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Cost-Benefit Analysis for Petrochemical Projects

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Key Points

Cost-benefit analysis (CBA) has been used to assess investment projects for decades with the aim of quantifying their externalities and potential impacts on social welfare. However, the domain where CBA is applied has been primarily limited to direct public financing in several sectors where such impacts are perceived to be the most pronounced. This study explores the applicability of CBA principles to petrochemical investment and utilizes the proposed framework to assess a sample ethylene production project. Based on our analysis, we find the following:

> The general principles of CBA are applicable to the evaluation of investments beyond the "traditional" sectors and industries, especially if the relevant markets are heavily regulated and if a government acts as an investor or a major stakeholder of a project.

> CBA adjustments significantly affect the outcome of a sample ethylene project based in Saudi Arabia, reducing its net present value (NPV) by $7.1 billion.

> Applying CBA can help identify critical risk factors that may not be visible at the financial planning stage and quantify potential impacts. The critical variables for the sample project are the ethylene price and natural gas and electricity tariffs.

> In the case of a joint international project, the perspectives of investors on certain CBA costs and externalities may not concur.

> CBA practices and outcomes can also vary significantly depending on the industry and project location. The CBA standards for specific sectors can contribute to methodological transparency and help address potential conflicts of interest.

1. Introduction: CBA and the Case for Its Application in the Petrochemical Industry

The key idea behind cost-benefit analysis (CBA) is that for some projects, the financial appraisal alone can fail to capture their gains for (or costs to) society at large. In such cases, supplementing financial indicators with those based on CBA aims to quantify a project's impact on social welfare in comparable units of currency. The concept of CBA emerged as a way to address the perceived "market failure" and "collective action problem" in the assessment of investment projects. Potential discrepancies between financial analysis and CBA can occur due to market interventions (e.g., fixed prices for a project's inputs or outputs or state-owned nonmonetized infrastructure) or because of a project's externalities, such as environmental effects or shifts in the land value in the surrounding area.

CBA was first applied in practice in the beginning of the 20th century in the appraisal of public projects by the U.S. Army Corps of Engineers (CCASA 2021). However, its conceptual framework did not crystalize until several decades later – around the 1960s and 1970s. At that time, methodological developments were driven by the proliferation of public investment, including international development/aid projects. Currently, many countries, international organizations and development agencies have adopted CBA as one of the requirements for project financing. However, the key objectives and relevant legal frameworks (i.e., the legal requirements of CBA depending on the project size, sector, or regulatory agency) vary across nations (OECD 2015).

The differences in CBA methodologies can also be observed across mandating institutions – ranging from general guidelines (OBPR 2020) to the listing of best practices for specific CBA items (ADB 2009) and the provision of detailed step-by-step instructions (EC 2014). Finally, sectoral specifics in terms of the output and externalities define the structure of costs and benefits included in CBA for a particular project, as well as their assessment methods.

CBA: Limitations and alternatives

Quantifying the externalities of projects and accounting for market distortions are a challenging task that can create many controversies. Assigning a specific monetary value to nonfinancial effects can lead to both a false sense of accuracy and the exclusion of intangible impacts. High discount rates may give lower value to benefits that accrue over an extended period. More general concerns relate to the applicability of the "market failure" and "collective action problem" arguments and to the fact that in CBA, the welfare effects are not distinguished by their beneficiaries. The proposed alternative approaches to project assessment from the policymaker perspective include cost–effectiveness analysis, cost–utility analysis, multicriteria decision analysis, economic impact analysis and the social return on investment, among others.

While some of these methods can arguably provide better visibility for certain outcomes of specific projects, at present, CBA remains the most established method applied for these purposes. In addition, CBA appears to be a compulsory requirement for project approval/financing in many countries and international institutions. Thus, for the purpose of this study, we limit the scope to the CBA methodology.

The major sectors in which CBA is usually performed include transportation, utilities, the environment, waste management, energy, education, healthcare, information and communication technology (ICT) and research and development (R&D). In this study, we advocate for the applicability of CBA for the investment decision process in the petrochemical industry, as illustrated by hypothetical projects in Saudi Arabia, China and Malaysia. While CBA principles have been applied within the industry to assess petrochemical investments, such estimates and methodologies largely remain inaccessible to the public due to the proprietary nature of such investment and financing decisions.

Petrochemical companies, similar to their peers in other sectors, often operate within regulated market structures. For example, as part of the policy suite to achieve their macroeconomic and social development goals, both China and Saudi Arabia implement price controls or oversight for input fuels, feedstock and electricity – via government-set prices, price caps or other nonmarket control mechanisms. At the macroeconomic level, sectoral interventions can be further exacerbated by foreign trade barriers, fixed exchange rates and interest rates set by the government.

Moreover, many petrochemical companies/projects in our exemplary jurisdictions can be deemed government owned (i.e., when a government controls over 50% of shares), either directly or via a parent company/holding structure, e.g., Sinopec or PetroChina in China and the Saudi Basic Industries Corporation (SABIC) or Saudi Aramco in Saudi Arabia. This ownership structure makes a corresponding government a major stakeholder in a company’s operations, including its investment decisions.

Given the significant role of the petrochemical industry in countries’ economies and development objectives, one can argue that for a government – defined above as a major stakeholder – the desired outcomes of investment projects in this sector may not be limited to their financial performance. New projects in this domain may bring additional macroeconomic benefits to a country in terms of employment, economic diversification, an improved trade balance, etc., as well as help achieve other goals outlined in strategic development plans. On the other hand, the potential environmental impact – among other relevant “nonmarket” effects – can impede the achievement of the sectoral or country-wide sustainability targets set by authorities.

Such externalities also manifest themselves at the local level, creating groups of “winners” (e.g., from employment opportunities and infrastructure development) and “losers” (e.g., from environmental concerns or a potential decrease in the value of surrounding land). Given the significant scale of a petrochemical investment project, which, as a rule, significantly exceeds the financial threshold requirements for CBA where it is mandatory, such externalities need to be assessed and accounted for.

Regulated markets, a substantial government role in the sector and a broad range of external effects of petrochemical investment projects call for a framework that should:

- account for and quantify – where possible – such impacts and distortions,
- provide an option to amend the financial key performance indicators (KPIs) of the project based on such calculations, and
- extend the project risk assessment framework accordingly.

In this paper, we propose such a methodology based on the general CBA framework and practices established for other sectors and illustrate the proposed theoretical framework with a petrochemical investment project case study.

This paper is structured as follows: Section 2 introduces the general approach to CBA for petrochemical industry projects and outlines specific items that need to be accounted for in such analysis. Section 3 presents a sample project evaluated using the proposed CBA framework, which includes financial, economic and risk estimations. The Conclusions section reflects on the applicability and limitations of CBA for future petrochemical projects.

