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Economic Feasibility Analysis of Oil Industry Chain with CCUS Technology

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Abstract: In the short term, the petrochemical industry remains highly energy- and carbon-intensive, and the widespread adoption of CCUS(Carbon Capture, Utilization and Storage) is severely limited by the prohibitive cost of implementing CCUS technology and the inherent uncertainties. Thus, in the context of the pursuit of carbon neutrality, it is essential to examine the entire CCUS process in oil industry chain to provide pragmatic insights as a guide for professionals, investors, and decision makers. Therefore, the authors propose an integrated system dynamics model related to the entire process of oil industry chain introducing CCUS technology and establish a simulation model combining subsidy and carbon tax scenarios to analyze the dynamic trends of the long-term economic feasibility of oil industry chain introducing CCUS technology. The results show that excessive increase or reduction of subsidies and carbon tax incentives will affect the change of CO_2 emission reduction rate and profits. When subsidies and carbon taxes are reduced by 25% in the baseline scenario, the oil industry chain will be more beneficial. Governments and enterprises should set incentives appropriately to ensure that the appropriate balance between economic viability and environmental sustainability is found.

1. Introduction

In recent years, an increasing number of CCUS(Carbon Capture, Utilization and Storage) field application projects have been proposed and developed in foreign countries and China[1,2], These efforts have made significant contributions to the promotion of national sustainable development and addressing climate change. Most of the investigations have examined single considerations of energy or environmental benefits, lacking a complete and comprehensive evaluation system. Although CCUS technology[3] and system dynamics(SD)[4] have been widely applied in various fields, limited research has used SD to investigate CCUS. Due to the complex feedback effect inside the system, it is difficult to accurately and quickly calculate the cost of CCUS during the whole operation period through traditional models, but SD is helpful for modeling complex phenomena, simulation and analysis of nonlinear behavior changes over time, which is very suitable for predicting complex systems under uncertain conditions, Yao, X., et al used the SD approach to analyze the technical and economic feasibility of implementing carbon capture in the iron and steel industry from a comprehensive process perspective[5]. Ye, J., et al investigated using the SD approach to compare the economic viability, operational stability, and CO_2 emissions reduction effectiveness of CCUS in vertical integration and CCUS operator models[6]. Early studies of CCUS technology primarily concentrated on assessing the economic and technical feasibility, primarily by employing the traditional net present value method to analyze the costs and benefits of CCUS projects[7].Previous analyses of the costs and benefits of CCUS investment have not considered the close interconnections between the components of complex CCUS systems, leaving room for improvement regarding the following concerns. First, previous research has focused on analyzing the economics of CO_2 captured in high-energy-consuming enterprises, and minimal literature has presented systematic studies of the economics of the entire CCUS process in the refining industry. Second, a majority of the existing literature has evaluated specific influencing coefficients, there are few studies have employed the SD approach to comprehensively evaluate system in terms of CCUS economics. Finally, most of the investigations have examined single considerations of energy or environmental benefits, lacking a complete and comprehensive evaluation system. Thus, in the context of the pursuit of carbon neutrality, it is essential to examine the entire CCUS process in oil industry chain to provide pragmatic insights as a guide for professionals, investors, and decision makers.

2. Methodology

Referring to *Y. Xinyan*, et al., the technical feasibility model of introducing carbon capture was analyzed from the perspective of the whole steel process, and the system dynamics model of the petroleum industry chain with the introduction of CCUS technology was constructed[5]. This study proposes an SD model to examine an oil industry chain's introduction of CCUS technology, constructing a Casual Loop Diagram(CLD) and a Stock Flow Diagram(SFD) for the entire oil industry chain process, and establishing a simulation framework to analyze the dynamic trends in the economic viability of the oil industry chain introducing CCUS technology over 25 years. The constructed CLD (Fig. 1).and SFD (Fig. 2) are shown below.

