Quantifying the Value of Flexibility in Oil and Gas Projects: A Case Study of Centralized Vs. Decentralized LNG Production Systems

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THE PAPER PRESENTS THE RESULTS OF AN ANALYSIS FOCUSING ON the evaluation of large-scale oil and gas projects under market uncertainty and flexibility in engineering design. Keppel Offshore and Marine Technology Centre (KOMTech) has developed a proprietary Pre-cooled Nitrogen Expander (PreNex) technology as a solution for offshore associated gas applications for small-to-medium scale capacity (~0.2 to 1 MTPA). This technology is also suitable for onshore micro-LNG applications. This study is concerned with the long-term design and deployment of the technology in the Australian market to provide LNG for transportation purposes. There are currently two designs considered: 1) small decentralized micro-LNG production facilities combined with fueling stations, and 2) a big centralized production facility with satellite fueling stations along the pipeline. The first alternative enables a flexible phasing deployment strategy in the design that can improve economic performance compared to the other solution, by dealing explicitly with market uncertainty. The results demonstrate about 36% economic value improvement for the decentralized system compared to the centralized inflexible solution, increasing as uncertainty in parameter estimation increases.

INTRODUCTION

Background and Motivation

The advantage of using gas products has increased over the last three decades, resulting in a considerable demand growth for LNG. For instance, demand and supply forecasts in Australia indicate a potential shortfall of 300 to 600 TJ/day by 2015, and between zero and 600 TJ/day by 2020. Forecasts indicate there is a need to source at least 1,100 TJ/day of new production by 2020.[1]

Over the past 20 years price differentials between fuel oil, gasoil/diesel and LNG have changed significantly. In 1997 oil prices hovered around $20 per barrel (West Texas Intermediate - WTI) and around $2.50 per MMBtu for Henry Hub natural gas in the US. Today, these are around $100 per barrel for oil and $5 per MMBtu for natural gas[2]. Natural gas prices have only doubled in 20 years while WTI prices gone up 5 times in 20 years, making the price difference even more attractive.

As gas production grows, related sectors have the potential for significant economic growth over the next ten years. Since LNG can be used reliably as on-road transport fuel, there is growing market opportunities for LNG production. In Australia, gas output has exceeded LNG production until 1987. From 1990 to 2009, gas compressed and exported as LNG has been around 70% of total gas production, with 30% piped to Western Australian consumers[1].

LNG is becoming popular as long haul transportation fuel due to its energy density over compressed natural gas (CNG). This increases the driving range significantly. With one fuel tank, a road truck can go around 800~1200 km distance[2]. This makes LNG an excellent option for the heavy transportation sector. One litre of diesel is equivalent to 5 liters of CNG at 200 bar and to 1.8 liters of LNG at (-)162 degrees Celsius, as shown in Figure 1. Australia has been using LNG in heavy duty vehicles since 2001.

Lower LNG tax compared to diesel tax is attractive for investors in this market for the following reasons:

1. From July 2015 onwards, on-road LNG will be taxed at $4.93/GJ while heavy on-road (> 4.5t vehicle) diesel will be taxed more at $7.41/GJ;
2. From July 2015 onwards, off-road LNG will remain untaxed at $0/GJ while off-road diesel will be taxed at $1.55/GJ;
3. In July 2012, the Australian government introduced carbon tax at $25/t, which creates an advantageous price differential of $0.35/GJ for LNG.

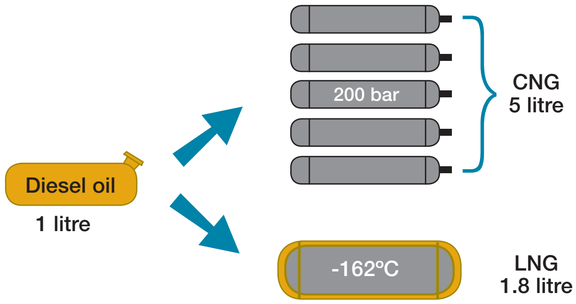

Figure 1. Energy equivalence: Diesel / CNG / LNG; Source: NGVA Europe

Keppel is evaluating the business opportunity to deploy its proprietary Pre-cooled Nitrogen Expander (PreNEx) technology for onshore micro Liquefied Natural Gas (LNG) production. This technology is suitable for the deployment in land-based areas near the gas resources, which can be targeted towards diesel replacement in transportation industry.

This study is concerned with the long-term design and deployment of Keppel's proprietary LNG production technology in the new Australian market. History has shown that market demand uncertainty is the key challenge for establishing LNG as a viable fuel for heavy transport[1, 3]. A wide range of socio-technical factors affect its growth, as summarized in Figure 2. It is unclear how fast this demand will grow over the coming years. There is a need to account for this uncertainty at an early design and evaluation stage to help clients select the design alternative offering better economic outputs.

KOM has been working with the Massachusetts Institute of Technology (MIT) and National University of Singapore (NUS) to introduce

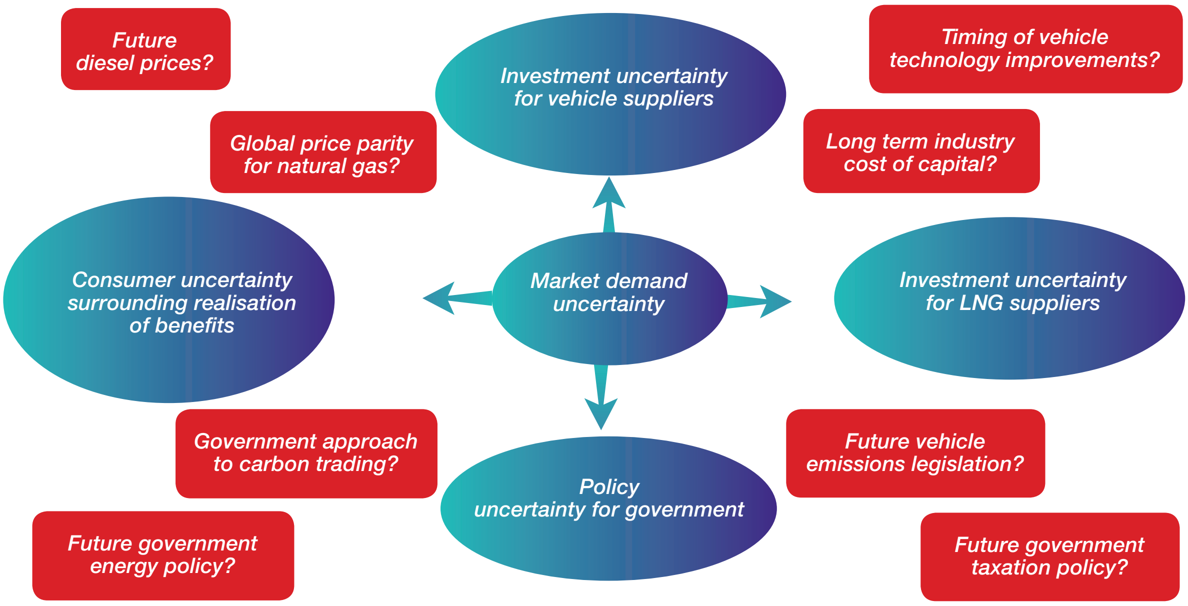

Figure 2. LNG demand as the key source of uncertainty in the heavy transport sector; Source:[3]

"Flexibility in Engineering Design" into its selection process. This approach improves the lifecycle performance of a project dependent on weightage of the project objectives under a range of potential uncertainties. To compare the design alternatives under uncertainty, a structured four-step methodology is introduced and applied based on several economic lifecycle performance indicators (e.g. Net Present Value, Initial CAPEX, etc.) in order to illustrate the "Value of Flexibility".

