's potential hydrogen strategy. Outcomes indicate that if Qatar aims to become a major exporter of clean commodities, its current H_2 production will require a minor expansion. However, to position itself as a leading hydrogen exporter, Qatar would need to act more decisively, since several other countries are ahead, as reflected by the 2050 projections, which indicate that Qatar will face less than a 40% probability to satisfy a demand as high as 20 MTPA.

Keywords: Bayesian Belief Network, Uncertainty, Hydrogen Strategy.

NONMENCLATURE

Acronyms	
ATR	Autothermal Reforming
BBN	Bayesian Belief Network
CBAM	Carbon Border Adjustment Mechanism
GCC	Gulf Cooperation Council
GHG	Greenhouse Gas
LNG	Liquified Natural Gas
MTPA	Millon Tons per Annum
NDC	Nationally Determined Contributions
SMR	Steam Methane Reforming
WEO	World Energy Outlook
Formulas	
CO_2	Carbon Dioxide
H_2	Hydrogen

1. INTRODUCTION

Qatar is a main player in the international energy market due to its vast natural reserves, which enable the nation to be among the leading liquified natural gas (LNG) exporters. Additionally, Qatar is aiming to expand its presence, by increasing its LNG production capacity from 77 to 142 MTPA by 2030 [1]. Moreover, QatarEnergy, the national oil and gas company, has established 2035 net-carbon intensity reduction goals of 25% and 35% for upstream and LNG facilities, respectively [2]; targets that seek to complement its flaring intensity (74%) and methane emission (38%) reduction objectives, and decrease the LNG production greenhouse gas (GHG) footprint [2].

From a larger viewpoint, Qatar's 2021 NDC aims to reduce its GHG emissions by 25% relative to business as usual, a target that incorporates multiple sectors like oil and gas, as well as hard-to-abate industries [3,4]. This approach creates opportunities for the country to expand its portfolio and include the production of clean commodities for export, to satisfy the growing demand created by policies such as the European Union's Carbon Border Adjustment Mechanism (CBAM). An approach in which clean hydrogen is a key input, as it serves both as a chemical feedstock and a fuel for the production of clean commodities.

While Qatar has yet to commit to developing a hydrogen (H_2) strategy, the plan to build the world's largest blue ammonia plant showcases the nation's decarbonization intentions in areas other than LNG. However, one of the issues that arises while contemplating the creation of a H_2 strategy is the uncertainty surrounding it. Hence, the present study incorporates a probabilistic approach via a Bayesian Belief Network (BBN), which considers said uncertainties and provides inputs that support the decision-making process linked with the potential development of a clean hydrogen industry in Qatar.

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1.1 Background

GCC countries, with the exception of Qatar, have stated the intention to build hydrogen industries; they have produced strategies, roadmaps, or at least white paper addressing the topic [5]. Hence, Qatar could consider exploiting its natural gas resources to foray into the international hydrogen market to diversify its source of income.

Given hydrogen's potential role in energy transition, multiple approaches have been taken to analyze the impact that the development of a hydrogen industry may have on oil and gas-exporting countries; these include multidimensional approaches such as STEEP, MLP, and REMES [6–8]. Moreover, TIMES modelling has been used to future impacts of the development of a H_2 market on fossil fuel exporters [9]. Despite the variety of studies, the deep uncertainty affecting the creation of hydrogen strategies for oil & gas exporting countries has not yet been adequately researched. Moreover, deterministic approaches provide solid input; nevertheless, they rely on fixed assumptions and yield point estimations associated with scenarios. Conversely, BBNs are versatile and account for uncertainties, providing a broader understanding that is useful to policymakers.

1.2 Aim of the study

The present study aims to address deep uncertainty surrounding the topic by incorporating Bayesian networks into the analysis of hydrogen strategies for Qatar.

2. METHODOLOGY

BayesFusion, LLC [10] is used to create a BBN that represents the deep uncertainty surrounding hydrogen markets and technologies in the context of Qatar. This graphical model comprises variables represented as nodes and probabilistic dependencies represented as arcs, forming an acyclic-directed diagram. The connections between nodes through these arcs express the factorization of the joint probability distribution, and the resulting inferences serve various applications.

Firstly, Qatar's nationwide H_2-related infrastructure and demand are mapped, and the outcomes are used to determine the potential availability of hydrogen for export. Subsequently, multiple variables associated with the study and their interactions are identified. The international hydrogen market is also represented, incorporating current and projected demand and production behaviors, which directly influence the potential H_2-market share of Qatar. Ultimately, the BBN's graphical representation is created (see Fig. 1), incorporating probability tables per input node, and complementing the interactions with required equation nodes.

