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Evaluation of the ocean ecosystem: Climate change modelling with backstop technologies

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HIGHLIGHTS

- A new model, the CEEM, is developed for analysing the impact of climate change on ecosystems.
- The model chooses the best technology endogenously.
- The model considers the utility decrease by ecosystem damages.
- To achieve strict targets, we might end up employing a technology that sacrifices the ecosystem.

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ABSTRACT

This paper discusses the economic impacts of climate change, including those on ecosystems, and whether a new backstop technology should be used under conditions of strict temperature targets. Using the dynamic integrated climate-economy (DICE) model, we developed a new model to calculate the optimal path by considering new backstop technologies, such as CO_2 capture and storage (CCS). We identify the effects of parameter changes based on the resulting differences in CO_2 leakage and sites, and we analyse the feasibility of CCS. In addition, we focus on ocean acidification and consider the impact on economic activity. As a result, when CCS is assumed to carry a risk of CO_2 leakage and acidification is considered to result in a decrease in utility, we find that CCS can only delay the effects of climate change, but its use is necessary to achieve strict targets, such as a 1.5 °C limit. This observation suggests that if the target temperature is too tight, we might end up employing a technology that sacrifices the ecosystem too greatly.

1. Introduction

The possibility of global warming began to be considered near the end of the 20th century, and global warming is now recognized as a problem throughout the world. In 1992, the United Nations Conference on Environment and Development (UNCED) was held in Rio de Janeiro, and the United Nations Framework Convention on Climate Change (UNFCCC) was adopted. The Intergovernmental Panel on Climate Change (IPCC) recommended that the average temperature increase should be kept to less than 2 degrees in the IPCC Fifth Assessment Report [1]. Moreover, a 1.5-degree limit was cited as a target at the 2015 United Nations Climate Change Conference (COP21) held in Paris in 2015.

The impacts of increasing temperature have been analysed by many researchers [2–4]. Recently, it has been reported that an increase in the average temperature is associated with climatic drought risks [5], coastal flood risks [6] and human health risks [7,8]. Parry et al. [9] noted that the various risks increase rapidly when the temperature increase is approximately 1.5–2 deg. Warren [10] warned of the impacts of an increasing average temperature on the ecosystem. It was suggested that a 1-degree increase in temperature may induce a 10% ecosystem transformation and a loss in cereal production of 20–35 million tons, that a 2-degree increase in temperature may induce a 97% loss of coral reefs, and so forth. Moreover, few ecosystems may be able to adapt to an increase in temperature of more than 3 deg. These risks are present, and we must take measures to rapidly mitigate or adapt to them.

In addition to evaluations of the individual risks, integrated evaluations of climate change have been presented. Cline [11,12] conducted a cost-benefit analysis of climate change, considering environmental loss, human life, disasters, water supply, and so forth. Based on the results of this analysis, Cline concluded that an aggressive policy that would require cutbacks of 70% of predicted emission by the middle of this century can be justified. Moreover, Stern et al. [13] claimed that

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Nomenclature

Abbreviations

BECCS	bio-energy with CO_2 capture and storage
BT1	conventional backstop technology
BT2	CCS-type backstop technology
CCS	CO_2 capture and storage
COP21	2015 United Nations Climate Change Conference
GHGs	greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
SCC	social cost of carbon
TFP	total factor productivity
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change

Models

AD-DICE	adaptation in DICE
CEEM	dynamic integrated climate-ecosystem-economy model
DICE	dynamic integrated climate-economy
ENTICE	endogenous technological change in DICE
IAMs	integrated assessment models

the benefits of strong early action are greater than the costs of no action.

By contrast, Nordhaus took a more optimistic stance on climatic change, based on his DICE model [14]. This model can comprehensively analyse economic impacts while considering dynamic CO_2 circulation.[1] The model indicates that long-term, continuous reduction of CO_2 emissions is preferable to a large, abrupt reduction in the near future.