2. Specifics of CBA Accounting for Petrochemicals

Established principles, which have been applied in CBA for other sectors, can be used to assess petrochemical investment projects. While varied at the level of specific revenue or cost items, the general structure of a proforma financial plan remains similar across industries. Thus, correcting the financial statement for CBA is performed based on its general guidelines. However, the specifics of the cost structure of petrochemical projects call for a particular focus on its major inputs – feedstock and electricity – as these markets are affected by government interventions in many economies.

Some petrochemical project externalities, which need to be addressed during CBA, are also common across other sectors. These can generally be attributed to the "consumer surplus", "producer surplus" or "innovation" categories. Sector-specific externalities primarily fall into the categories of energy security (which can vary depending on the economy's energy balance), pollution and climate costs.

Finally, the project location can also affect the specific items of CBA. Depending on the origins and perspectives of investors and stakeholders, certain costs (e.g., tariffs) or economy-wide externalities may be assessed differently.

In this section, we highlight the major CBA items for a sample petrochemical project located in Saudi Arabia from the perspective of this country. The proposed CBA clauses are grouped into two major areas – dealing with adjustments to a financial plan and project externalities.

Amending a proforma financial plan

If the project outputs target the global market or a particular foreign market (as is the case in this study), **revenues** can be considered market priced and do not need to be amended[1]. However, if products are to be sold on the domestic market subject to regulated prices, such products will need to be repriced. As an adjustment proxy, one can use the prices of similar products – on the cost, insurance, and freight (CIF) basis – imported into Saudi Arabia. In addition, any relevant government subsidies will need to be removed from the calculations.

The structure of the capital expenditure (**CAPEX**) for a petrochemical project is similar to that of other sectors where CBA has already been applied. The **project design**, **construction**, **replacement,** and **decommissioning costs** in this case can be deemed market based and do not require any amendments. If the **acquisition of the land plot** for the project is subsidized, the market rate, which can be estimated by looking at the $/m costs of similar land plots in the region, should be applied for CBA. The **cost of equipment** that would have to be imported into Saudi Arabia should be recorded net of import tariffs[2]. **Construction materials**, such as steel or cement, produced in Saudi Arabia are affected by subsidies. For the purpose of CBA, subsidized prices will have to be substituted with market-based equivalents: either the CIF import prices for similar products or domestic "shadow" prices if such estimations are available.

In the case of Saudi Arabia, most of the operation expenditure (**OPEX**) must be adjusted for CBA. The only exception is the **general overhead**, which can be assumed to be market based. **The cost of inputs** – for the purpose of this study, defined as natural gas – for the financial plan is calculated using government tariffs. Since Saudi Arabia has not yet recorded any substantial amount of natural gas imports, the preferred adjustment method is estimating the domestic shadow price. Moreover, this method captures domestic sectoral policies and specific constraints a country may have (Karanfil and Pierru 2021) A similar approach can be applied to **electricity costs,** where regulated tariffs need to be substituted with shadow prices. If calculated on the marginal cost basis, they should include transmission and distribution costs.

Labor costs, broken down into skilled and unskilled labor, generally need to be adjusted for the country’s unemployment rate using the “costs*(1-rate)” formula. Due to the significant presence of foreign labor, the total unemployment rate – 6% (Trading Economics 2022) – differs from that of citizens – currently at 11.3% (Saudi Press Agency 2022) – which has to be taken into account. Moreover, if the proposed project mostly relies on an expat workforce – especially for skilled labor – these costs can be considered market based and do not require adjustments for CBA. Localization labor requirements enforced by the government tend to increase the cost of the workforce. However, these differentials are generally captured by the location coefficients (see the Initial Assessment sections below).

If an owner/operator of a proposed petrochemical project has taken advantage of subsidized government financing, the relevant **interest costs** have to be recalculated based on the market rates. The rates for long-term Saudi bonds – e.g., the recent 3.36% yield on 30-year bonds (Reuters 2021) – can be used as a proxy.

Finally, CBA requires the proforma financial plan to be net of all **domestic taxes,** including value-added tax (VAT), Zakat and income tax (for foreign participants).

The **discount rate** applied to calculate the economic net present value (ENPV) of a project differs from that used in financial forecasting and is usually established by governments or funding authorities. If the country's economy is heavily reliant on its petroleum industry, it may consider amending a project's ENPV based on the risk premium associated with such dependence (Pierru and Matar 2014).

Accounting for externalities

For many economies, the expansion of the domestic output of petrochemicals increases **consumer surplus** by substituting more expensive imports (calculated as the CIF border price + relevant transportation costs). However, in this particular case, Saudi Arabia does not import any significant quantities of ethylene, thus making this potential benefit irrelevant.

The **producer surplus** category of positive externalities associated with petrochemical investment comprises the potential benefits at the micro (company) level. The **economies of scale** resulting from the implementation of a project can be estimated using the industry or company cost elasticity in relation to output. The benefits derived from the **diversification of the product portfolio** depend on the product structure of the company undertaking the petrochemical project and the market conditions (prices and their fluctuations) for the company’s products.

Market access benefits are relevant if the product is planned to be shipped to a particular international location(s). These benefits are not limited to preferential **tariff** conditions. The surplus derived from the reduction in **nontariff barriers** can be estimated with the help of relevant quantified country datasets, e.g., those developed by the United Nations Conference on Trade and Development (UNCTAD) (2022). This parameter can affect the location choice for the project, especially for a multinational company. At present, there is no formal framework, such as a free trade agreement between Saudi Arabia and China, which are selected as the project location and target market for this study, respectively.

If the proposed petrochemical project is planned in an energy-exporting economy, it can improve this economy’s **energy security** (viewed from the exporter perspective) through an increase in demand for feedstock inputs and diversification of energy/feedstock demand.

Finally, from the **innovation** perspective, the potential contribution of a petrochemical project may include the following:

- **Development of new products and processes** – quantified using the value of relevant patents**.**
- **Human capital development** – quantified by estimating incremental lifelong salary.
- **Technology transfer** – assessed by applying technology valuation models.

The benefits derived from externalities on a micro level are driven by a company’s structure, product line and business processes and, thus, are difficult to assess for outsiders. However, the disclosure of relevant assumptions – as a part of CBA – can be framed as a requirement for access to subsidized government financing or for obtaining necessary licenses and permits.

The negative externalities of petrochemical projects primarily relate to various **pollution costs**. The costs related to potential future emissions of **SOx**, **NOx** and **PMs** can be estimated by multiplying the projected emissions per ton of inputs by the total input volume and by the cost of pollutants. The costs associated with the **degradation of water and land also** must be considered. Relevant benchmarks may include cleaning costs per square meter or historical damage estimates.

Finally, **climate costs** must be taken into account by using a similar approach: multiplying the per unit emissions of **CO_2** associated with project inputs by the total amount of inputs and by regional or global carbon benchmark costs. The impact of other greenhouse gases, such as **CH_4** and **NO_2,** can be measured using the same approach with adjustments for the relative impact of these gases compared to CO_2.