Public domain data is used to meet the input requirements. For the local context, sector-specific reports were used, while international demand scenarios

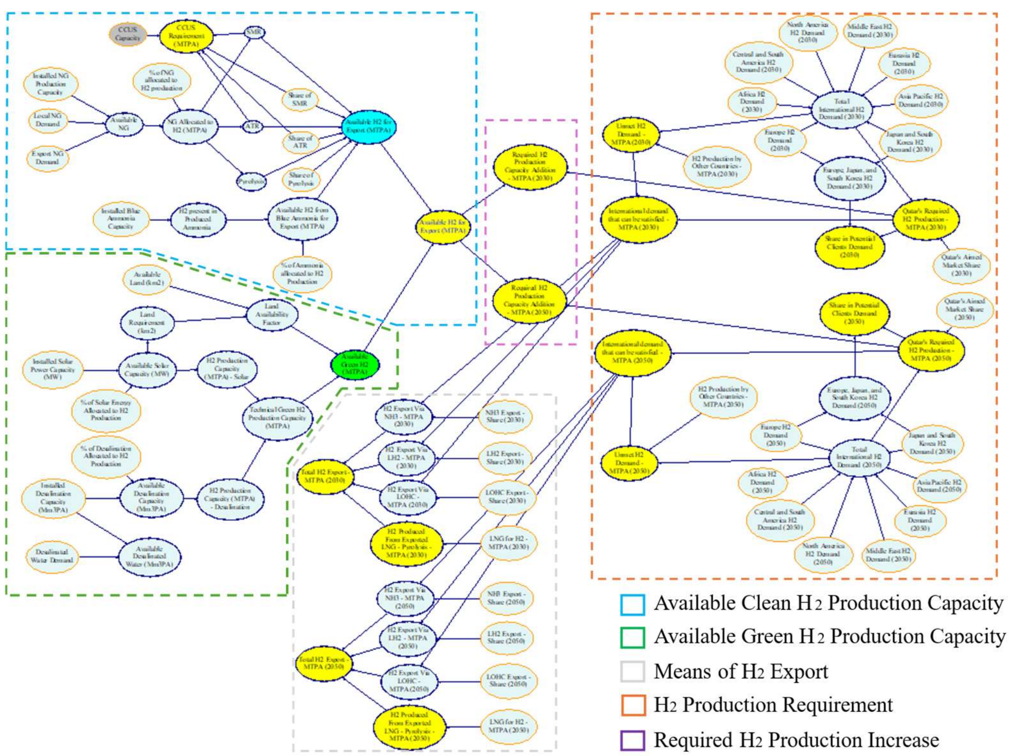

Fig. 1 Bayesian Belief Network Diagram

were based on the International Energy Agency's 2024 World Energy Outlook (WEO), the global hydrogen review, hydrogen strategies/roadmaps, and the hydrogen for net-zero document redacted by the Hydrogen Council [11–15].

3. RESULTS

BBN output provides upper and lower bound values, as well as averages. Additionally, probability distributions are also obtained, providing insights into probable outcomes for multiple elements.

3.1 Available H_2 Production for Export

As represented in Fig. 1, H_2 production is divided into: a) Clean, including Steam Methane Reforming (SMR), Autothermal Reforming (ATR), and Pyrolysis, and b) Green, from water electrolysis using renewable energy. For clean hydrogen, a partition of 26%, 68%, and 6% is considered, while solar PV is used for green H_2 production. With these considerations and as reflected in Fig. 2, the average capacity available for export is 2 MTPA, with 1 MTPA as the most likely (40%) outcome, and as much as 15 MTPA as maximum. Due to limited physical space and water scarcity, less than 1% of the potential H_2 production is green, while over 99% originates from natural gas.

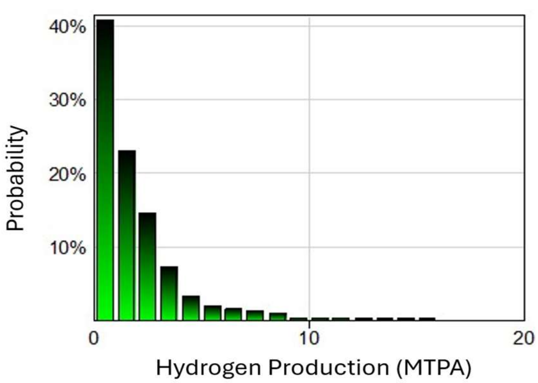

Fig. 2 Available H_2 production for export

3.2 International Demand

The analysis of international demand considers projected market behavior of other countries to determine the demand gap that Qatar could fill. As shown in Fig. 3, in 2030, there is a broad distribution, with an occurrence probability above 8% for values between 20 and 110 MTPA. For 2050, however, the market gap that Qatar could fill becomes limited, with approximately 61% likelihood of demand up to 20 MTPA; this is driven by the aggressive exporting goals set by other countries.

