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Determining the economic consequences of natural gas substitution

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ABSTRACT

Resource depletion is a key aspect of sustainability, because the consumption of finite resources impacts on their availability for future generations. There are many proposed methods for accounting for the depletion of a particular resource, amongst which include the proportion of the resource depleted, the rate of resource depletion, and the energy, exergy, or monetary cost of extraction as the resource becomes harder to find or extract.

This paper is part of a wider study to measure resource depletion using its environmental and economic impacts for the case of natural gas, where depletion of natural gas requires substitution by black coal or coal seam gas. The capital and operating costs are estimated both for upstream fuel extraction and purification and downstream use of the fuel to produce electricity, hydrogen and ammonia. These costs are based on a commercial scale of operation, using the same basis for economic modelling in each case. Black coal was found to have the lowest transfer price from upstream to downstream processing among the three feedstocks, but the highest capital and operating costs in the downstream processes. Conventional gas produced slightly higher transfer prices and downstream processing costs compared to coal seam gas.

The favourable economic and environmental indicators for natural gas and coal seam gas are expected to lead to increased demand for these resources over coal, running the risk of a gas shortage. The economic consequence of a scarcity of either gas resource will be a penalty in capital and operating costs to produce the three products should gas be substituted with black coal.

1. Introduction

Australia is rich in high-quality and diverse energy resources, such as natural gas and coal. Energy exports were reported by the Bureau of Resource and Energy Economics (BREE) [1] to account for one third of the value of Australia's total commodity exports in 2010–2011. Unlike minerals which are mined solely for their chemical components, fossil fuels are extracted for their inherent energy properties as well. From a sustainability viewpoint, increasing exploitation of fossil fuel resources will hasten their depletion, impacting on future generations. Various indicators have been developed using Life Cycle Assessment (LCA) methodology to enable resource depletion of fossil fuels to be measured. LCA is an environmental assessment method used to identify and quantify potential environmental burdens and impacts of a product or process. Typically, the output of the LCA is a set of environmental impact indicators under a common basis (e.g. environmental impact for every tonne of product produced).

Traditionally, the ISO LCA framework only covers environmental burdens. As a result, the economic consequences, such as the change in operating and capital costs for products derived from the different fossil fuels, are not captured for resource depletion. Additionally, there are economic risks associated with extracting resources from more remote or environmentally sensitive locations as well as risks of higher government taxes on greenhouse gas emissions for inferior quality resources.

A methodology was proposed to measure the full impacts of resource depletion, which includes environmental and economic differences between alternatives. Previous work had been performed by the authors using LCA to capture the environmental impacts due to the substitution of natural gas by coal in a scarcity scenario [2]. In this work, existing resource depletion approaches were examined in the context of natural gas depletion. These approaches included the role of resource depletion based on estimates of consumption rate and reserves, as well as estimates of the energy, exergy or monetary cost of extraction as the resource becomes depleted. An additional methodology was proposed to measure impact changes when fossil fuel substitution occurs as a result of scarcity. The methodology was applied to a scarcity situation of natural gas in Australia where black coal is substituted for

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Nomenclature

A	annualised capital cost
A$	Australian dollars
b	capacity exponent
FC	fixed costs which are unaltered with change in production rate
GJ	giga (10^9) joule
HHV	higher heating value, assumes that the latent heat of vaporisation of water in fuel and reaction products is recovered
i	fractional interest rate per year, %
I_p	fixed capital investment cost of proposed plant
I_r	fixed capital investment cost of reference plant
MW	mega (10^6) watt
MW h	mega (10^6) watt-hour
n	project life, years
OL	operating labour costs in the form of wages or salaries for shift operators responsible for the operation of the plant
PC	production costs which are a total of fixed and variable operating costs, excluding non-manufacturing costs
PO	payroll overheads, additional employee costs incurred by the employer
£	British pounds
Q_p	production capacity of proposed plant, 2011AUD
Q_r	production capacity of reference plant, 2011AUD
t	tonne
US$	US dollars

gas for production of electricity and hydrogen. The resulting impacts or emissions to air and water, as well as solid waste generation and water depletion were determined.