3. Assessment of a Sample Project

Key assumptions

Technical assumptions of the sample project

For the purposes of this exercise, we will use a simple methodology to produce a set of cost estimates for an ethylene plant in various locations. To make the comparisons as direct as possible, the following assumptions are held:

1. The plants use the same technologies and feedstocks (natural gas fed).
2. The plants are the same size (1.5 Mtpa).
3. The plants were constructed at the same time (2021).
4. The only differences are the locations and associated construction and operating costs (KSA, China, Malaysia).

Market assumptions

The CAPEX cost estimates at this level of assessment for building a facility are typically assumed to be "overnight costs", meaning that they are at current or known prices and that completion is instant. This assumption avoids the complicating factors of changing costs for inputs that may drift over the course of construction. For materials and equipment, the procurement process may mean that the overnight cost is perfectly adequate, but specifically for labor, there could be some variation. This is a known issue but is not considered here.

For OPEX, the time element is much more relevant because the operating lifetime of a facility is on the order of decades and because it is unreasonable to prepurchase consumables (even long-term contracts have limits). In this case, a forecast for consumable inputs can be applied as necessary. For the chemicals and products produced, global prices are sufficient, as it is assumed that these facilities are operating in an efficient global market. Since we are comparing these facilities primarily based on their locations and because equipment and consumables are assumed to be purchased at global prices, the only OPEX costs that have a significant local dimension are power and labor. Labor can be ignored, as it is already factored into the core location factor, and only the differences in the relative costs between locations will be meaningful. Unless there is a strong belief that labor in one location will grow in cost much faster relative to the other locations under consideration, this factor can be ignored. Electricity costs, however, may have a local element (especially considering the reform efforts underway in Saudi Arabia) and warrant investigation for a reasonable forward price estimate.

Methodology

Cost estimation for large industrial facilities, particularly those in the oil and gas and petrochemical industries, can be performed at many different levels of detail, with associated levels of accuracy. Typically, progressively deeper and more complex costing exercises are performed as a project moves from the initial proposal to the end of construction. There are a few different systems to describe the levels of cost estimation, including the American Association of Cost Engineers (AACE), the United States Department of Energy (U.S. DoE), and the American Society of Professional Estimators (ASPE), among others. Most systems define the levels of estimates as a range of five classes, with Class 5 as the earliest and least defined all the way up to Class 1 as the definitive estimate provided at project completion. The following is a chart of the different estimates provided by the U.S. DoE.

Table 1. Cost estimating levels and the associated degrees of accuracy.

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**DEGREE OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges[a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 70%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	70% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Notes: [a] The state of process technology and availability of applicable reference cost data affect the range markedly.
The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.
Source: U.S. Department of Energy (2011).

While it would be preferable to create a cost estimate that has the highest level of accuracy possible, the resources and effort to provide these estimates become exponentially more difficult. A Class 1 estimate, for example, is essentially impossible to create unless actual receipts from a real project for materials and services are available, and it is less of an estimate than an accounting exercise.

Class 2-4 estimates are generally provided by engineering, procurement, and construction (EPC) firms to their clients while completing a feasibility study, by a front-end engineering and design (FEED) exercise, or from more detailed engineering work associated with preparing a final bid to construct the facility.

In this paper, we will focus on a Class 5 estimate with some elements of a Class 4 estimate. This kind of capacity-factored estimate may have the lowest accuracy of the levels described but does not require detailed engineering work or specialized software.

Initial assessment - CAPEX

Reference case selection

The first step to creating a factored cost estimate is to find an appropriate reference case. If possible, it is best to use a reference that is similar to the desired outcome. A recent facility of the same size and in the same location is ideal but often is not available. This issue can be overcome through the use of cost factors for capacity, time, and location. With these factors, the only real requirement is that the facility uses the correct technology and the capacity, time of construction, location, and total cost are known. When available, multiple reference cases are useful because they allow for different pathways toward a target estimate. If the results from factoring multiple references are similar, this similarity serves as support for the outcome.

Adjusting for capacity

Adjusting the cost of a facility to account for a change in size is accomplished through the widely used “Rule of Six-Tenths” (Chilton 1950), as shown in the formula below:

$$CAPEX_{Target} = CAPEX_{Ref} * \left(\frac{Capacity_{Target}}{Capacity_{Ref}}\right)^{0.6}$$

where $\text{CAPEX}_{\text{Ref}}$ is the known CAPEX cost, $\text{Capacity}_{\text{Ref}}$ is the known capacity of the reference facility, and $\text{Capacity}_{\text{Target}}$ is the desired capacity of the target facility. $\text{CAPEX}_{\text{Target}}$ is the resultant cost for the resized facility.

In practice, the doubling in size of a facility yields a 51% rise in cost. This result is partly due to economies of scale but primarily due to engineering considerations (e.g., a pipe that can handle twice the flow does not need twice the steel, as the area of the cross section grows faster than the circumference).

Adjusting for time

Costs change over time for many reasons. Inflation, market cycles, advances in technology, supply chain shifts, and regulations can all shift costs up or down temporarily or as long-term trends. Such variability can also impact different individual costs (e.g., materials vs. labor). To simplify this issue, there are various indices available that can account for these changes at the facility level and that do not require detailed knowledge of individual cost items. Examples of these indices are the Nelson-Farrar Refinery Cost Index (BakerRisk 2021), which covers the period from 1926 to the present; the Chemical Engineering Plant Cost Index (CEPCI 2021), which covers the period from 1947 to the present; and the IHS Capital Cost Indices (IHS Markit 2021), which cover the period from 2000 to the present. For the purposes of this paper, we tested these sources against one another and determined that the results are largely equivalent from a CAPEX perspective.

To apply either of these indices, all that is required is a simple ratio:

$$CAPEX_{Target} = CAPEX_{Ref} * \left(\frac{Time_{Target}}{Time_{Ref}}\right)$$

where $\text{CAPEX}_{\text{Ref}}$ is the known CAPEX cost, Time_{Ref} is the index presenting the known construction date of the reference facility, and $\text{Time}_{\text{Target}}$ is the index that refers to the desired construction date of the target facility. $\text{CAPEX}_{\text{Target}}$ is the resultant cost for the new facility.

One important note to understand about time factors for this kind of estimate is that they typically assume an overnight cost, where the construction is completed all at once. This assumption simplifies matters significantly because the input costs for materials, services, or labor can shift over a multiyear project, which is one of the major sources of uncertainty and why most project budgets include a significant contingency of approximately 20%.

Adjusting for location

Costs also change based on location for several reasons. While some items are sourced from a global supply chain with identical costs (e.g., specialized equipment), many others are regional (e.g., steel), or local (e.g., labor). In addition, there are fundamental differences that can impact the design (e.g., climate), the construction times (worker productivity), or even the method of construction (e.g., modularization). In the same manner as the time indices, there are location factors available that can account for these differences at the facility level and allow for easy application.