The proposed methodology is applied to analyze LNG production alternatives under demand uncertainty, considering carefully designed flexibility as a way to deal with this market uncertainty. The approach starts from a standard evaluation process for major investment projects, and the main uncertainty drivers affecting economic value. It recognizes value stemming from flexibility in the design as well as intelligent management decisions over time, as a way to minimize the impact from possible downside losses (e.g. like buying insurance), and preparing the system to capture possible upside opportunities (e.g. like buying a stock option). Preparing the system to cope with a range of demand growth scenarios (as opposed to point deterministic forecasts) is expected to increase the expected economic value of the system.

This analysis extends standard design and project valuation approaches that are typically centered on optimizing for the most likely or average scenarios. It shows that relying entirely on such forecasts may lead to the selection of a design that is not necessarily the best. It shows Keppel's ability to generate better value for its client.

Flexibility in Engineering Design

Flexibility in engineering design is an interdisciplinary field for research and practice[4]. It adapts the concept of financial options to real engineering systems, with the goal of increasing the expected economic value by providing the "right, but not the obligation to change a system" to respond to uncertainties most profitably[5]. Flexibility exists "on" and "in" engineering systems. Flexibility "on" systems is associated with managerial flexibility like abandoning, deferring until favorable market conditions, expanding/contracting/reducing capacity, deploying capacity over time, switching inputs/outputs, and/or mixing the above[5]. Flexibility "in" systems refers to technical engineering and design components enabling real options – another word for flexibility – in deployment and operations[6]. Table 1 summarizes the major difference between this new approach and the standard design and evaluation process.

Table 1. Standard design and flexible design process (based on de Neufville and Scholtes 2011)

Standard Design Process	Flexible Design Process
Relies on forecasting to design for specification	Considers different scenarios to design for variation
Passive way to deal with uncertainty	Active way to deal with uncertainty
Inadequate for capital intensive and long-term projects due to higher chance of failing forecasting trend	Suitable for strategic and long-term projects as it provides insurance from downside risk

According to Savage's[7] "Flaw of Averages", relying on the most likely or average scenario may lead to incorrect design selection and investment decisions. This is because the output from an upside demand scenario (e.g. high demand growth) does not necessarily balance the output from a downside scenario (e.g. low demand growth). This is captured in equation (1) below:

$$f(E[x]) \neq E[f(x)] \quad (1)$$

Here, $E[x]$ represents for instance expected LNG demand, and $f(E[x])$ the Net Present Value (NPV) associated to such demand scenario. What Equation 1 means is that a design evaluation based on the average or expected demand scenario – as captured by $f(E[x])$ – does not lead to the same value as an evaluation relying on individual system responses from different demand scenarios, and then taking the average of the responses – as captured by $E[f(x)]$. If a systems design is chosen based on the left hand side – as often done in standard design and evaluation – a better design that can adapt to each scenario and provide better average NPV may be ignored.

Therefore, a design decision based on standard analysis may lead to incorrect production capacity and project selection, given that the real expected return of a system cannot be measured via standard methods. A different approach is needed to capture the full value of oil and gas systems, and different approach to systems design recognizing both uncertainty and flexibility is needed.

Because the economic response from complex systems is highly nonlinear, long term decisions should not be made considering only the average or most likely scenario. The NPV of projects based on most likely demand scenario is not the same as the expected NPV resulted based upon different demand scenarios, as captured by equation (1). A system may appear more or less valuable than it is, as compared to other mutually exclusive design alternatives.

Flexibility enables a system to better capture the potential value associated with different scenarios. A flexible system might enable, for instance, capturing more demand in the high demand scenario, thus increasing the expected economic value (i.e. like a call option). It might reduce the financial losses in a downside demand scenario (i.e. like insurance). Because of these combined effects, it has been shown that flexibility can improve expected lifecycle performance between 10% and 30% as compared to standard design and evaluation approaches[4]. This study aims to provide guidance into applying this thinking for oil and gas projects, with the prospect of being applicable to a wider range of systems at Keppel, and delivering better value to the clients.

PROBLEM DEFINITION

Design Alternatives

The problem is to design a LNG production and fuelling system for trucks used in on-road transportation and mining operations. There are currently two design alternatives considered (see Figure 3): 1) deploying small LNG production facilities combined with fuelling stations, or 2) a big centralized production facility with satellite fuelling stations along the pipeline. Design alternative 1 – referred as decentralized strategy in Figure 3 (a) – consists of building 5 satellite plants with initial production capacity of 25 tpd with the possibility to expand up to 50 tpd at each site. Fuelling stations are located along the pipeline at strategic points to accommodate demand. This design alternative is referred as 25 tpd flexible. Design alternative 2 – referred as centralized strategy in Figure 3 (b) – consists of building a centralized LNG plant (250 tpd) with trucking fleets for distributing the fuel to satellite fuelling stations. For the design alternative 2, fuelling stations should be laid out along the trucking routes. In both cases, maximum projected capacity can reach up to 250 tpd.

There are advantages and disadvantages associated with both design strategies. In the decentralized alternative, there are benefits like more compact size, and enabling LNG production in close proximity to the demand points. The responsiveness in deploying small plants can also lead to decreased transportation and LNG costs for consumers. There is also the possibility to take advantage of the time value of money, by deferring costs to later in the future, and not investing all the money at once.

