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Investment portfolios under uncertainty for utilizing natural gas resources

Rajab Khalilpour, I.A. Karimi*

Department of Chemical & Biomolecular Engineering, National University of Singapore, 4 Engineering Drive 4, Singapore 117576, Singapore

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ABSTRACT

Numerous reasons including lower carbon and sulfur emissions have led to the rapid growth of natural gas (NG) demand. However, more than one-third of world NG reserves are stranded, i.e., either remote (e.g., offshore) or in regions with saturated markets. This reality makes the investment decisions complex and uncertain for NG field developers. In this study, we consider the case of a company that wishes to develop a stranded natural gas reserve for some potential nearby markets under uncertain prices of crude oil and feed gas, and demands of liquefied NG (LNG), compressed NG (CNG), and gas-to-liquid (GTL) products. We present a 2-stage stochastic mixed-integer linear program (MILP) that yields maximum-ENPV (expected NPV) decisions on production capacities, market allocations, and delivery vessels. The small model size allows us to consider many stochastic scenarios in our scenario-based approach. We illustrate our approach using several examples.

1. Introduction

Natural gas (NG) is the cleanest fossil fuel due to its lower carbon, nitrogen, sulfur, and particulates emissions. More importantly, the costs of NG-based processes such as power generation are much lower than those of coal- or oil-based (US-DOE, 2003). As policies and/or mechanisms for carbon taxes/credits/penalties are under discussion, the economic advantages of NG grow. All these are leading to the rapid growth of NG exploration, processing and consumption. The current growth in energy demand along with global concerns and treaties about climate protection will continue to foster NG demand.

Although NG is the most favored resource of fossil fuels, its transportation to the demand sites poses a challenge due to its gaseous state. The NG trade has largely been via pipelines between limited supply countries and their neighbors. Thus, unlike crude oil, the disconnection between remote and offshore gas reservoirs and markets has obstructed a fully developed market and globally traded commodity status for NG. It is estimated that a significant portion of NG reserves (between 30 and 80% of proven and potential NG reserves) is still "stranded" (Holditch, 2003; Thackeray & Leckie, 2002). Stranded fields are those in remote (e.g., offshore) regions too far from the nearest markets, or those in a region with saturated markets. The utilization of gas from such fields is not economical due to the high investment required for a pipeline or liquefaction facility.

The rise in energy prices, increase in the consumption of NG, and reducing market share of existing sources such as oil have raised the specter of gas supply shortages in many regions. The emerging demand and new market opportunities are generating tremendous interest for the utilization of gas from stranded fields. For this reason, extensive research is underway to develop alternative gas utilization options for monetizing remote NG. They include compressed natural gas (CNG), gas-to-liquids (GTL), gas-to-chemicals (GTC), gas-to-solids (GTS), and gas-to-wire (GTW) (Thomas & Dawe, 2003). All these aim to reduce NG volume to make its transport practical and cheaper for export over long distances. While the conceptual origins of some of these methods can be traced back to more than one century ago (Davis, 2002), the commercial interest began in 1960s and has grown markedly with the start of the 21st century due to the current energy landscape. CNG, LNG, and GTL are currently the most attractive technologies for gas utilization.

The combination of discrete NG markets, multiple utilization options, and uncertainty in energy prices makes the planning decisions of upstream NG investors a complex and stochastic problem. Thomas and Dawe (2003) reviewed possible options for NG utilization and transport. Their study was primarily qualitative, and they analyzed the pros and cons of several available alternatives. Deshpande and Economides (2005) compared CNG and LNG. They defined various thermodynamic scenarios for CNG compression and refrigeration, and studied their effects on the economics of the entire value chain. Subero, Sun, Deshpande, Mclaughlin, & Economides (2004), using the available data on CAPEXs (capital

* Corresponding author. Tel.: +65 6516 6359; fax: +65 6779 1936.
E-mail address: cheiak@nus.edu.sg (I.A. Karimi).

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Nomenclature

Subscripts

c	capacity discrete size
h	products demand scenario
i	crude oil price scenario
j	feed gas cost scenario
k	market
o	option
s	scenario
t	time (year)