One example of a location index is available in the Compass International Inc. Global Construction Costs Yearbook (Compass International 2022). Similar to the time factor, a simple ratio is all that is required:

$$CAPEX_{Target} = CAPEX_{Ref} * \left(\frac{Location_{Target}}{Location_{Ref}}\right)$$

where $CAPEX_{Ref}$ is the known CAPEX cost, $Location_{Ref}$ is the known construction location of the reference facility, and $Location_{Target}$ is the desired construction site of the target facility. $CAPEX_{Target}$ is the resultant cost for the relocated facility.

However, when using location factors, it is important to remember two things. First, one must use the most recent edition available, as the ratio of costs changes over time. Second, the appropriate index should be used for a complex facility (e.g., processing facility) as opposed to simple construction (e.g., office building).

Combining factors

Chaining the factors together yields the complete equation:

$$CAPEX_{Target} = CAPEX_{Ref} * \left(\frac{Capacity_{Target}}{Capacity_{Ref}}\right)^{0.6}$$

$$* \left(\frac{Time_{Target}}{Time_{Ref}}\right) * \left(\frac{Location_{Target}}{Location_{Ref}}\right)$$

Special considerations

It is worth mentioning a few special considerations and idiosyncrasies of this factorized method. First, the time and location factors are based on the construction costs and trends in the U.S. Gulf of Mexico (GoM), specifically Texas and Louisiana.
If using a GoM reference case (as we are), and the CAPEX is reported in U.S. dollars, the equation remains very straightforward, and the order of operations is irrelevant.

However, if a case is reported in foreign currency, this calculation can become more complicated.
A suggested remedy is as follows:

1. Convert $CAPEX_{Ref}$ to US$ using the average exchange rate in the year of construction.

2. Shift the facility to the U.S. GoM with the location factors from the year of construction.

3. Now follow the regular method outlined above with the current location factors.

Initial assessment – OPEX

Estimating the OPEX for a complex facility can be simpler than a CAPEX estimate if a reasonable reference is available. However, it requires some assumptions about future costs because the lifetime of these facilities is typically approximately 30 years. In a well-maintained continuous processing facility, the quantities of inputs (materials, energy, labor) should be relatively stable when considered on an annualized basis. This stability simplifies some intra-annual variability, including maintenance schedules and purchasing cycles, and can average out some multiyear costs, such as major equipment replacements. Conceptually, there are only two types of costs that matter in a simple OPEX estimate: fixed costs related to operations and maintenance (O&M), and variable costs associated with consumables, such as feedstocks and fuel/power.

Fixed costs are connected to the facility itself and have a similar relationship to the capacity as seen with the size factor for CAPEX. Larger facilities need less manpower or spares for maintenance per process unit because of the same economies of scale described in the earlier section. There are also location factors and time factors for O&M, but we do not need to characterize these factors. All the same factors, size, location, and time, which were accounted for in the CAPEX estimate, are already included in the OPEX estimate if they are expressed as a percentage. In early-phase estimates, this is a standard method because similar labor and similar materials are used for the running of the plant as was needed in the building of the plant. Typically, this is set at 5% of CAPEX, as shown in the equation below:

$$OPEX_{Fixed} = CAPEX_{Target} * 5\%$$

For consumables, the amounts needed are directly proportional to the capacity of the plant and are used at the rate of production, making them a variable cost. It is generally assumed that a plant will run at the designed capacity; otherwise, it would make sense to build a smaller (cheaper) plant. Thus, the capacity is the important value to use because it is dictated by the chemical processes involved, which (if it is a healthy facility) run at an optimal level. One cannot produce twice as many products without using twice as much feedstock. Electricity and fuel usage can have a very minor efficiency gain with larger plants, but such a gain is usually negligible if plants are designed, built, and operated correctly. Location and time do not impact the quantities used, as the chemistry involved does not change. For each consumable, the quantities based on a reference case can be determined in the target facility as follows:

$$Quantity_{Target} = Quantity_{Ref} * \left(\frac{Capacity_{Target}}{Capacity_{Ref}} \right)$$

Once the quantities of the variable inputs (fuel, power, feedstocks) have been determined, all that remains is to find the local price per unit and to multiply to find the final value.

$$OPEX_{Variable} = \sum \left(Quantity_{Target} * \; Price_{Target} \right)$$

The location component introduced in this study adds another OPEX variable: shipping costs and tariffs. Assuming that the target market for the project outputs is known, the shipping costs can be estimated as the per unit (tonne) transportation costs for particular routes multiplied by the project output. Import tariff costs are calculated based on the current tariff rates that the target market economy applies to specific trading partners and sales values for project outputs in CIF terms.

$$OPEX_{Total} = OPEX_{Fixed} + OPEX_{Variable}$$

As stated earlier, the determination of OPEX costs is generally easier in principle than the determination of CAPEX costs. However, it is important to remember that since prices for variable costs can change over the very long lifetime of a facility, it may be prudent to use price forecasts for fuel, power, and feedstocks when solving for lifetime profitability.

Financial assessment

To compose a proforma financial plan, the initial cost estimates laid out in the previous section must be modified. The major adjustment is defined by the assumed project operational period of 30 years (since the completion of the CAPEX phase). In this analysis, we use nominal $ to distinguish between the inflation rates projected for each project location. Specifically, we use annual country-specific CPI projections obtained from the Oxford Economics model (Oxford Economics 2021) to adjust the following costs:

- CAPEX for all locations
- M&O costs
- Natural gas tariffs for Saudi Arabia
- Electricity costs for all locations
- Shipping costs between Saudi Arabia and China and between Malaysia and China

Apart from inflation adjustments, CAPEX and M&O costs are calculated based on the methods described in the previous section.

Natural gas costs are calculated using the current tariff for industries in Saudi Arabia and the average industry prices for China and Malaysia. For the latter two locations, the projected price of natural gas is adjusted based on the forecasted trajectory of the Japan-Korea Marker LNG (liquefied natural gas) benchmark (World Bank 2021).

A similar approach is applied to electricity costs: the current industry tariff for Saudi Arabia and the average industry prices for China and Malaysia observed in the base year and adjusted for the countries' CPI.

Tariff costs are based on the current applied import tariff rates for imports of ethylene into China. For Saudi Arabia, it is 2% (not adjusted for the projected period), and for Malaysia, it is assumed to be at the 0% level under the Regional Comprehensive Economic Partnership (RCEP) agreement.

Shipping costs are calculated based on the per tonne costs derived from the rates observed on routes from the Middle East and from Southeast Asia to China (Clarksons 2021), multiplied by the total project output and adjusted by the average CPI of the importer and exporter (KSA – China and Malaysia – China).

The transportation and tariff costs for China are set to zero because the final destination for all products (the end market) is assumed to be China.

All tariffs and prices are used net of tax. This projection also does not consider corporate taxes in the respective locations.