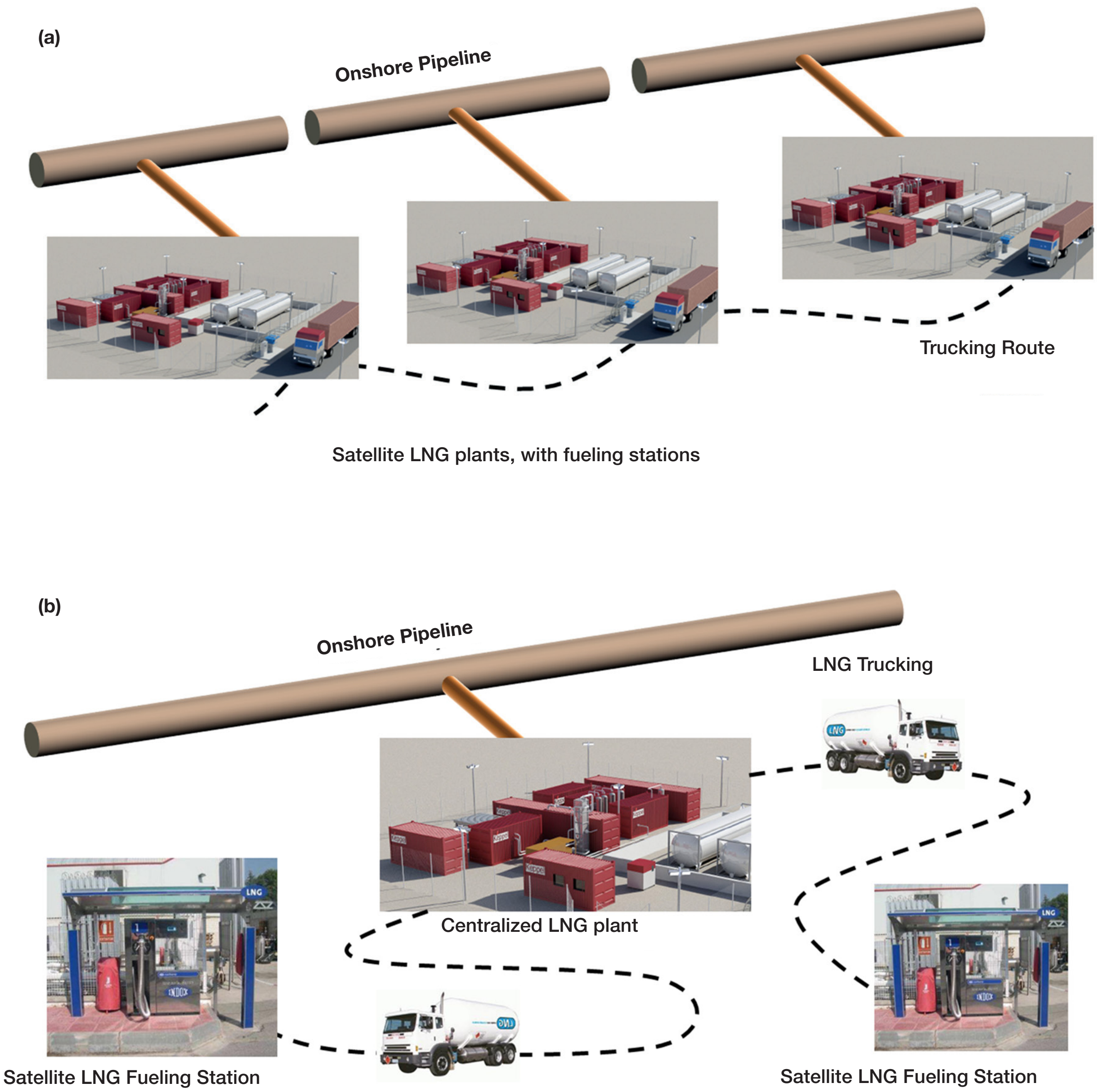

Figure 3. Decentralized (a) and centralized (b) design alternatives

Indeed, it is possible to deploy capacity on-site only when demand growth is good enough to warrant more production capacity. Such system can be deployed initially with less capacity (i.e. 25 tpd on each of the five sites), with the ability to deploy to full 50 tpd if needed. This added flexibility acts like insurance, since less capital and production capacity is needed initially. On the other hand, the system is still designed to accommodate high demand growth since on-site production capacity can be expanded up to 50 tpd. In the centralized design, the main advantage resides in the economies of scale (EoS), and the possibility to reduce average cost per unit produced. Such alternative requires that fuel be delivered to fuelling stations, and therefore requires more transportation than a decentralized system. Both systems benefit from the possibility of adjusting production capacity as part of daily operations, where the centralized plant can cover a wider range of production rates.

METHODOLOGY

The steps below describe the generic process followed to analyze the system for flexibility, under market uncertainty related to LNG demand growth. The process is summarized in Figure 4.

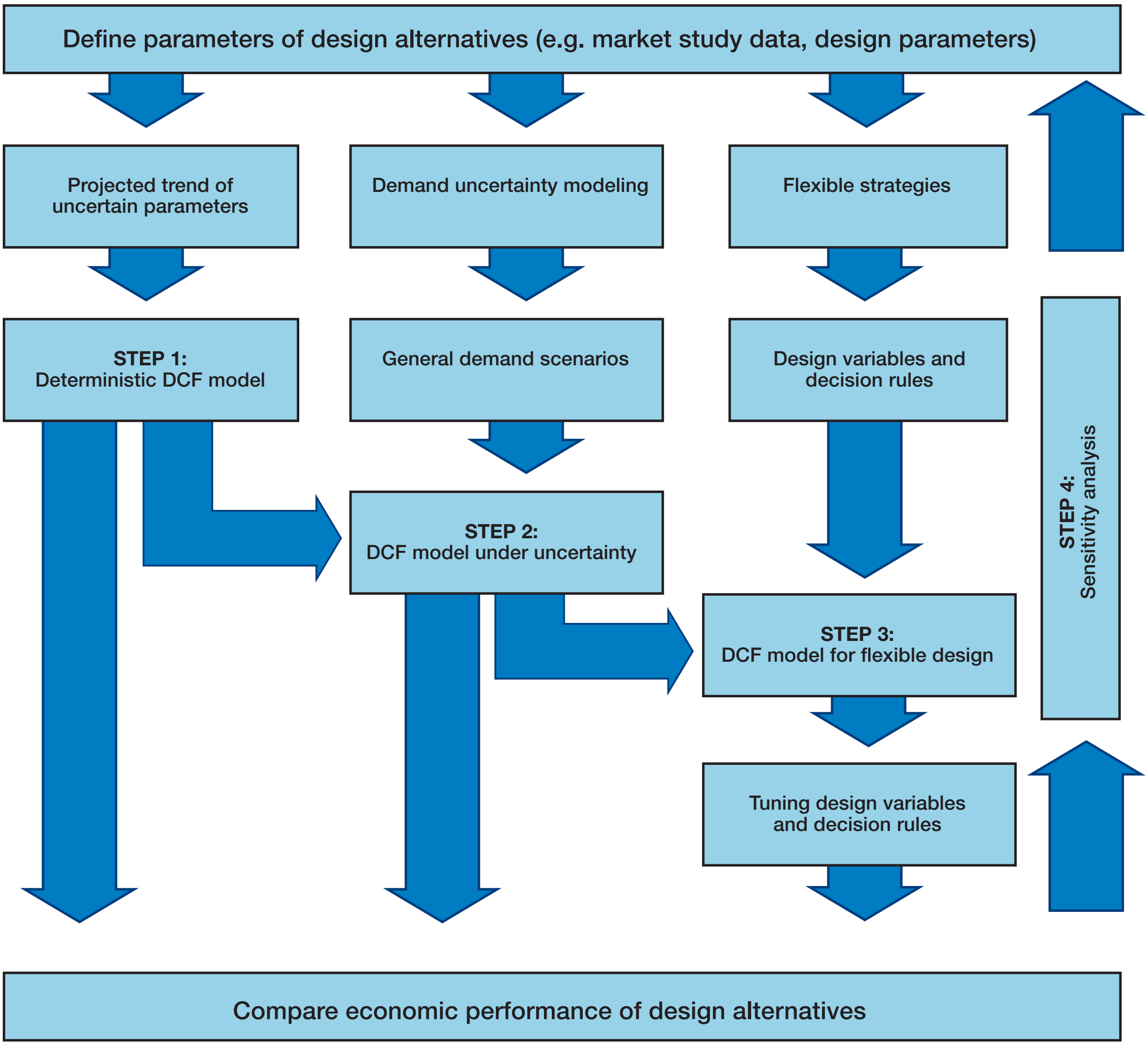

Figure 4. A methodology to evaluate and compare candidate design alternatives

Step 1: Baseline DCF Model

Step 1 is the starting point of the analysis. It generates a baseline Discounted Cash Flow (DCF) model for the above design alternatives, subject to a number of assumptions about the cost and revenue drivers. Once the main components concerned with each alternative are defined, the economic model is developed, and lifecycle economic performance of the project is measured using NPV. Using this model, candidate alternatives are evaluated and compared to identify the best design alternatives. The DCF analysis is developed assuming deterministic values of the main uncertainty factors, and fixed design variables and parameters. The design alternatives studied here are considered as "baseline", in the sense that they serve as points of comparison to determine the value of flexibility, later in Step 3.