Superscripts

U	upper limit

Parameters

$CAPEX_{oct}$	CAPEX for a train of capacity c of option o at year t
C_o	number of discrete capacity sizes for option o
D_{okts}	forecast demand of market k for option o at time t under scenario s
f_o	fractional capacity factor for option o
GC_{ts}	feed gas cost
GR_t	maximum natural gas at year t
H	number of product demand scenarios
I	number of crude oil price scenarios
J	number of feed gas cost scenarios
K	number of potential
M	construction period (years)
N	production life (years)
NGD_{kts}	forecast natural gas demand of market k at time t under scenario s
OP_{ts}	crude oil price at time t and scenario s
p_{okts}	*DES* price of option o for market k during year t under scenario s
P_s	probability of scenario s
q_{oc}	capacity of option o with discrete size c
r	discount rate
S	number of scenarios
V_o	fixed capacity of vessels for option o
VC_{ot}	Vessel construction/procurement cost for option o during year t
tt_{ok}	total time for one round trip delivery to market k for option o
η_o	yield for option o
φ_o	annual fractional operating factor of the vessel for option o
β_{okts}	operating cost per vessel delivery for option o to market k during year
τ_t	tax rate during year t
γ_{ok}	fraction of product lost during the delivery of option o to market k

Integer variables

m_o	number of vessels of size V_o for option o
n_{oc}	number of trains of capacity for option o
y_{okts}	number of full vessels of product o delivered to market k during year t in scenario s

Continuous variables

CF_{ts}	cash flow during year t under scenario s
CX_t	total CAPEX at year t
ENPV	expected NPV
NPV_{os}	NPV for option o under scenario s
EX_{ts}	total expenditure during year t under scenario s
OX_{ts}	OPEX during year t for scenario s
Q_o	installed capacity for option o
SR_{ts}	total sales revenue during at year t under scenario s
TAX_{ts}	tax for year t under scenario s
TI_{ts}	taxable income for year t under scenario s
α_{ots}	total OPEX per unit amount of feed gas for option o in year t under scenario s

expenditures) and OPEXs (operating expenditures), compared CNG and LNG, and identified the distance thresholds below which CNG was more attractive than LNG. In another study, Economides, Sun, & Subero (2006) further developed the model by Subero et al. (2004) to justify the attractiveness of CNG over LNG for small gas reservoirs. Economides (2005) performed an economic comparison between LNG and GTL considering different crude oil and gas price scenarios. He used several distant markets as case studies. Dong, Wei, Tan, & Zhang (2008) also compared GTL and LNG, and concluded the commercial viability of GTL, but did not report any economic model. They claimed that while a GTL facility is more complex, less efficient, and more expensive than an LNG facility, their end-to-end supply chains are quite comparable. This makes an investment decision quite challenging. They suggested that other factors besides CAPEX, such as technology risks, plant availability, local markets, political considerations, etc., may also be important in LNG vs. GTL decision-making. Recently, Al-Saadoon (2007) considered different CAPEX and OPEX scenarios and assessed the economic viability of GTL plants. However, the study did not link oil and gas prices to CAPEX and OPEX, and thus did not result in an integrated economic model.

Several studies have focused on specific regions such as Canada's Newfoundland (Imperial-Ventrue, 1998), USA's Gulf of Mexico (Ward, Wolford, Mick, Hauser, et al., 2005; Ward, Wolford, Mick, & Tapia; Ward, Wolford, Mick, Tapia, et al., 2005), Iran's South-Pars (Javanmardi, Nasrifar, Najibi, & Moshfeghian, 2006; Javanmardi, Nasrifar, Najibi, & Moshfeghian, 2007; Najibi, Rezaei, Javanmardi, Nasrifar, & Moshfeghian, 2009) and Russia's Sakhalin Island (Marongiu-Porcu, Wang, & Economides, 2008). These studies considered the markets around these specific regions, feasibility of various gas utilization options, and development of a utilization strategy.

Other studies have focused on deep offshore gas reservoirs requiring floating production units such as FPSOs (Floating Production Storage and Offloading) (Alvarado, Cone, & Wagner, 2002; Wagner, 2003; Wagner & Cone, 2002). They have investigated the feasibility of different gas processing options overboard floating platforms. In contrast to onshore, offshore field development faces the extra constraints of weight and layout. Alvarado et al. (2002) evaluated a combined oil/gas production FPSO with LNG, CNG, and GTL. They investigated the weight of each process and the feasibility of integration with oil production. This is essential for preventing undesirable gas flares. Wagner et al. (Wagner, 2003; Wagner & Cone, 2002) technically and commercially compared the developments of LNG–FPSO and CNG–FPSO for a specific gas reservoir capacity. They used a simple payback approach with a wide range of assumptions with consequential reduced accuracy. Their analysis exhibited the highest ROI for CNG.

In spite of numerous other publications addressing gas utilization or monetization alternatives (Chang, 2001; Cornot-Gandolphe, Appert, Dickel, Chabrelie, & Rojey, 2003; Patel, 2005; Wagner & Wagensveld, 2002; Wood et al., 2008; Yost & Dinapoli, 2003), there is a need for a systematic approach for quantitatively analyzing these technologies as functions of reservoir capacity, distance to market, CAPEX & OPEX, oil/gas price uncertainty, etc. Another