Revenues are calculated based on the project output and the price projection for ethylene (Bloomberg 2021). In all three scenarios, the revenue streams are the same since the project is assumed to target the Chinese market regardless of its location. We also assume that Chinese domestic prices for ethylene will not significantly differ from the global forecast.

The (nominal) discount rate for financial net present value (NPV) calculations is based on the industry weighted average cost of capital (WACC) of 6.58% (Riyad Capital 2020) adjusted for the average global projected CPI of 2.4%.

Detailed assumptions and data sources are listed in Appendix A.

Table 2 shows that Saudi Arabia would be the only profitable location for the project under the stated assumptions. In contrast choosing China as the project base would result in a significantly negative NPV. Since the revenue streams are assumed to be similar for all locations, the difference in the financial outcome is driven by the locations' cost competitiveness.

The variance in M&O costs is not significant, with Malaysia and China exceeding the KSA by 11% and 13%, respectively. While relatively substantial (from the project total of 0 in China to $1.0 billion for Malaysia and $3.6 billion for the KSA), the

Table 2. Financial plan for the project in three locations.

	2022	2023	2024	2025	2026	2027	2032	2037	2042	2047	2052
KSA											
CAPEX	**$290.70**	**$887.39**	**$904.19**	**$307.08**	**$-**	**$-**	**$-**	**$-**	**$-**	**$-**	**$-**
OPEX	**$-**	**$-**	**$-**	**$-**	**$893.74**	**$913.54**	**$1,005.59**	**$1,113.91**	**$1,231.08**	**$1,358.71**	**$1,499.85**
M&O	$-	$-	$-	$-	$119.47	$121.84	$134.39	$148.36	$163.80	$180.85	$199.67
Natural gas	$-	$-	$-	$-	$226.59	$231.09	$254.90	$281.38	$310.67	$343.00	$378.71
Electricity	$-	$-	$-	$-	$447.64	$456.53	$503.57	$555.89	$613.75	$677.63	$748.15
Transport and tariffs	$-	$-	$-	$-	$100.04	$104.08	$112.73	$128.28	$142.86	$157.23	$173.32
Revenues	**$-**	**$-**	**$-**	**$-**	**$1,536.72**	**$1,666.05**	**$1,699.74**	**$2,037.63**	**$2,274.77**	**$2,443.30**	**$2,636.15**
NPV	**$(290.70)**	**$(887.39)**	**$(904.19)**	**$(307.08)**	**$642.98**	**$752.51**	**$694.15**	**$923.73**	**$1,043.69**	**$1,084.59**	**$1,136.29**
$3,955.36											
China											
CAPEX	**$310.66**	**$956.10**	**$978.89**	**$333.90**	**$-**	**$-**	**$-**	**$-**	**$-**	**$-**	**$-**
OPEX	**$-**	**$-**	**$-**	**$-**	**$2,346.49**	**$2,305.22**	**$2,169.71**	**$2,199.87**	**$2,329.72**	**$2,475.21**	**$2,638.21**
M&O	$-	$-	$-	$-	$128.98	$131.95	$147.83	$165.64	$185.58	$207.93	$232.97
Natural gas	$-	$-	$-	$-	$1,506.80	$1,446.21	$1,207.26	$1,121.52	$1,121.52	$1,121.52	$1,121.52
Electricity	$-	$-	$-	$-	$710.71	$727.06	$814.62	$912.71	$1,022.62	$1,145.76	$1,283.72
Transport and tariffs	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-	$-
Revenues	**$-**	**$-**	**$-**	**$-**	**$1,536.72**	**$1,666.05**	**$1,699.74**	**$2,037.63**	**$2,274.77**	**$2,443.30**	**$2,636.15**
NPV	**$(310.66)**	**$(956.10)**	**$(978.89)**	**$(333.90)**	**$(809.77)**	**$(639.16)**	**$(469.97)**	**$(162.24)**	**$(54.95)**	**$(31.92)**	**$(2.07)**
($4,619.24)											
Malaysia											
CAPEX	**$309.06**	**$950.85**	**$972.20**	**$331.35**	**$-**	**$-**	**$-**	**$-**	**$-**	**$-**	**$-**
OPEX	**$-**	**$-**	**$-**	**$-**	**$1,801.55**	**$1,777.64**	**$1,707.76**	**$1,753.27**	**$1,869.45**	**$1,999.29**	**$2,144.38**
M&O	$-	$-	$-	$-	$128.17	$131.05	$146.45	$163.65	$182.87	$204.35	$228.36
Natural gas	$-	$-	$-	$-	$1,027.33	$986.01	$823.10	$764.64	$764.64	$764.64	$764.64
Electricity	$-	$-	$-	$-	$617.74	$631.62	$705.81	$788.72	$881.37	$984.90	$1,100.59
Transport and tariffs	$-	$-	$-	$-	$28.31	$28.95	$32.40	$36.25	$40.56	$45.39	$50.79
Revenues	**$-**	**$-**	**$-**	**$-**	**$1,536.72**	**$1,666.05**	**$1,699.74**	**$2,037.63**	**$2,274.77**	**$2,443.30**	**$2,636.15**
NPV	**$(309.06)**	**$(950.85)**	**$(972.20)**	**$(331.35)**	**$(264.83)**	**$(111.58)**	**$(8.02)**	**$284.37**	**$405.32**	**$444.01**	**$491.77**
($1,251.79)											

Source: KAPSARC calculations.

distinctions in transport and tariff costs – driven by the location factor – do not define the location ranking in their projected financial performance. However, in the case of the KSA, these costs would amount to 11.5% of the total OPEX.

The major impact on relative financial performance is explained by difference in the input costs. The total project costs associated with natural gas in Saudi Arabia comprise only 25.1% of those in China and 36.8% in Malaysia. The differences in electricity costs are less significant: the costs in the KSA are equal to 60.3% of those in China and 69.9% of those in Malaysia. However, this discrepancy expressed in absolute values also becomes substantial.

As a result, the cost structure for the project in the KSA differs from that in the other locations. Natural gas accounts for only 25.3% of the total project OPEX compared to 43.4% in Malaysia and 50.7% in China. In addition to an obvious opportunity, this difference could present a major risk. Since the prices of natural gas (as well as electricity) in Saudi Arabia are currently set by the government at subsidized levels and are not driven by the market, there is a possibility of rapid changes in input prices and a potential for a general price increase in the case of market liberalization.

Comparing the remaining two options, Malaysia seems preferable to China due to the cost advantage observed in all areas (natural gas costs in particular), except for transportation and tariffs. Given the zero import tariff rates on ethylene coming from Malaysia to China and its relative geographical proximity, Malaysia can be considered a viable alternative for a petrochemical project location targeting the Chinese market.

In all three scenarios, the projected financial outcome is heavily dependent on the forecasted performance of the global and regional markets for ethylene and natural gas, which have been prone to significant fluctuations. These uncertainties can be alleviated by thorough data input management, relevant scenario analyses and risk assessment. Liberalized input prices under the CBA framework help quantify such scenarios.