Step 2: Uncertainty Analysis

In step 2, the economic lifecycle performances of the designs are investigated under uncertainty of the major uncertainty drivers. The lifecycle performance of the system is recognized as highly sensitive to varying sources of uncertainty. To model the behavior of uncertainty throughout the evaluation period, a stochastic function can be used such as Geometric Brownian Motion (GBM), S-curve function, Mean Reverting Process, etc. Using this stochastic model and Monte Carlo simulation, one can generate a large number of possible scenarios (e.g. LNG demand). After the risk profiles of the different design and deployment alternatives are generated, they can be compared based on mean or Expected NPV (ENPV), VAR (Value At Risk (e.g. P5 or 5th percentile value, which quantifies the downside potentials), VAG (Value at Gain) (e.g. P95 or 95th percentile, quantifying the upside potentials), initial CAPEX (capital expenditures), and/or variability (i.e. standard deviation).

Step 3: Flexibility Analysis

Step 3 introduces the notion of flexibility in the design, deployment, and evaluation of the different alternatives. In this step, investigation is carried out to determine which source of flexibility is best suited to cope with the major uncertainty drivers. The most appropriate strategy is identified to exercise the flexibilities embedded in a system. The flexible strategy is characterized by design variables and decision rules. To incorporate design variables in the system, a feasible design space need to be defined. To embed the decision rules into the evaluation model, logical statements such as "IF…, then…" are used. To provide further improvement for the flexible design, the design variables and decision rules need to be tuned through optimization techniques. To find the best design alternative(s), available alternatives are evaluated based on multi-attribute decision-making.

Step 4: Sensitivity Analysis

In order to observe how sensitive the response of the system is to parameter and input data assumptions, sensitivity analysis is performed. In this study, the effects of uncertainty and discount rate on the simulation results, expected NPV are investigated.

APPLICATION AND DISCUSSION

Step 1: Baseline DCF Model

A DCF model was developed in Excel® based on the following assumptions:

1. Electricity cost has been considered as a separated cost item rather than to be as a part of OPEX. The electricity cost is calculated as a function of production volume rather than the number of production units/fuelling stations.

2. OPEX is calculated as a function of production/service unit (e.g. number of micro LNG plants or fuelling stations).

3. Transportation cost is calculated as a function of distance and production volume – using frequency of fuel truckloads needed to meet the demand point with current fuelling truck fleet.

4. Revenue generating schema has been taken into account using gas purchase cost, LNG selling price and escalation factor, which determines how the purchasing cost and the selling price grows over time.

5. For the centralized design 2, capacity of each fuelling station is capped to 75 tpd, provided that the total aggregate capacity does not exceed the big plant capacity (i.e. 250 tpd).

6. For the centralized design 2, a capacity reallocation feature has been devised and

incorporated into the DCF model. This feature provides a freedom to distribute flexible portion of the big plant's capacity to the fuelling stations rather than rigidly dedicate a particular portion of its capacity to each fuelling station.

7. The number of fuelling trucks is updated as uncertainty in demand varies and consequently production volume changes. For simplicity, this number is set based upon the worst case – when the realized demand is strong, as in average scenarios.

8. Demand is projected as an S-curve. Volatility of all parameters in the S-curve function is set to zero but non-zero for the sharpness factor (i.e. capturing demand growth). The purpose is to observe performance of flexible design under different volatilities of sharpness factor.

9. The performance of the flexible decentralized design 1 is sensitive to the sharpness factor (i.e. no point in getting flexibility if 100% sure of high demand growth).

10. The sensitivity analysis is conducted based on different LNG demand volatilities and discount rates, also referred as Minimum Attractive Rate of Return (MARR). It is assumed that CAPEX and OPEX of additional capacity are fixed.

In order to compare the economic performance of the different design alternatives, risk profiles are generated based on NPV. NPV is calculated based on the sum of discounted cash flows throughout the lifetime of the project. The general form is shown in equation (2), where TR_t and TC_t show the total revenue generated and total cost occurred in year t. T shows the lifetime of the design alternative, set to 20 years, and r is the discount rate or MARR, which is considered $0 \leq r \leq 1$. Under these assumptions, the NPV for the decentralized system is \$20.06 million, and \$41.66 million for the centralized system. This standard analysis would lead to the selection of a centralized system based on NPV maximization, mainly stemming from strong economies of scale, and cost reduction.

$$NPV = \sum_{t=1}^{T} \frac{TR_t - TC_t}{(1 + r)t} \qquad (2)$$

Step 2: Uncertainty Analysis

The effects of the most important uncertainty parameters on the system's performance are analyzed. This study assumes a stochastic S-curve function to model LNG demand over the study period (i.e. 20 years). The rationale is that LNG demand initially grows slowly for some time, because the market and LNG infrastructures are evolving. Then over time demand increases exponentially, and finally growth tapers off as demand approaches a saturation limit.

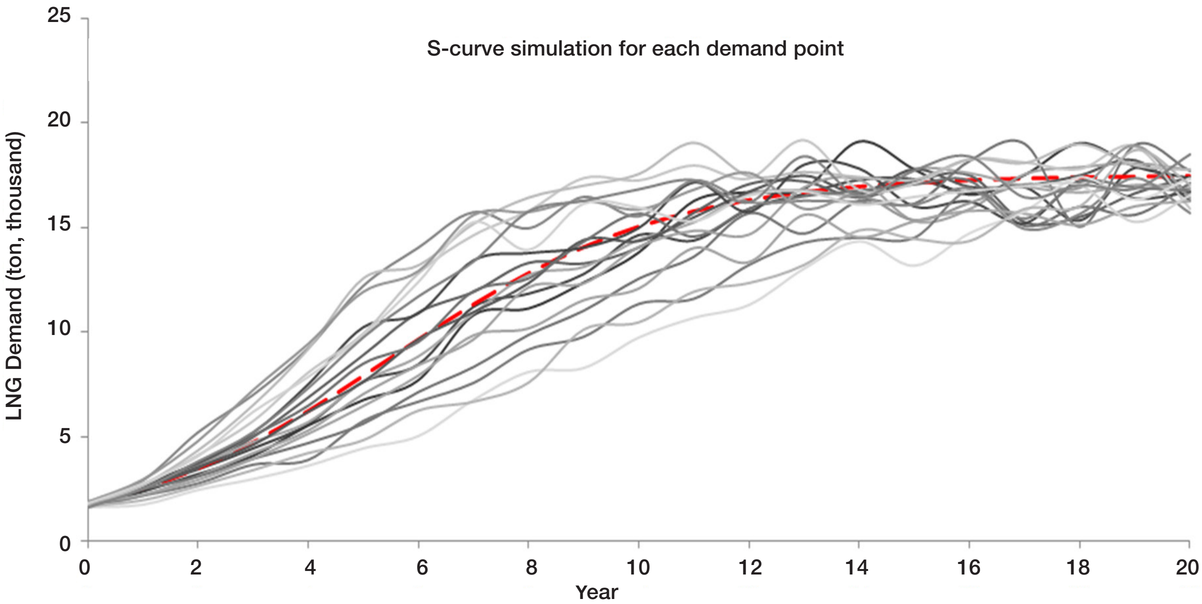

Figure 5. simulation of LNG demand during the lifecycle of the project for one demand point