The current study is a continuation of the previous work, which is to incorporate capital and operating cost differences incurred from fuel extraction and purification to downstream product manufacture to reflect the economic impacts of resource depletion. A case study has been undertaken involving the substitution of natural gas with coal or coal seam gas. All three fuels are plentiful in Australia, but they are also being rapidly consumed. The consequences of switching between them are evaluated by comparing their respective capital and operating costs over their extraction, purification and downstream processing stages. The evaluation will consider three product systems: electricity, hydrogen and ammonia. Each of these products is of key commercial and strategic importance to Australia.

2. Definition and assumptions

Each production system contains an upstream section, where the feedstock is extracted from its natural state and processed into a saleable fuel, and a downstream section, where conversion of feedstock into the end product occurs. The cost of transport from the upstream section to the production section, as well as the distribution of the final product to the market, is not included in the analysis, although the effect of relevant distances and fuel forms are recognized as having a significant influence on fuel and product costs.

The economic parameters examined are capital and operating costs. In the process of substitution, capital costs could be incurred in decommissioning and dismantling, but these are not included in this study. All capital and operating costs are expressed in or adjusted to 2011 Australian dollars (A$). The exchange rate at the year 2011 is used for currency conversions (e.g. 0.9687 A$ for 1 US$) [3].

3. Methodology

In this study, capital and operating costs for the upstream and downstream sections of conventional natural gas, black coal, and coal seam gas systems are estimated using a set of common assumptions (e.g. discount rate). The projects examined in this study are new, greenfield plants with the purpose of replacing existing plants. Firstly, the capital and operating costs of the extraction and purification sections are estimated for all alternatives. This allows the calculation of a transfer price for each purified feedstock for use in the downstream manufacturing process. Transfer prices account for cash operating costs, annualized capital costs and royalties but exclude further margins derived from market opportunities or distribution costs.

Capital costs for a number of Australian upstream projects have been compiled for each feedstock type to ensure reasonable estimates. A baseline project is selected from these projects on the basis of a suitable configuration (e.g. domestic gas rather than LNG exports) and level of supporting detail in cost breakdown and assumptions. The capital costs are accounted for as annualized capital costs over the operating life of the system and calculated using the following equation:

$$A = I_p\left(\frac{i(1+i)^n}{(1+i)^n - 1}\right) \tag{1}$$

Annualized capital costs are added together with the cash operating costs, which consist of feedstock and utility costs, wages, fixed operating costs and administrative, research and marketing costs, to obtain total operating costs. Cash operating costs are calculated based on literature data for technology performance supported by cost assumptions listed in Table 1.

Royalties are paid to the owners of fossil fuel resources, and are integrated into the transfer price of the feedstock. Royalties are calculated as a percentage of the value of production (total revenue less allowable deductions). Based on Australian state government websites [6–8], the royalty rates for petroleum royalties lie between 10.00% and 12.5% of the wellhead value of petroleum produced, while for coal royalties, the percentage is between 6.2% and 8.2% of the mined value of the coal. A mid-point percentage is taken for each feedstock.

Transfer prices for conventional gas, black coal and coal seam gas were derived from data outlined in Table 1. The production capacities for each product system were brought to a common basis in MW (electricity) or tonnes per year (hydrogen and ammonia), independent of the feedstock.

It was assumed that the capital cost of upstream and downstream processing plants can be adjusted to account for variations in capacity using Eq. (2), and adopting a value of $b = 0.7$ as outlined in Table 1.

$$I_p = I_r\left(\frac{Q_p}{Q_r}\right)^b \tag{2}$$

The operating costs for all process plants are calculated using a conventional operating cost model and the economic parameters from Table 1.

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