Economic (CBA) assessment

In this section, we apply the general principles of CBA based on the guidelines listed in the European Commission (2014) to the most financially viable project option identified in the previous section. We assess this project from the perspective of Saudi Arabia, applying domestic market rates and relevant pollution costs. For the purpose of CBA, the following amendments to the financial plan are made:

> To reflect shadow market prices, the regulated natural gas tariffs currently applied in the KSA are changed to marginal costs following Alyousef and Stevens (2011)
>
> For the same purpose, the current Saudi electricity tariff is substituted with the long-run marginal electricity costs estimated by Matar (2021)
>
> Pollution costs are added to the ENPV calculations. They include the costs associated with emissions of SOx, NOx and PM10 added by the project. Annual emissions are estimated using a project with similar specifications (TASNEE Petrochemicals 2005), and per tonne costs are taken from the Environmental Prices Handbook (CE Delft 2018), adjusted for real $
>
> Climate costs are calculated based on the CO_2 and NH4 emissions from a comparable project (IPCC 2021) and the CO_2 cost projections (medium scenario) listed in the European Commission (2014).

CAPEX, O&M and transportation/tariff costs, as well as the prices for the project outputs, are assumed to be market based and are not changed from their financial plan values. The detailed assumptions and data sources for CBA are listed in Appendix A.

The applied economic discount rate (in nominal $) is 5% based on the EU guidelines (European Commission 2014), adjusted for the global average CPI of 2.4%. The CBA results of the Saudi-based project are shown in Table 3.

CBA adjustments significantly impact the project economics, sending its ENPV into the red. While

Table 3. Economic (CBA) projections of the KSA-based project.

	2022	2023	2024	2025	2026	2027	2032	2037	2042	2047	2052
KSA											
CAPEX	**$290.70**	**$887.39**	**$904.19**	**$307.08**	**$-**	**$-**	**$-**	**$-**	**$-**	**$-**	**$-**
OPEX	**$-**	**$-**	**$-**	**$-**	**$1,843.90**	**$1,850.31**	**$1,871.51**	**$1,901.02**	**$1,931.05**	**$1,962.46**	**$1,997.38**
M&O	$-	$-	$-	$-	$119.47	$121.84	$134.39	$148.36	$163.80	$180.85	$199.67
Natural gas	$-	$-	$-	$-	$991.93	$991.93	$991.93	$991.93	$991.93	$991.93	$991.93
Electricity	$-	$-	$-	$-	$632.45	$632.45	$632.45	$632.45	$632.45	$632.45	$632.45
Transport and tariffs	$-	$-	$-	$-	$100.04	$104.08	$112.73	$128.28	$142.86	$157.23	$173.32
Pollution costs					$49.73	$49.73	$49.73	$49.73	$49.73	$49.73	$49.73
Climate costs					$101.56	$104.04	$116.42	$128.81	$141.19	$153.58	$165.96
Revenues	**$-**	**$-**	**$-**	**$-**	**$1,536.72**	**$1,666.05**	**$1,699.74**	**$2,037.63**	**$2,274.77**	**$2,443.30**	**$2,636.15**
ENPV	**$(290.70)**	**$(887.39)**	**$(904.19)**	**$(307.08)**	**$(458.46)**	**$(338.02)**	**$(337.92)**	**$(41.92)**	**$152.80**	**$277.53**	**$423.07**
($3,111.42)											

Source: KAPSARC calculations.

accounting for $5.0 billion or 9.6% of the adjusted project OPEX, pollution and climate costs, which are added to the calculations, are not the main determinants of this outcome. Removing the domestic subsidies for key project inputs – natural gas and electricity – by applying shadow market prices impacts the economic outcome of the project the most. After such adjustments, the cost of natural gas would account for 51.8% of the total project OPEX, followed by the electricity cost at 33.0%. The resulting outcome is still more favorable than that of the “Chinese location” financial plan. However, it would make Saudi Arabia a less attractive project location than Malaysia.

Notably, CBA was conducted from the Saudi perspective. If the “KSA location” scenario had been analyzed via the Chinese lens (e.g., a potential investment decision by a Chinese petrochemical company), the result would have been different. First, such a hypothetical Chinese company could disregard the potential impact on the domestic Saudi economy via subsidized inputs, leaving the projected costs of natural gas and electricity at their regulated levels (assuming deregulation is not projected to happen during the project lifetime). Second, some of the pollution costs, given their local (regional) nature, could also be omitted from the CBA. One remaining major adjustment would be the climate costs due to their global impact. A similar approach could be applied for a CBA performed from the Saudi perspective for China and Malaysia as project locations.

The goal of this analysis was not to advise on the potential investment decision. In this case, much more detailed and sophisticated financial planning and forecasting processes are required. Moreover, additional benefits – including diversification, economies of scale, market access, energy security, etc. – under the CBA framework, which can be properly assessed and quantified only by the company or government insiders, could tilt the ENPV back into the black. Rather, the purpose of this exercise was to highlight the necessity of a comprehensive approach to project analysis and its potential impacts on the domestic economy – especially in cases of regulated domestic markets.

Risk management

CBA helped uncover additional factors with potentially significant impacts on the project. To formalize and quantify such effects and potentially identify other critical factors, we performed a sensitivity analysis of the major items in NPV and ENPV. Their values were modified by 1% compared to the base-case scenario, while other items remained unchanged. The resulting variations in financial and economic outcomes are shown in Table 4.

Under the conventional financial plan, the only critical variable for the KSA-based project would be the projected price of ethylene. This variable becomes even more impactful for the CBA calculations: a 5.5% change in ENPV corresponds to a 1% shift in the ethylene price. In addition to sales prices, the costs of inputs – natural gas and electricity prices – under the CBA (liberalized markets) scenario become critical factors, with ENPV variations of 2.7% and 1.7%, respectively. Other cost items, including CAPEX, can be deemed not critical, as their impact on the financial (NPV) and economic (ENPV) outcomes remains below 1%.

The next step in risk analysis is to determine the levels at which the shifts in critical factors alter the outcome of the project. Since the projected financial result for the KSA-based project is positive and the economic (CBA) result is negative, the postulates for such analysis can be formulated as follows:

> By how much does the cost have to increase/ the product price have to decrease until the NPV equals zero?

> By how much does the cost have to decrease/ the product price have to increase until the ENPV equals zero?

Table 5 shows the estimated switching values for the critical factors identified earlier.

The price of ethylene remains the most impactful driver in both the NPV and ENPV calculations.

Table 4. Sensitivity analysis of the KSA-based project.