Equation (3) represents the LNG demand of location l in year t as an S-curve function. Variable M_l shows the maximum expected demand for LNG at demand point l; b is the sharpness parameter that determines how fast demand grows through the temporal range to reach the upper bound for demand at any demand point l, M_l; a is a translation parameter that interacts with b, but translates the curve horizontally. Since economic performance of the designs is highly influenced by the sharpness parameter b, uncertainty is considered and modeled using an additional uncertainty factor σ_b. This stochastic model generates different LNG demand scenarios, as shown in Figure 5.

$$LNGD_{lt} = \frac{M_l}{1 + ae^{-b(1 \pm \sigma_b)t}} \quad (3)$$

Monte Carlo simulation is used to observe how the design alternatives behave under uncertainty in terms of different economic metrics. Figure 6 demonstrates the risk profile for the inflexible centralized design alternative 2 (250 tpd) under demand uncertainty. This profile is represented in red as a Cumulative Density Function (CDF), showing the cumulative probability of having NPV outcomes less than a certain value. The mean or average NPV (referred here as expected NPV or ENPV) is shown as a red dashed vertical line, with value ENPV = \$13.60 million. The NPV under the deterministic conditions described in step 1 is shown at value NPV = \$41.66 million (the red dashed vertical line further to the right). The latter shows the flaw of averages described above, leading to a reduction of the ENPV under uncertain demand in comparison to the NPV under deterministic conditions. This occurs because the response of the designs under different demand scenarios is nonlinear, since LNG production capacity for the centralized alternative is capped at 250 tpd. The benefits generated by upside scenarios (e.g. high LNG demand growth) do not counterbalance the potential losses (or smaller profits) generated by downside scenarios (e.g. low LNG demand). Uncertainty modeling provides a more accurate view of the true performance of the centralized design alternative, and therefore serves as baseline for comparing with the flexible decentralized design alternative, considered next.

Step 3: Flexibility Analysis

To deal with uncertain demand growth, capacity expansion flexibility was identified as the most relevant strategy, which can be exploited with the decentralized alternative. To embed the expansion policy, a simple decision rule was incorporated in the Excel® DCF model: IF "the observed demand

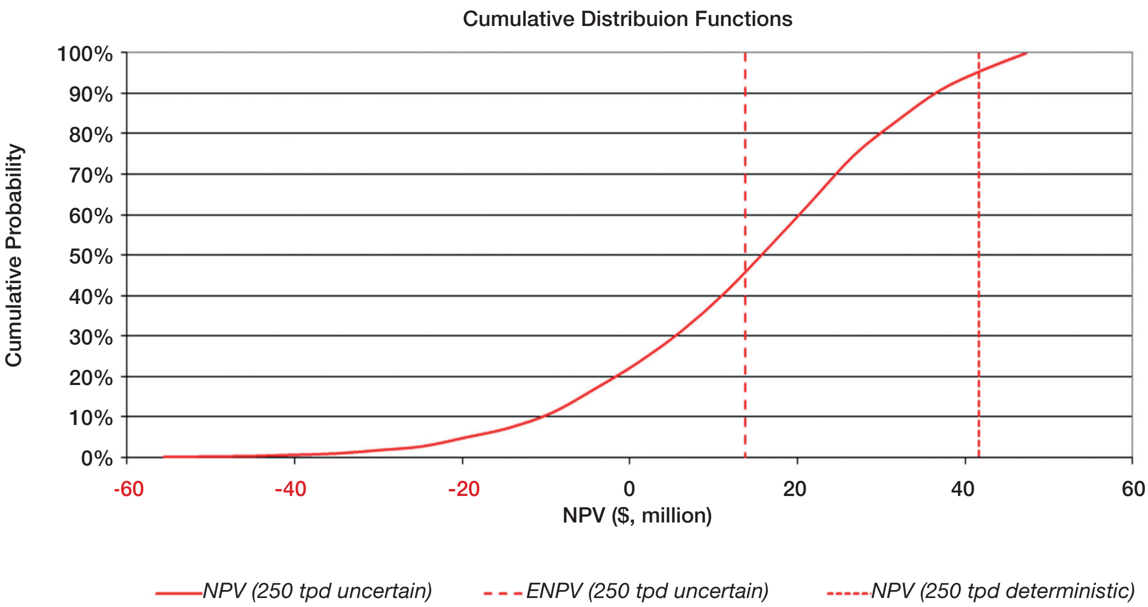

Figure 6. Simulation results for the centralized design alternative 2 (250 tpd uncertain) based on 2,000 simulated LNG demand scenarios

in the last year is higher than a certain threshold value at the given site" then "capacity is expanded to its maximum planned level until the end of the lifecycle" else "do nothing". Figure 7 shows the simulation results corresponding to both design alternatives, with the decision rule affecting only the flexible decentralized system (25 tpd flex). The ENPV of the decentralized design 1 (green) is ENPV = $18.45 million, as compared to the centralized system (250 tpd) at ENPV = $13.60 million. For the decentralized system, Figure 7 shows the profile for the following decision rule: "*if observed demand in the last year at a site was higher than 85% of maximum planned capacity (i.e. of 50 tpd)" then "add 25 tpd in extra LNG production capacity at the site" else "do nothing*". Note that the decision rule is applied independently at each of the five sites, depending on the demand scenario realized.

The flexible design alternative provides better-expected performance than the inflexible centralized design 2. It reduces downside losses by limiting the initial capital investment. This is seen by the fact that the left side tail of the green curve does not go as far left as the inflexible centralized design 2 into negative NPV outcomes. The flexibility acts like insurance: a small amount invested upfront to enable the flexibility may save from significant loss generating events. It also captures some upside opportunities by enabling the initial design to be expanded when demand grows fast, as seen on the right end tail. This is similar to what happens when one buys a call option on a stock: the investor gets access to upside payoffs, while limiting the initial cash outflow. The flexible decentralized design captures just about as much upsides as design alternative 2 (250 tpd), because when demand grows fast, additional capacity can be rapidly deployed.

Designing extra contingencies for flexibility may require additional upfront costs. Therefore, designers must be prepared to justify the extra cost objectively and quantitatively, as there are cases where flexibility may cost too much, and is not worth the extra investment. In reverse, there are also cases where flexibility comes for free, or lowers the initial capital expenditures, which should also be recognized explicitly[4].

