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Monte-Carlo simulation of investment integrity and value for power-plants with carbon-capture

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ABSTRACT

Reducing CO_2-emissions from electricity-generating power-plants is a high priority. Several advanced low-carbon power-plants have gained wide acceptance. Uncertainties concerning future costs and performances of new pertinent technologies and unit fuel-prices as well as the types and the comprehensiveness of CO_2-emissions regulations exacerbate the difficulty of selecting promising candidates to be considered for future investments. A computer-based Monte-Carlo simulation technique has been devised to help choose the best technology for financial investments: it allows for the stated uncertainties and assesses the trade-offs between expected returns and the key risks imposed on decision makers. The economic-modelling methodology is described. The computer-based model assesses the investment in a new low-carbon integrated reforming combined-cycle (IRCC) power-plant. The worthwhileness of this financial investment is evaluated in terms of net present-value (NPV), internal rate-of-return (IRR) and pay-back period (PBP).

1. Introduction

The main contributor to the total anthropogenic rate of CO_2 emission is the electric-power-generation industry [1,2]. According to the Stern Review, "the power sector around the world will have to be at least 60%, and perhaps as much as 75%, decarbonised by 2050" in order to achieve sustainable CO_2-concentrations in the atmosphere [2].

Carbon capture and storage (CCS), the most frequently-advocated means for solving this challenge, involves extracting CO_2 at source from power-plants rather than it being expelled into the atmosphere: the CO_2 is then injected into an underground store. This option, if universally adopted, could allow fossil fuels to continue to be combusted without contributing significantly to greenhouse warming [2]. Electricity is currently generated world-wide primarily by combusting fossil-fuels: so they are likely to remain the key contributor to meeting energy-demands [3,4]. Thus, the development and implementation of CCS can represent a major contribution towards inhibiting climate-change, while ensuring energy affordability and security of supply.

Selection of the most promising candidate to pursue for long-term investments is the aim. The power-conversion units (PCUs) envisaged are larger and more complex than currently employed. All options proposed are accompanied by a significant plant-efficiency drop because of the power required for carbon capture and CO_2 compression for its long-term storage. All carbon-abatement systems incur a cost penalty: increased 'product' and operation costs will arise through the reduced overall plant-efficiency, as well as by increased challenges with respect to reliability and availability. Furthermore, most of these CO_2-capture techniques have not been developed or optimised originally for this type of application and, although limited commercial uses of some variants are being made, relatively few plants with CO_2-capture currently exist. The reductions in capital-costs per kilowatt output for larger capacities, widely observed and documented for all conventional power-units, are not as yet proven for CCS-based power-plants. Similarly, it is not possible to obtain exact data for the associated Operation and Maintenance (O&M) costs, which are difficult to predict even for conventional power plants [5,6]. The absence of historical antecedents and reference data makes assessing capital costs and O&M costs subject to uncertainties.

The environmental challenges encountered complicate the investment decision: this has introduced another factor, namely the cost that would otherwise be incurred if dealing with the emissions [7]. Although the type and extent of CO_2 emissions regulatory mechanisms are nowadays uncertain in several countries, any investment analysis should include the current and potential future costs of emissions [7]. To compound the complexity of this matter is the volatility of one of the most critical cost-components for any power-plant, namely the future unit-fuel price, which not only introduces a further uncertainty, but affects the relative costs of carbon-abatement opportunities [8,9].

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Nomenclature

ATR	auto-thermal reformer
BESP	break-even selling price
BFW	boiler feed water
C	cost
C_0	base specific cost
CC	combined cycle
CAC	cost of CO_2 avoidance
CCS	carbon capture and storage
CF_t	net cash-flow at the end of year t
CH_4	methane
CHP	combined heat and power
CO	carbon monoxide
CoE	cost of electricity
CO_2	carbon dioxide
$\eta_{\infty,c}$	compressor polytropic efficiency
DCF	discounted cash-flow
ECLIPSE	European Coal Liquefaction Process Simulation and Evaluation
f	scaling factor
GDP	gross domestic product
GT	gas turbine
H_2	hydrogen
HRSG	heat recovery steam generator
i	discount rate
I	initial cost of the investment
IEA	international energy agency
IECM	Integrated Environmental Control Model
IGCC	integrated gasification combined-cycle
IRCC	integrated reforming combined-cycle
IRR	internal rate-of-return
n	project's life (years)
NPV	net present-value
O&M	Operation-and-Maintenance
PBP	pay-back period
PCU	power-conversion unit
POX	partial oxidation
PR	pressure ratio
PSA	pressure swing adsorption
R&D	research & development
S	size
S_0	base size
SMR	steam methane reforming
t	time of the cash-flow
TPC	Total Plant Cost
W	mass flow
WGS	water gas shift