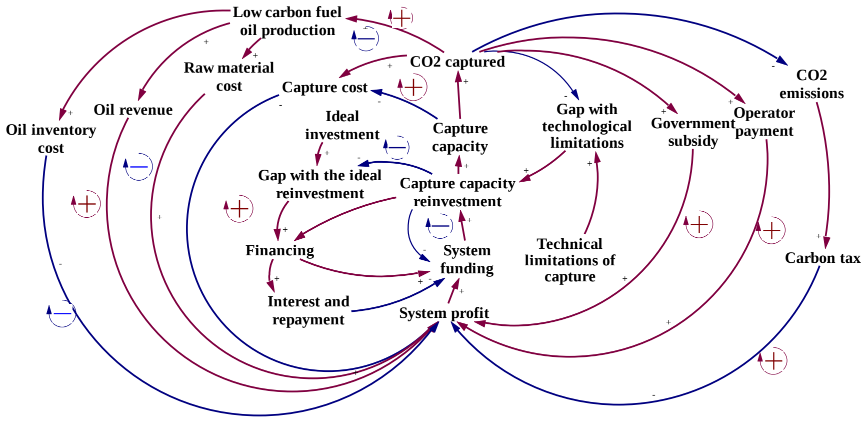

Figure 1: Causal loop diagram of oil industry chain

In order to simplify the analysis, it is assumed that there is no secondary leakage of captured CO_2, like coal-fired power plants and steel mills, upstream and downstream will also have an impact on the funding for the introduction of carbon capture technologies and systems in the oil chain. From the upstream perspective, the extraction of crude oil also affects the implementation of carbon capture. The initial operation of the system tends to utilize some of the lighter crudes that are easier to extract, reducing the cost of extraction, while the extraction of lighter crudes reduces the CO_2 emitted directly from production, and thus reduces the carbon tax. The economics of capturing CO_2 is to sell the captured CO_2 mainly to EOR projects or related industry consumers and store the rest. Downstream oil processing and wholesale and retail sales of refined products also increase system revenues. By introducing CCUS technology, the downstream of the petroleum industry chain can produce low carbon fuel oils, it can be used in the upstream oil well extraction and refining process, reducing raw material costs, carbon emissions and environmental impacts. The introduction of CCUS technology can also be used to optimize the oil refining process to produce cleaner and lower carbon crude oil and petroleum products. These products can be used upstream to improve the efficiency of oil well extraction and reduce CO_2 emissions. Part of the model formula is as follows:

1) Government subsidy = (Carbon tax + Social welfare * Subsidy coefficient)* Refinery subsidy coefficient

2) Carbon tax = CO_2 emissions * Carbon tax rate

3) CO_2 captured = function (CO_2 capture willingness, Capture capacity, Operating capacity, Theoretical CO_2 emissions)

4) Theoretical CO_2 emissions = Petroleum production * Carbon intensity per unit of petroleum production

5) CO_2 emissions = theoretical CO_2 emissions - CO_2 captured

6) System profit = Added low carbon fuel oil revenue + Operator payment + Government subsidy - Raw material cost - CO_2 capture cost - Oil inventory cost - Carbon tax

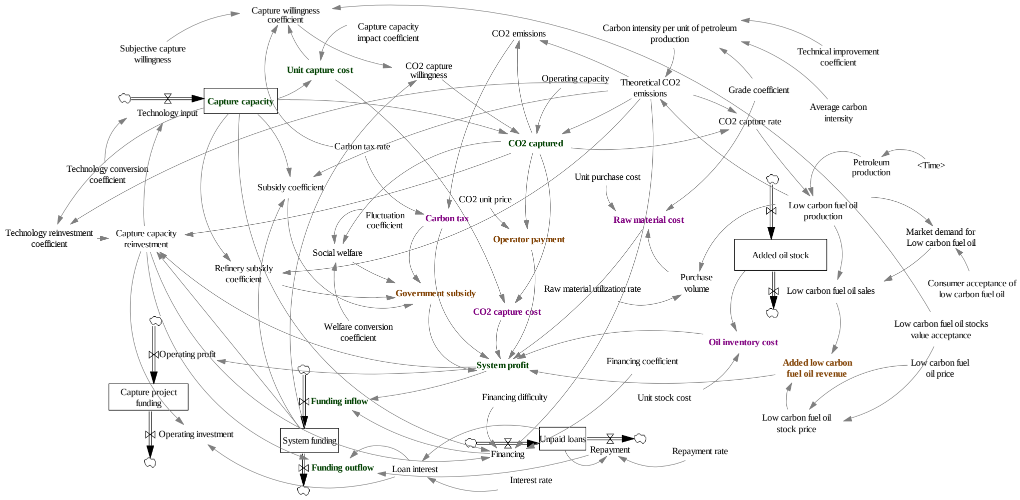

Figure 2: Stock-flow diagram of oil industry chain

3. Result and discuss

In the base scenario (subsidy factor +25%, carbon tax +25%), CO_2 emissions can achieve steady operation, the system profit can be as high as 2.71B $, and the system profit is stable at 360 M$/Month, this study sets two final scenarios, including the refinery subsidy coefficient -50%, carbon tax rate -50% (Scenario 1), and the refinery subsidy coefficient +50%, carbon tax rate +50% (Scenario 2) to analyze the trend of economic changes in the system.

The low level of subsidy and tax rates in Scenario 1 imply weak economic incentives for firms to introduce CCUS technologies (Fig. 3). System faces high investment costs when introducing CCUS technology, and if subsidy is low or non-existent and the carbon tax rate is low, enterprises do not have sufficient incentives to introduce carbon capture technology, and enterprises do not have sufficient economic incentives to bear these costs. This reduces system' willingness to introduce CCUS technology, making the incremental amount of CO_2 capture is small, but in the later stages of system operation CO_2 emissions can still be maintained at steady-state emissions. After the 66th month, system funding is already higher than the funding required for the capture project. In addition, the system requires a steady stream of financing as the capture capacity is reinvested, but in the later stages of the system's operation, there is no need for financing and no outstanding loans, and the system can realize a positive return in the later stages of operation if it is operated for a long enough period. Therefore, the system can still be commercialized in this scenario.