To see whether flexibility in the decentralized design is cost effective or not, a measure for value of flexibility is used, as shown in equation (4). The value of flexibility suggests the discounted money

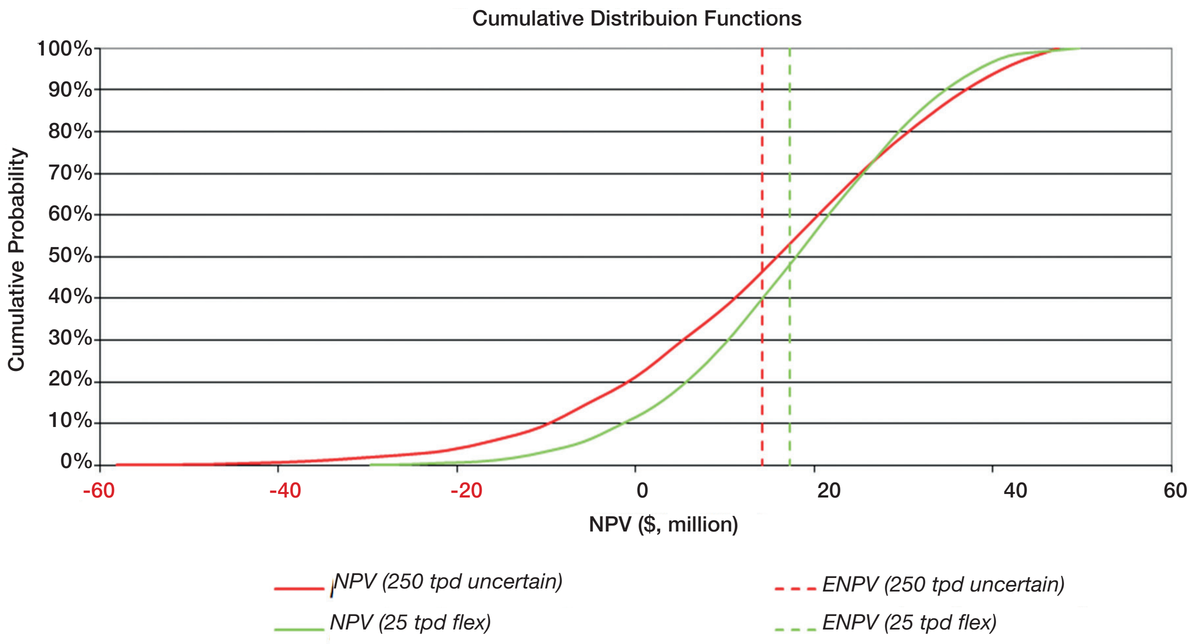

Figure 7. Cumulative distribution of NPV based on 2,000 LNG demand scenarios

saved compared to the baseline design alternative, which is the difference between the expected NPVs of the flexible design and the baseline inflexible centralized design.

$$Value\ of\ Flexibility = ENPV_{flexible\ decentralized\ design} - ENPV_{inflexible\ centralized\ design} \quad (4)$$

Here the baseline design for comparison is the inflexible centralized design (alternative 2). The expected value of flexibility is quantified in comparison to this baseline. For instance, the results in Figure 7 show that the value of flexibility is about \$18.45 million – \$13.60 million = \$4.85 million. This expected value can be compared with the cost incurred to enable the flexibility (e.g. buying extra piece of land, preparing existing infrastructures at production site for possible expansion, etc.). This provides a way to make a better-informed decision in flexibility, and determine whether it is truly worth it.

Tuning the Capacity Expansion Decision Rule

To see the effect of uncertainty on the economic performance of the flexible design, a number of computer simulations were conducted. After running simulations under different degrees of demand volatility, the sharpness parameter b (see equation (3)) was recognized as the most crucial parameter. Figure 8 demonstrates 30 simulation replications (2,000 scenarios for each replication) with $\sigma_b = 70\%$ within a given range of capacity expansion threshold values for the decentralized system (i.e. 50% to 95% with 1% step size). This means that capacity expansion flexibility is evaluated when demand was observed to be higher than a certain threshold fraction of maximum planned capacity (i.e. 50 tpd in each site), by threshold amounts ranging between 50% and 95% of maximum planned capacity. The results suggest that the default threshold value used in the capacity expansion decision rule in Figure 7 can be tuned further to yield better flexibility value. While the default threshold value was set to 85%, 72% was found as the optimum threshold value based on exhaustive search – although it is subject to stochastic fluctuations.

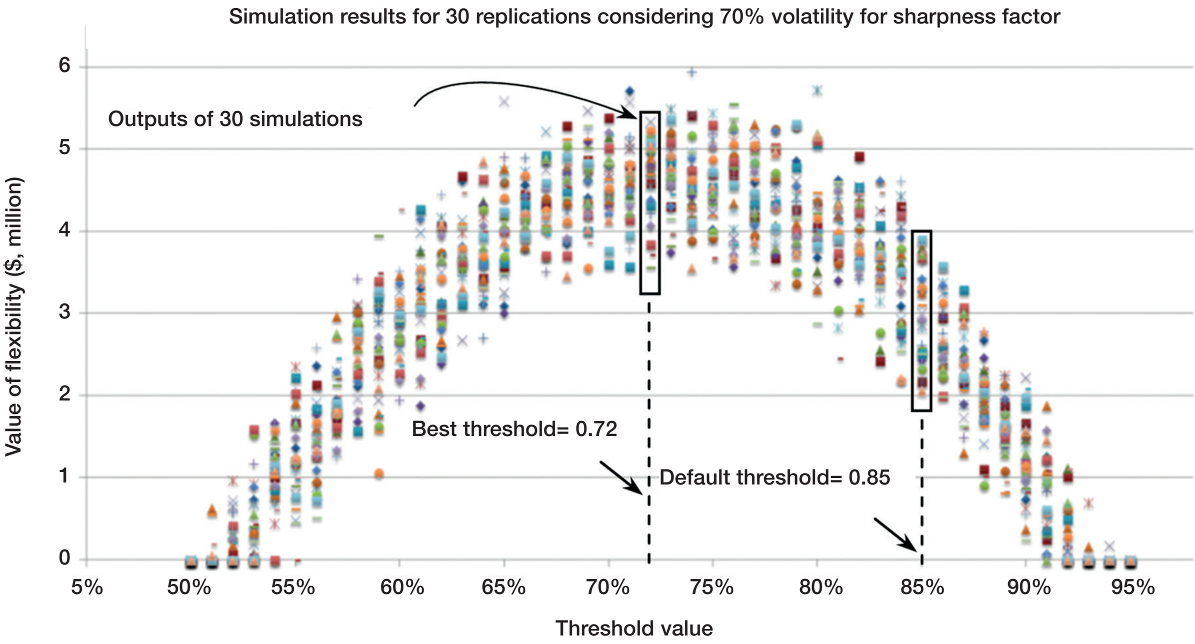

Figure 8. Simulation results for 30-times replication considering 70% volatility in sharpness factor of LNG demand, and 2,000 scenarios for each simulation replicate.

Table 2. Summary table of multi-attribute decision-making[3]

Metric	Centralized Design (Inflexible)	Decentralized Design (Flexible)	Best Design?	Flexibility Value	Value Improvement [1]
Initial capacity (tpd[2])	250	125	N/A	N/A	N/A
Mean NPV	$13.60	**$18.45**	Decentralized	$4.85	35.66%
P5	-$20.00	**-$5.81**	Decentralized	$14.19	70.95%
P95	**$41.00**	$40.73	Centralized	$0.00	0.00%
Standard deviation	$18.56	**$14.29**	Decentralized	$4.27	23.00%
Initial CAPEX	$154.36	**$125.00**	Decentralized	$29.36	19.02%

[1] Decentralized flexible design compared to the inflexible centralized design in terms of given criteria
[2] Ton per day
[3] All $ values in million

Multi Attribute Decision-Making

The best design alternative can be chosen based on many criteria. Some common economic metrics in project evaluation under uncertainty are shown in Table 2. All values for the decentralized system correspond to the best decision rule (i.e. threshold value 72% of maximum planned capacity). The aim is to choose a design based on the highest value for ENPV (or mean NPV), P5 and P95, and smaller values for standard deviation of NPV distribution and initial CAPEX. Simulation results illustrated in the table indicate that the flexible decentralized system would be the best design among all decision criteria, except for P95, a measure of upside potential, although the difference is small. The reason is that if high demand growth scenarios occur, the centralized plant is better positioned since it has more initial capacity than the flexible system. The flexible decentralized system provides better economic performance on average (i.e. mean NPV), better protection against downsides (i.e. P5) as would insurance do, less variability (i.e. standard deviation), and requires less upfront investment.