Variable	Variation in the NPV due to a ± 1% variation (%)	Criticality judgment	Variation in the ENPV due to a ± 1% variation (%)	Criticality judgment
CAPEX	0.5	Not critical	0.6	Not critical
M&O costs	0.3	Not critical	0.4	Not critical
Natural gas tariff (price)	0.5	Not critical	**2.7**	**Critical**
Electricity tariff (price)	0.9	Not critical	**1.7**	**Critical**
Transport and tariff costs	0.3	Not critical	0.2	Not critical
Cost of carbon	N/A	N/A	0.3	Not critical
Ethylene price	**3.2**	**Critical**	**5.5**	**Critical**

Source: KAPSARC research.

Table 5. Switching values of the major variables in the KSA-based project.

Variable	Switching values	%
Ethylene price	Decrease until the NPV equals 0	31%
	Increase until the ENPV equals 0	19%
Natural gas tariff (price)	Increase until the NPV equals 0	211%
	Decrease until the ENPV equals 0	37%
Electricity tariff (price)	Increase until the NPV equals 0	105%
	Decrease until the ENPV equals 0	68%

Source: KAPSARC research.

Despite a significant increase in input costs under the CBA scenario, a 19% growth in projected prices would be sufficient to cover all economic and social costs associated with the project. On the other hand, it would take a 31% drop in product prices to erase the positive NPV even under the current input subsidy regime.

A similar outcome (zero NPV) would be registered if the current industry tariff for natural gas in Saudi Arabia increased by 211% or if the electricity tariff for industry doubled from the current levels. While such significant hikes are unlikely to occur at once, the trajectory of increasing regulated tariffs in the KSA suggests that these rate levels could be seen within the project lifespan. Similar to the other sectors of the Saudi economy that depend on fuel and power subsidies, the development of the domestic petrochemical industry is contingent on a balanced approach to bridging domestic tariffs with associated costs and in deregulating the fuel and power sectors.

From the ENPV perspective, keeping everything else constant, the prices of inputs have to decrease substantially to achieve at least a neutral (zero) outcome: a 37% decrease in the domestic market (shadow) price of natural gas or a 68% drop in "liberalized" electricity prices. Given that shadow prices represent marginal costs, such a significant reduction seems unlikely. In the case of natural gas, the shadow price is based on the marginal cost of conventional gas. The development of unconventional resources would raise marginal costs even higher. Regarding electricity, there is room for cost optimization, e.g., phasing out expensive oil-based generation capacities. However, halving the marginal cost level – required for the positive project ENPV – in the short or medium term is extremely unlikely.

The potential changes in other factors – including CAPEX and other OPEX items – which were established as not critical, have to be too substantial to be realistically considered in this analysis.

However, not all potential risks relevant to the chosen project scenario can be easily quantified. In addition, some seemingly unlikely events could have a significant impact on project performance. Hence, it would make sense to consider all relevant risk factors that may impact the outcome of the project and its specific variables – even if only qualitative assessment is possible. Table 6 provides a list of

Table 6. Qualitative risk assessment for the KSA-based project.

Risks/adverse events	Variable	Causes	Effects	NPV/ ENPV	Timing	Severity
Regulatory						
Increase in import tariffs (domestic)	CAPEX	Fiscal deficit, rise of protectionism, deterioration of bilateral/multilateral relationships	Increase in costs	NPV	Medium-long	II
Increase in import tariffs (products)	Transport and tariffs			Both		II
Increased NTBs	OPEX		Increase in costs, problems with market access	Both		III
Economic sanctions	Revenues	U.S.-China trade war, deterioration of relationships with the U.S.	Problems with market access, payment processing, loss of revenues	Both	Medium-long	IV
Increased tax burden	NPV, Cash flow	Fiscal deficits, shift in priorities of economic development	Reduced cash flow	NPV	Medium-long	II
More stringent requirements: SOx, NOx, PM emissions	CAPEX, Pollution costs	Deteriorating environmental conditions, public pressure	Additional costs	Both	Medium	II
Higher carbon price	ENPV costs	Increased international commitments, fluctuations in the carbon market	Additional costs	ENPV	Medium	II
Changes in regulated prices and subsidies	Natural gas, electricity costs	Fiscal deficits, market reforms	Impacts on OPEX	NPV	Medium-long	IV
Delays in permits and approvals	NPV	Established practice/historic probability	Delays in achieving a positive cash flow	Both	Short-medium	II
Procurement						
Delays (local counterparties/ procedures)	NPV	Established practice/historic probability	Delays in achieving a positive cash flow	Both	Short-medium	II
Shipping disruption	NPV	Military conflicts, natural disasters, etc.	Increased costs and/or a delayed positive cash flow	Both	Short-medium	II
Demand						
Drop in demand	Revenues	Regional/global crises	Reduced utilization and revenues	Both	Medium	III
Price fluctuations	Revenues	Regional/global crises, market volatility	Reduced revenues	Both	Short-medium	IV
Cost estimates						
Fluctuations in inputs prices	Natural gas, electricity costs	Regional/global crises, market volatility	Higher costs, reduced import substitution benefits	ENPV	Short-medium	IV
Higher CAPEX	Total CAPEX	Increased inflation	Higher costs	Both	Medium-long	II
Higher OPEX	M&O, transport costs	Increased inflation	Higher costs	Both	Medium-long	II
Shipping disruption	Revenues	Military conflicts, natural disasters, etc.	Reduced revenues and/or a delayed positive cash flow	Both	Short-medium	II
Force majeure						
Accidents and technical issues	CAPEX, M&O	Qualification of personnel, force majeure	Increased costs, delays in operations	Both	Short	II
Natural disasters	CAPEX, M&O, Revenues	Force majeure	Increased costs, delays in operations	Both	Short-medium	I-V

Notes: Severity categories: I - no relevant effect on social welfare, even without remedial actions. II - minor loss of the social welfare generated by the project, minimally affecting the project's long-run effects; however, remedial or corrective actions are needed. III - moderate social welfare loss generated by the project, mostly financial damage, even in the medium-long run; remedial actions may correct the problem. IV - critical: high social welfare loss generated by the project; the occurrence of the risk causes a loss of the primary function(s) of the project; remedial actions, even large in scope, are not enough to avoid serious damage. V - catastrophic: project failure that may result in serious or even total loss of the project's functions; the main project effects in the medium-long term do not materialize (European Commission 2014).
Sources: European Commission (2014), KAPSARC research.

such risks for a KSA-based petrochemical project, grouped into subcategories and analyzed using a qualitative risk assessment framework based on (European Commission 2014).

Severity categories for the potential adverse events can be assigned based on their impact on specific project variables. These categories are identified as “critical” or “not critical” based on the quantitative analysis. Consequently, regulatory changes in input pricing and market price fluctuations fall into category IV. Other potentially significant risks for the project include natural disasters, a drop in demand, economic sanctions, and market access barriers. Although other adverse events could reduce the economic and/or social welfare generated by the project, they are unlikely to undermine its long-run outcomes.

Notably, the analysis presented in Table 6 is location specific. Adverse events and their potential effects and severity will differ across project locations, calling for a separate risk assessment process in each case. For example, in the case of China, the market access risks become irrelevant, but the potential impact of Chinese economic sanctions would be much more severe.