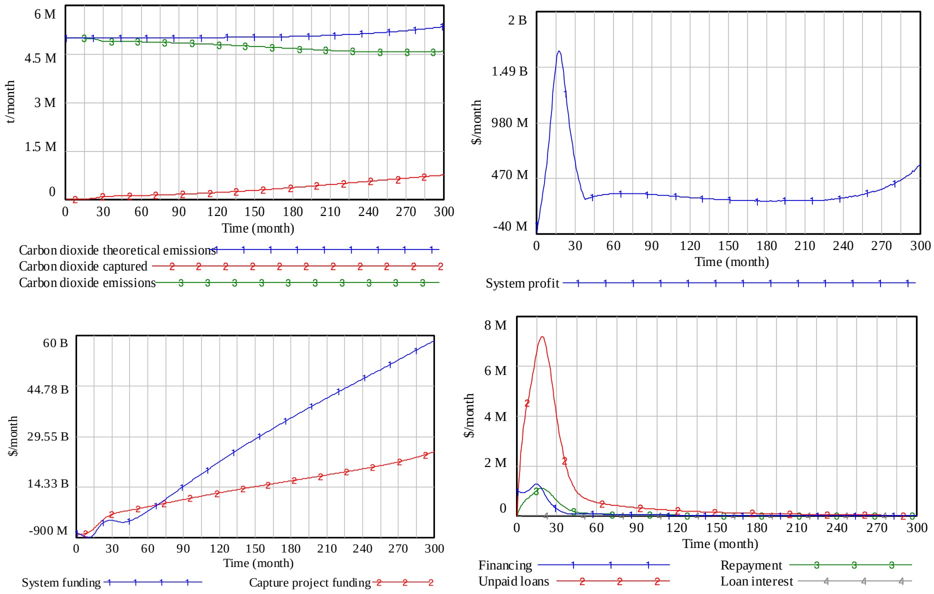

Figure 3: Dynamic changes of environmental and economic indicators under scenario 1

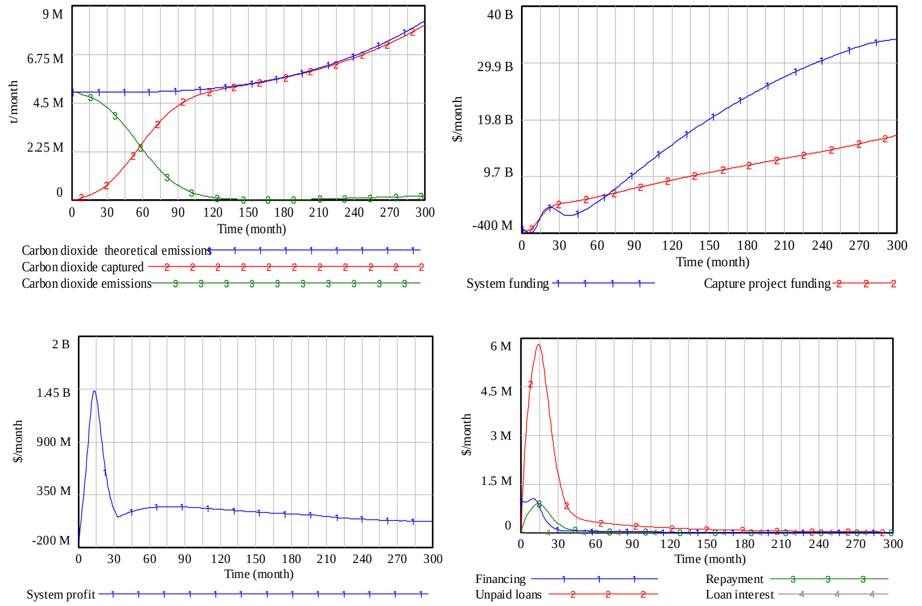

Figure 4: Dynamic changes of environmental and economic indicators under scenario 2

The combined scenario of high government subsidy and high tax rates can encourage system to continuously improve the capabilities and effectiveness of CO_2 capture technologies (Fig. 4). With continuous technology improvement and optimization, system can be motivated to reduce CO_2 emissions significantly, with CO_2 capture approaching its theoretical emissions near the 142nd month of system operation and emissions stabilizing within the [1.4, 2.8] Mt/month range, significantly advancing progress toward sustainable development and combating climate change. In addition, under the high-intensity policy incentives, although the frequency and amount of financing are low, the system no longer needs to be financed at month 130, and there are no more outstanding loans at month 250, but system profit are much lower than scenario 1, and the combined scenario of high subsidy and high tax rates further increases the financial burden on the government and firms, which results in a waste of funding to some extent.

4. Conclusion

In this study, the authors provide a simulation framework by constructing a comprehensive SD model to analyze the dynamic trends of the long-term economic viability of system introducing CCUS technology. Indiscriminately increasing or decreasing incentives will affect CO_2 capture and emissions reduction rates and the change in profit. The government and enterprises should establish reasonable incentives and consider multiple coefficients when formulating relevant policies to ensure that a suitable balance is found between economic feasibility and environmental sustainability and encourage system to adopt other emissions reduction measures along with the introduction of CCUS technology to promote the development of more environmentally friendly and efficient CCUS technology.

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