Economic data, concerning the new low-CO_2 emission power-generators, are available, but their reliabilities are uncertain. The absence of a systematic framework for the analyses of economic performances exacerbates the difficulty of the economic assessments [10]. Their various quality levels and the assumptions adopted in the studies complicate the screening of values. Further exacerbating cost-uncertainties is the diversity of currencies adopted in the literature because of the volatilities of currency exchange-rates [11].

A simple but effective computer-based model, for evaluating the worthwhileness of each investment option available for low-carbon power-plants, is presented in this paper. On the basis of the aforementioned issues, the feasibilities of rival plants are considered in probabilistic terms. The uncertainties associated with forecasting future cash-flows, for each project, as arising from the determinations of some key factors (e.g. capital-cost, O&M costs, unit-fuel price and cost of emissions) are modelled by means of a Monte-Carlo simulation.

This report consists of six sections. In the second section, the main methods for the appraisal of advanced low-carbon power-plant investment proposals are reviewed. The third section presents the economic modelling methodology, with emphasis on the Monte-Carlo method, and describes the issues that the model considers. The potential for the model to be used in advanced low-carbon project assessments is demonstrated through a case-study, to which the fourth section is dedicated. The data used and the assumptions made are explained in the fifth section, which also reports and discusses the main results. In the sixth section, the main findings of the study are summarised.

2. Appraisals of advanced low-carbon power plant investment proposals

Before undertaking an investment in a low-carbon power-technology, its cost effectiveness needs to be ascertained [7,12,13]. One method that can facilitate the decision-making process is the so-called "discounted cash-flow technique" (DCF) [14]. This approach takes into account the time-dependent value of money and involves predicting cash inflows and outflows for the project over its whole lifespan. All cash-inflows and -outflows that happen in the future are discounted back to their present-worth values at the beginning of the project. One of the advantages of DCF is its ability to quantify the relative merits of even complex and large-scale investments in single parameters (e.g. NPV) [15].

On the other hand, DCF has its own limitations in dealing with risks and uncertainties. The approach widely employed in investment-appraisals involves calculating a "best estimate" for each input variable (capital-cost, O&M costs and so on) based on the available information and using it in the evaluation model [13]. By doing so, it is assumed that it is possible to associate, with each input of significance, a single value and that such values used in the assessment are precise. The result of the project is then presented as accurate with no error associated with it. However, actual cash-flows can differ considerably from the forecasted ones [15–17]. Uncertainties arise concerning costs, unit-prices, completion periods and the achievement levels attained for the original objectives, and so cannot be accurately summarised by a single value. There can be an artificial compensation for the volatility of the project being considered by increasing the discount rate used in the analysis: thus all the uncertainties are simply channelled through the discount rate. However, the reliability of the analysis itself is then reduced.

The inappropriateness of the DCF method alone to evaluate advanced low-carbon power-plant options has resulted in several authors adopting different approaches, such as sensitivity analysis and scenario analysis.

The economic performance of CCS-power plants has been widely analysed previously using sensitivity analysis [18,19]. This involves varying the value of each variable in order to determine its impact on the final outcome. Among all the examples available in the open literature, is the so-called ECLIPSE (European Coal Liquefaction Process Simulation and Evaluation) process simulator, a tool widely used for the full technical and economic analyses of fuel conversion and power-generation systems (with or without CO_2-capture). Developed by the Energy Research Centre for the European Commission [20], the ECLIPSE simulator offers the user