Step 4: Sensitivity Analysis

Influence of uncertainty

To illustrate the overall system performance, an average value of flexibility with its confidence intervals was generated using t-student distribution. Figure 9 depicts average, lower bound and upper bound with 95% confidence interval for the value of flexibility at each decision threshold value. The results are shown within a given range of threshold values, for sharpness factor volatility σ_b = 70% and σ_b = 80% respectively, using the same number of simulation replication (i.e. 30 times 2,000 scenarios). The results indicate that the more volatile LNG demand is, the higher the value of flexibility. This confirms the fact that flexibility is more valuable the more uncertainty there is. In contrast, if the future is known with full certainty, there is no need for flexibility!

Influence of the discount rate

The value of flexibility for the decentralized system changes for different values of the discount rate, *r*. To see this sensitivity, additional simulations were conducted for values ranging from *r* = 8% to 20%, with a 1% step. For each value of the discount rate, the value of flexibility is derived, as shown in Figure 10, and as calculated in equation (4). One sees that the value of flexibility increases with the discount rate. This is because at higher *r*, a flexible system benefits from deferring capacity deployment, leading to decreasing capital and operating costs in present value terms. At higher discount rates, there are more incentives to defer additional capacity deployment, which is translated here by the higher value of flexibility.

GUI INTERFACE

To facilitate the evaluation process, a Graphical User Interface (GUI) was developed. Figure 11 depicts the interaction between users and relevant

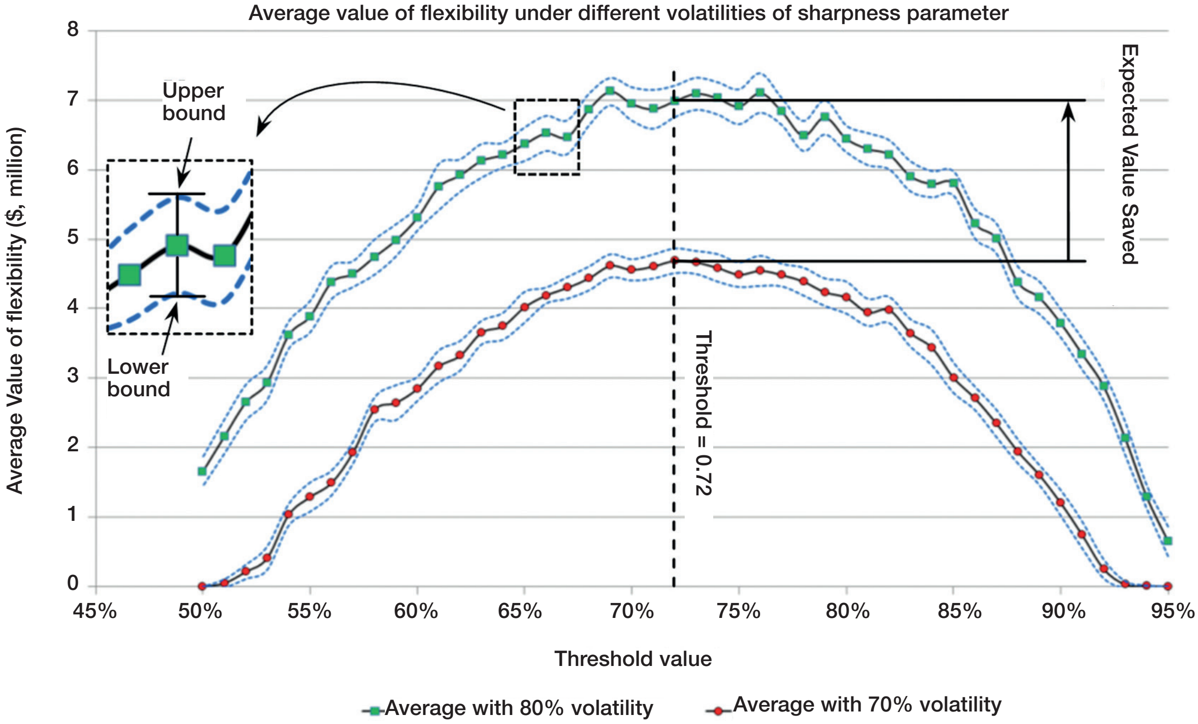

Figure 9. Value of flexibility in terms for σ_b = 70% and σ_b = 80% uncertainty factors

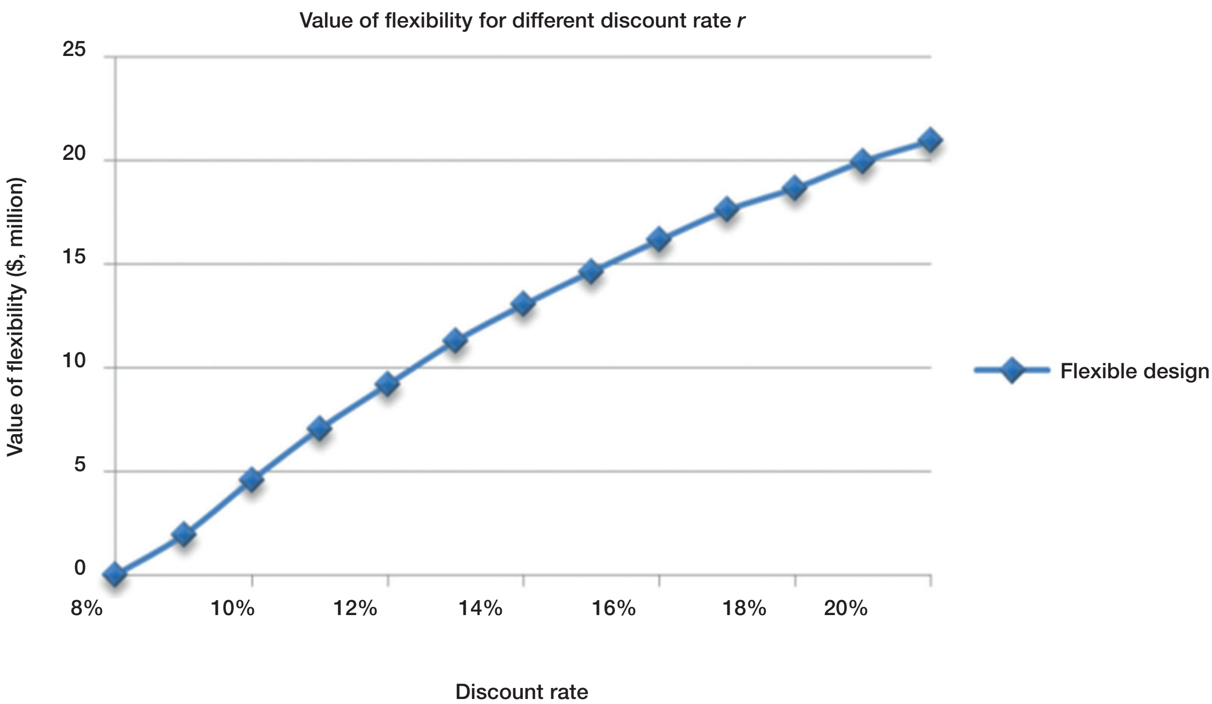

Figure 10. Value of flexibility for different discount rates *r*

user forms. The GUI is shown in Figure 12. Using this interface, the data needed for evaluation is collected, yielding representative results to designers and decision makers. With this feature, decision makers can evaluate flexible strategies as well as baseline designs efficiently. A standard set of inputs describes the salient features of the design problem analyzed. The main outputs are the DCF models, risk profiles as CDFs, and multi-criteria table. Those can be consulted directly without going through the whole process of generating the spreadsheets, figures, and tables from scratch for every new system analyzed.

