CO_2 removal and 1.5°C: Sharing the Gains from Inter-regional Cooperation using a Game-Theoretic Approach

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Overview

To limit global warming, humanity will most likely have to become carbon negative by the end of the century (IPCC, 2022). In other words, more CO2 should be removed from the atmosphere than emitted. To that aim, research on Carbon Dioxide Removal (CDR) methods is gaining momentum (twelve methods are cited in IPCC's 2022 report on mitigation pathways: Pathak et al., 2022). In particular, Afforestation/Reforestation (AR) (Canadell and Raupach, 2008), Bioenergy with Carbon Capture and Storage, (BECCS) (Gough and Upham, 2011), and Direct Air Carbon Capture and Storage (DACCS) (Keith et al., 2018) are increasingly represented in Integrated Assessment Models (IAMs) (Minx et al., 2018).

Under 1.5°C scenarios, IAMs require 190 to 1,190 GtCO2 CDR by 2100 (Huppmann et al., 2018; Rogelj et al., 2018). To illustrate, 1,190 GtCO2 CDR is equivalent to removing 33 times our current annual emissions from the atmosphere (IEA, 2021). These large scale projections have raised concerns concerning competition for resources, biodiversity, and social justice (Fajardy et al., 2018; Fuss et al., 2018; Heck et al., 2018; Smith et al., 2016). More research on sustainability bounded CDR pathways is required (Fuss et al., 2018). Additionally, IAMs usually rely on a global cost-optimization, thereby implicitly positing that a benevolent social planner controls all CDR investments. In practice, the incentives to invest in CDR vary greatly by country due to their common but differentiated responsibility towards climate change. Hence, the previously mentioned CDR projections rely on successful international cooperation (Fajardy and Mac Dowell, 2020). Chiquier et al. (2022) show that, without international cooperation, it becomes less likely to deploy CDR to levels compatible with the Paris Agreement, and the related costs rise by 51–69%.

The Paris Agreement acknowledges the necessity for international cooperation. Article 6 outlines how countries may "pursue voluntary cooperation" to meet their climate targets, and Article 6.2. lays down the foundations for exchanging emission reductions and removals through bilateral or multilateral agreements between countries. The resulting credits are named Internationally Transferred Mitigation Outcomes (ITMOs). ITMOs would make it possible for countries to account for carbon removal that takes place in other countries in their own climate target (or Nationally Determined Contribution). While these deployments are encouraging, the possibility of exchanging carbon removal credits is not sufficient to ensure cooperation: the gains from cooperation must also be shared in a mutually acceptable manner for multilateral agreements to succeed.

The purpose of this paper is to examine whether international cooperation is feasible to deploy CDR at levels compatible with the Paris Agreement. Specifically, we assess whether the gains from international cooperation can be shared in an incentive-compatible manner.

Methods

We propose an original combination of two markedly different tools. The first one is the previously developed Modelling and Optimization of Negative Emissions Technologies (MONET) framework that is stemmed from the engineering literature (Chiquier et al., 2022; Fajardy et al., 2018). The MONET model provides a large-scale computerized dynamic representation of CDR deployment, with a particular focus on AR, BECCS and DACCS. MONET is a deterministic, discrete-time, finite-horizon model that is formulated as a linear-programming problem solved numerically. Using this optimization model, a series of simulations under different scenarios are conducted to determine the least-cost CDR deployment for any subgroup of countries, which are: Brazil, China, the United Kingdom (UK), the European Union (EU), and the United States of America (USA). These results obtained with MONET are then combined with our second tool: cost-sharing notions drawn from the theory of cooperative game. For cooperative games, various solutions have been proposed to share cost in a mutually acceptable and fair manner. In this paper, we compare several standard classical solution concepts from cooperative game theory – the core, the Shapley value, and variants of the nucleolus – to investigate how the cost of future CDR deployment should be apportioned among countries in the event of cooperation.

Results

Our analysis provides four highlights. First, we repeat that international cooperation leads to substantial cost reduction in deploying CDR to levels compatible with the Paris Agreement. Second, our case study shows that substantial financial transfers need to be directed towards Brazil in China for cooperation to be possible (see Table 1). Third, we illustrate the importance and complexity of designing fair and mutually acceptable cost allocations to ensure the success of international cooperation. Finally, we discuss whether the transaction costs related to cooperation can be covered.

Table 1: Overview of 2100 CO_2 removals and costs in the standalone and cooperation scenario.

	Brazil	**China**	**EU**	**UK**	**USA**	**Total**
CDR ($GtCO_2$)						
Standalone scenario	7	56	64	15[a]	87	228
Cooperation scenario	43	98	41	2	47	231
Cost of CDR (billion $)						
Standalone scenario	48	251	1,646	2,946[a]	3,398	8,289
Cooperation under the Shapley value cost allocation	-819	-567	1,115	932	2,027	2,689
Relative cost reductions[c]	1,788 %	326 %	32 %	68 %	40 %	5,601

[a] The UK doesn't meet its individual 2100 CDR target in its standalone coalition.
[b] In the grand coalition, the cost allocated to each region depends from the chosen allocation. These are presented in the next sections.
[c] The cost reduction induced by cooperation for a region i is defined as the difference between the cost x_i allocated to region $\{i\}$ under the Shapley value approach and the cost $C(\{i\})$ faced by the region $\{i\}$ in the standalone scenario. The relative cost reduction is hence: $\frac{C(\{i\})-x_i}{C(\{i\})}$

Conclusions

At an empirical level, this paper contributes to the small, and very much needed, literature attempting to shed light on the economics of international cooperation in deploying CDR (Chiquier et al., 2022; Fajardy and Mac Dowell, 2020). Other related works, though more loosely connected to our methodology and not focused on CDR deployment, have explored the formation of "climate clubs" and environmental coalitions (Botteon and Carraro, 1997; Carraro and Siniscalco, 1998; Luqman et al., 2019; Stua et al., 2022; Wu and Thill, 2018). This paper represents the very first application of notions rooted in cooperative game theory to the case of international CDR deployment. The present paper proposes an original approach that combines an engineering perspective with concepts drawn from the theory of cooperative games. Indeed, we apply the MONET model – a detailed engineering-based representation of least-cost CDR future deployments – to evaluate the cost data needed to apply standard solution concepts proposed in game theory. We highlight the importance of cost-sharing in the success of international cooperation in deploying CDR.

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