The causes of these conflicting conclusions include the magnitude of the discount rate, the uncertainty or ambiguity of the parameters, and the irreversibility of climate change. The conservative stance of the DICE model is often criticized. Kaufmann [16] reported that the DICE model contains unsupported assumptions, simple extrapolations, and misspecifications and that it consequently underestimates the effects of climate change. The robustness of the DICE model with respect to ambiguity was assessed by Hu et al. [17]. [17] observed that the ineffectiveness noted by Nordhaus is significantly increased when the ambiguity of distribution is considered but insisted that a lack of any emission control policies may carry a high risk and doing nothing is by no means a rational response. Other researchers have extended the DICE model in various directions to achieve greater realism. For example, De Bruin et al. [18] developed the AD-DICE model by introducing adaptation as another control variable. The AD-DICE model can estimate the adaptation costs of climate change by splitting the net damages into residual damages and protection costs. The ENTICE model developed by Popp [19,20] separates energy units from inputs and treats technological change as an endogenous variable. The uncertainty in the DICE model with regard to the level of damage caused by global warming was also analysed by Traeger [21] and Crost and Traeger [23]. In addition to the DICE model, various other Integrated Assessment Models (IAMs) have also been developed. The features of these models have been summarized by Dowlatabadi [22] and Stanton et al. [24].

These models, such as the DICE model, are classified among the welfare optimization type. Nevertheless, many IAMs use other methodologies; general equilibrium[25], simulation [26–28] and so forth. Welfare optimization models are simple yet transparent, making them suitable for the analysis of conceptual models. In addition, CCS technology investment is evaluated by using real option approach [29]. Also CCS had been introduced to some energy-economic system models [30,31].

This study focuses on the impact on ecosystems or the environment. The DICE model assumes that the technological costs of emission reduction will be reduced in the future by virtue of technical innovations. This assumption is not unsupportable, but new technologies will not necessarily bring only benefits. Some new technologies may carry unknown risks. For example, a mitigation technique known as CO_2 capture and storage (CCS) has recently been attracting attention. CCS is a method based on capturing waste CO_2, such as that from power plants, and transporting it to deep underground storage areas. According to Metz et al. [32], CCS could reduce global emissions by 9–12% by 2020 and 21–45% by 2050. The GlobalCCSInstitute [33] reports that in sectors with high-concentration gas streams (natural gas processing sector, ammonia/fertiliser production sector, bio-ethanol production sector, hydrogen production sector, iron and steel production sector), large-scale CO_2 capture projects are underway. Three principal types of capture technologies are used; pre-combustion, oxyfuel combustion, and post-combustion. These technologies have been analysed, and their impacts and efficiencies were reported [34–36]. The optimal technology is selected and implemented according to the physical properties of CO_2 emitted from each emission source across several industries. For example, post-combustion technology is used to capture CO_2 in the cement industry [37], and with pre-combustion being used in industrial processes, such as natural gas [38] and oil [39]. In addition, the technology of bio-energy with carbon capture and storage (BECCS) [40], which combines CCS technology in biomass power plants or biofuel manufacturing processes, has also attracted attention. The energy potential and cost-effectiveness of negative emissions have been assessed by many researchers [41,42].[2]

However, some researchers are concerned about the possibility of CO_2 leakage. Such leakage may cause local ocean acidification [43] and may impact the biodiversity of marine life [44]. Currently, CCS is still expensive, but its cost is expected to decrease to a feasible level in the future. At that time, it will be necessary to decide whether to adopt this technology. To determine the best among the possible technologies, it will be important to assess the effects that we may suffer from their unknown risks. Efforts have been made to perform comprehensive evaluations of CCS at the plant and macroeconomic levels [45–50].

Moreover, we cannot overlook the potential damage to the ecosystem. Although we do not have a detailed picture of the services provided by the ecosystem and their value because of the complexity and vastness of the ecosystem, many researchers have presented estimates. For example, the value of ecosystem services as estimated by Costanza et al. [51] and Balmford et al. [52] is in the range of US$ 16–54 trillion per year. Focusing on commercial value, Narita et al. [53] reported that the global economic costs of mollusc loss from ocean acidification may be more than US$ 100 billion if the mollusc demand increases with future income rise.

With these studies in mind, we attempt to determine whether technologies that reduce CO_2 but carry ecosystem pollution risks should be used under conditions of strict temperature targets. To address this question, we modify the DICE model accordingly and analyse the temperature targets. The three main contributions of this study can be summarized as follows. The first contribution is a modification of the DICE model. By addressing several backstop technologies, we consider the possible effects of introducing technologies such as CCS. We show

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[1] Nordhaus later improved the dynamic CO_2 circulation model and several functions of the DICE model and was able to calculate more realistic economic impacts [15].

[2] Our research does not deal with the difference of technologies, but such differences are important and should be introduced into future models.