This GUI provides freedom to perform sensitivity analysis more easily than dealing with several spreadsheets. Users do not have to deal with unnecessary detailed information, data and procedures, by efficient programming in Visual Basic Application (VBA). Moreover, this platform enables the designers to provide a standard toolkit to evaluate problems for a similar class of systems. For instance, the current centralized versus decentralized problem can be used for wide range of problems at Keppel (e.g. real estate, waste-to-energy systems, water treatment, etc.) The only difference between the different analyses will be the input parameters, which are also standardized across the project evaluation phase. The interface can also be customized for different activity sectors, depending on the kinds of inputs required. For example, some parameters may be relevant to oil and gas project evaluations, but also for real estate, or other infrastructure systems.

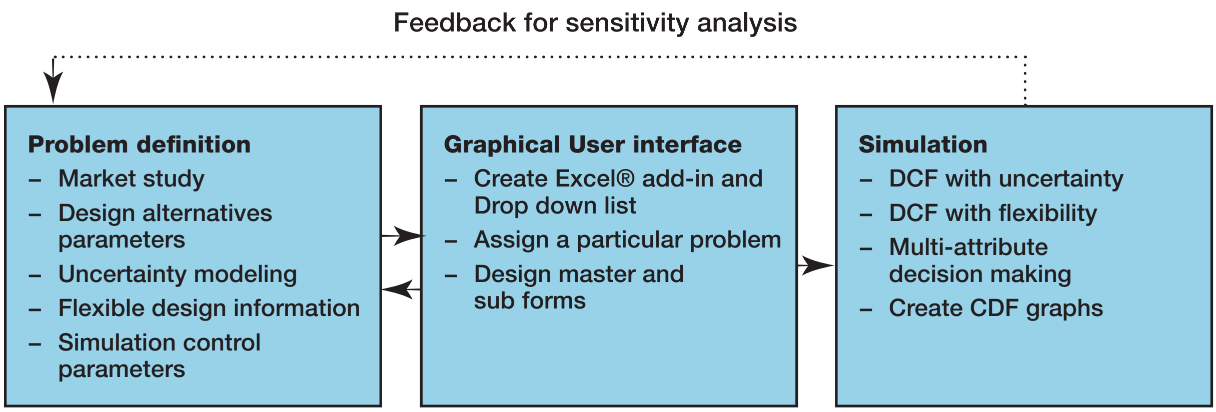

Figure 11. A Graphical User Interface (GUI) to facilitate the evaluation process

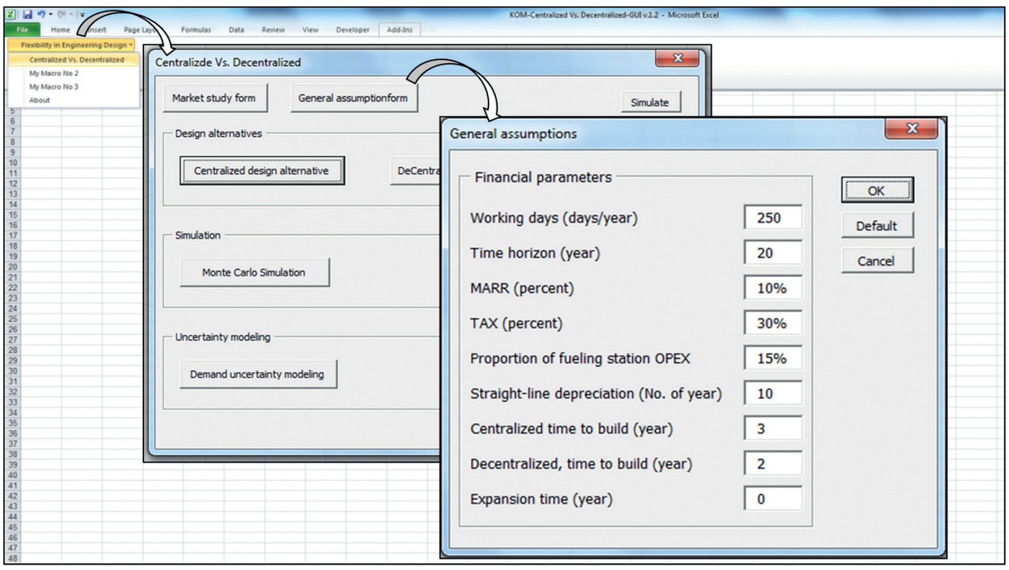

Figure 12. A screenshot of the GUI developed in Excel®

CONCLUSIONS

This study shows how to extend standard design and valuation of oil and gas projects by considering a case study in centralized vs. decentralized LNG production system. It shows how to capture and deliver better value to clients by 1) considering explicitly a range of LNG demand scenarios, and 2) enabling flexibility in the design to better adapt towards demand uncertainty. An example application of a structured, four-step methodology shows how to extract this additional value. In step 1, the analysis shows that relying on a standard approach may lead to the selection a centralized production facility, due mainly to strong economies of scale. As uncertainty is recognized and modeled in step 2, and flexibility is considered in step 3, the analysis shows that a decentralized system relying on Keppel's proprietary PreNex technology provides better economic value to potential clients. The flexible decentralized solution enhances economic performance on average by about 36% compared to the centralized system. A sensitivity analysis in step 4 shows that value improvement increases the more uncertainty there is in LNG demand growth estimates, and with a higher opportunity cost of capital.

The economic improvement of a decentralized solution stems from better responsiveness in close proximity to localized LNG demand points. The ability to deploy small plants leads to decreased transportation and LNG costs for consumers. It also allows investors to defer initial capital outlays to later in the future, and take advantage of the time value of money. Additional production capacity can be added only when it is needed, as demand becomes strong enough to warrant extra production. The flexibility acts like insurance, since less capital is needed initially, which reduces exposure to possible losses if demand ramps up slowly. The system also gives the opportunity to capture high demand, since it is designed for quick additional capacity deployment at each demand site.

A GUI was developed to simplify such evaluation process, and provide better support for design decision-making and dissemination across Keppel's activities. The interface provides a user-friendly platform for designers and decision-makers, and makes this evaluation process applicable to a wider range of problems sharing similar properties (i.e. centralized vs. decentralized facilities). Further application of the methodology to other systems can be considered at Keppel, and the interface developed in this study can be modified and extended to suit a wider range of design problems.

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