After a comprehensive list of risks is created and assessed based on the proposed framework, industry experts need to assign the probability of such adverse events to each risk. Based on the resulting matrix – severity X probability – the most significant risks can be identified, and relevant prevention/mitigation strategies can be developed. After this process, residual risks can be re-evaluated.

4. Conclusions

The CBA framework can provide a useful perspective for analyzing potential projects in sectors of economy beyond those where CBA has been traditionally applied, such as utilities or public transport. CBA becomes especially relevant in cases in which markets are affected by price controls, subsidies or other forms of government interventions and in which a government acts as a major investor or stakeholder in a project. In an environment where nonfinancial factors – including energy security, climate goals and protectionism – increasingly drive economic policy and investment, CBA provides a broader assessment of project outcomes and can help align the interests of investors and policymakers.

A broader scope – characteristic of CBA – also contributes to a more comprehensive project risk assessment, which is becoming increasingly relevant given the escalating trend of macroeconomic and geopolitical shocks.

Traditionally, CBA has been primarily applied to domestic investment projects. However, projects can not only span across country borders in their operations and impacts but also have foreign investors and stakeholders, leading to varying (and potentially conflicting) benefits and costs from the CBA perspective. This reality calls for a further conceptualization of how CBA is applied on an international scale and the further development of relevant theoretical frameworks.

The sample petrochemical project presented in this study illustrates the above theses. The most beneficial project location from the financial NPV perspective would yield a negative ENPV if the CBA principles are applied. Moreover, CBA reveals additional critical risk factors in this project related to natural gas and electricity tariffs. However, some other potential CBA costs and externalities, whose impacts are limited to the local economy and environment, may not be of great concern to foreign investors.

While it is hardly possible to achieve complete objectivity and transparency in the CBA appraisal process, the relevant industry guidelines issued by the supervising authorities will substantially clarify and standardize the process, at least at the country level.

It should also be noted that the proposed CBA framework for petrochemical investment projects is subject to the controversies inherent in the general concept of CBA. Specifically, these include the following:

- the degree of freedom in defining and quantifying project externalities,
- the applicability of “market failure” and “collective action problem” arguments, and
- potential conflict of interest: who orders and who conducts such appraisal?

Endnotes

[1] Some economies may levy an export tax on products; in that case, it needs to be removed for the purpose of CBA.

[2] Currently, the average tariff rate for the relevant product group (HS 8419) is approximately 4% (World Bank 2022).

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Appendix A. Data and Sources

Table A1. Data inputs used in the sample project assessment.

Data inputs	Sources
CAPEX	
Initial benchmark data	Spallina et al. (2017), Compass International (2022), Petrochemical Update (2018)
Capacity factor adjustment	Chilton (1950)
Time factor adjustment	IHS Markit (2021): U.S. Gulf of Mexico as a reference case
Location factor adjustment	Compass International (2022): U.S. Gulf of Mexico as a reference case
OPEX: Fixed costs	
Operation & maintenance	5% of the project CAPEX (location specific)
OPEX: Variable costs	
Natural gas tariffs	
Saudi Arabia	Natural gas price for industries (Hasan and Shabaneh 2021)
China	Average natural gas price for industries Q4 2021 (CEIC 2021)
Malaysia	Average selling price for industries in Q4 2021 (The Star 2021)
Natural gas price forecast	Japan-Korea Marker LNG benchmark forecast – World Bank commodities price forecast (World Bank 2021)
Electricity tariffs	
Saudi Arabia	Business electricity price (Global Petrol Prices 2021)
China	Electricity prices for industries – Ningbo Q4 2021 (CEIC 2021)
Malaysia	Business electricity price (Global Petrol Prices 2021)
Import tariffs	Current Chinese import tariffs for Malaysia and Saudi Arabia (World Bank 2022)
Shipping costs	Per tonne shipping costs on the routes from the Middle East to China and Southeast Asia (Clarksons 2021)
Financial assessment	
Ethylene price and forecast	Bloomberg (2021)
Inflation adjustment	CPI projections for China, Malaysia and Saudi Arabia derived from the Oxford Economics model (Oxford Economics 2021)
NPV discount rate	WACC: Assumed discount rate for a company based in Saudi Arabia with a capital structure consisting of 20% debt and 80% equity (Riyad Capital 2020) – adjusted for real rates
Economic (CBA) assessment	
Marginal costs	
Natural gas (Saudi Arabia)	Alyousef and Stevens (2011)
Electricity (Saudi Arabia)	Based on Matar (2021) – dynamic pricing case
Project emissions (tonnes)	
CO_2	Based on similar projects listed by the IPCC (2021) and adjustment factors (Climate Policy Watchers 2021). NH4 emissions converted to the CO_2 equivalent
NH_4	
SOx	Based on emission data from the TASNEE Petrochemicals ethylene and polyethylene projects (TASNEE 2005) – adjusted for project size
NOx	
PM10	
Emission costs	
CO_2	Based on EC (2014) – medium case
SOx	Based on CE Delft (2018) – adjusted for real prices and converted from EUR
NOx	
PM10	
ENPV discount rate	Based on EC (2014) adjusted for real rates

Source: KAPSARC research.

Notes

Notes

About the Authors

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Philipp is a visiting research fellow specializing in the economic and policy aspects of energy supply and trade. He holds a Ph.D. in international economic relations from the Saint Petersburg State University of Economics and an MBA from the University of Southern California.

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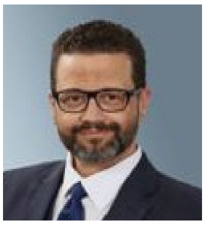

Colin Ward

Mr. Ward has worked in all aspects of the energy industry from summer jobs on seismic rigs to designing refineries, upstream field development, consulting and strategy work; now, he conducts high-impact academic analysis of issues facing the energy system. Much of Mr. Ward’s work in recent years has focused on CCUS-related topics, including upstream carbon intensity, CO2-EOR, blue hydrogen, hydrocarbon producer strategy in a carbon-constrained world, and blockchain-based carbon tracking and trading.

About the Project

This research project will assess the implications of China’s Belt and Road Initiative (BRI) for Saudi Arabia.

China’s evolving BRI was first conceived by China’s President Xi Jinping in 2013 and officially launched in March 2015 by the Chinese government as the Vision and Actions on Jointly Building the Silk Road Economic Belt and the 21st-Century Maritime Silk Road. The initiative has become a focal point in the analysis of the impact of Chinese policies on the international community, particularly for the countries along the BRI routes.

The project seeks to answer the following key questions:

- Has the BRI ever been properly defined?
- What are its main elements, and why is it controversial at times?
- Will China’s future energy demand be affected by the evolving BRI and, if so, in what way(s)?
- How should Saudi Arabia react to China’s BRI — are there areas that can deepen the bilateral relationship and areas to avoid?

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