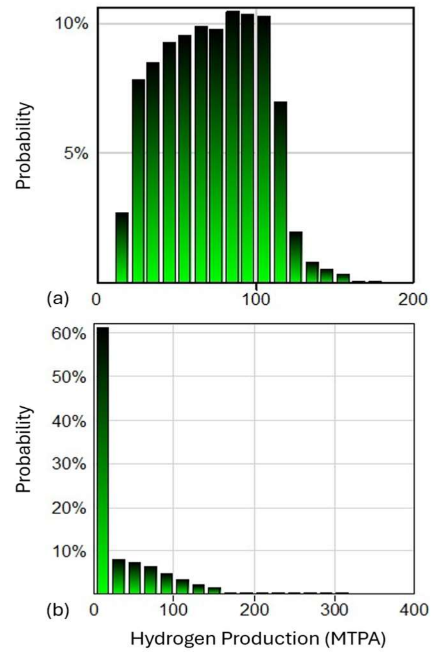

Fig. 3 Unmet International Demand: (a) 2030, (b) 2050

3.3 Production Capacity Increase

Since the present study assumes that Qatar will aim to, on average, meet 5% of the international market, the calculated capacity increase depends on the estimated market demand gap available for Qatar and the country's infrastructure.

Fig. 4 shows that Qatar may not need to add extra capacity to meet its goal since the most probable outcome is an addition of less than 1 MTPA. On average, however, the country should add roughly 5 and 9 MTPA

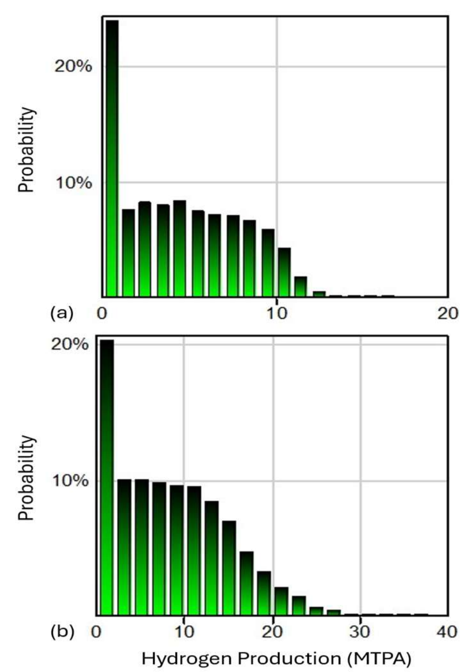

Fig. 4 Production capacity increase: (a) 2030, (b) 2050

to meet the 2030 and 2050 targets. Nonetheless, this may vary depending on the nation's ambition and market saturation.

4. DISCUSSION

The findings highlight that an early mover strategy guarantees the nation's presence in the H_2 market, particularly due to the decreasing unmet demand in 2050 compared with 2030. Additionally, due to its limited land area, water scarcity, and vast natural gas reserves, Qatar relies heavily on hydrocarbon-based H_2, where several technologies can be implemented. However, depending on the H_2 production method, carbon capture and storage must also be developed.

Furthermore, a non-substantial capacity expansion will likely be required if Qatar wishes to achieve 5% of the international market share. However, if Qatar aims to satisfy clean commodities production (i.e., clean steel) and secure a share in the international hydrogen market, this infrastructure growth will rise accordingly.

5. CONCLUSIONS

The present article employs a Bayesian Belief Network to assess uncertainties surrounding Qatar's potential international hydrogen market engagement and determine probable requirements for doing so. This approach allows the analysis of multiple variations and their occurrence probability, which results in various outcomes. Hence, trend analysis provides a better understanding than a deterministic approach, and it may play a key role in the decision-making process. Findings indicate that while clean commodity manufacture is not a priority for the country, minor H_2 production capacity expansion will be required. However, to ensure an international hydrogen market presence, Qatar should aim to take part early on, since, despite higher H_2 requirement, unmet demand will decrease by 2050.

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