Advances in negative emissions technologies generate heterogeneous knowledge spillovers

Keywords: Science of science, Knowledge spillovers, Climate change, Networks, Innovation

Extended Abstract

Negative emissions technologies (NETs) are essential to meet the Paris Agreement and halt climate change. However, their maturity and desirability are highly debated [7]. In most scenarios, the transition toward net zero emissions will require the extensive deployment of NETs to balance the inevitable difficulties of cutting short-term emissions even more drastically [8]. Furthermore, NETs might contribute to smooth the so-called green transition, which will prove challenging from an economic, social, technological, and political perspective.

Unfortunately, to date, NETs do not yet represent fully developed technologies ready to be deployed at scale; research and innovation will be key to turn these technologies into practical options. Against this backdrop, we use an innovation network perspective or, more precisely, a science of science perspective to quantify knowledge spillovers from NETs scientific advances within and beyond the academic realm [3, 2]. Because tackling climate change requires basic scientific research, practical innovation, and political support, we move beyond standard citation counts in our analysis [1, 9, 10]. Hence, in addition to collecting all NET-related articles from the Web of Science (WoS), using keywords in titles and abstracts, we retrieve information from patents, policy documents, and media outlets (by incorporating different data sources: Reliance on Science, Microsoft Academic graph, and Altmetric).

We focus on eight major NET domains: Afforestation and Reforestation (AR), Bio-energy with Cabon Capture and Storage (BECCS), Biochar, Blue carbon (BC), Direct Air Capture (DAC), Enhanced weathering (EW), Ocean fertilization (OF), and Soil carbon sequestration (SCS).

The main goal of our analysis is to quantify knowledge spillovers from research in NETs by estimating the likelihood that scientific advances across these eight carbon removal solutions stimulate (i) further production of knowledge, (ii) technological innovation, and (iii) policy and public discussion.

Leveraging methods developed in the innovation and applied economics literature, we measure knowledge spillovers by analyzing citation networks reconstructed using the last 20 years of data on scientific production. We ensure stability by constructing 30 suitable baseline control groups, including articles published in the same year and the same journal, not directly related to NETs. In addition, to better characterize the role of NETs within the broader climate change academic debate, we construct a second set of control groups (i.e., climate control), following the same strategy yet restricting to the climate change literature.

Our results suggest that NETs-related research generates significant, positive knowledge spillovers within science and from science to technology and policy. However, significant differences exist across carbon removal solutions. For instance, Direct Air Capture (DAC) is the only option linked to practical technological innovation, while Bio-energy with Carbon Capture and Storage (BECCS) appears to lag. Interestingly, policymakers tend to overlook advances in DAC, focusing on solutions such as BECCS and Blue Carbon (BC). See Figure 1 for more details. Finally, we also study the spatial distribution of NET-related research with network analysis tools, identifying cities and countries that can serve as research hubs for supporting future collaborations.

From a policy perspective, our findings provide at least two clear insights. First, when considering the applicability of a diversified portfolio of NETs, their knowledge base, spillovers, and development trajectory should be considered carefully. Indeed, our analysis supports evidence of little synergies between various NETs, and suggests the existence of coordination gaps between science, technology, and policy. Second, given the current distance of negative emissions research from the technological frontier, the prospective diffusion of NETs at scale would benefit from both conventional and unconventional innovation policies [6, 5, 4] Innovation can play an essential role in dealing with the climate change crisis; however, science, technology, and policy must be better coordinated to boost the efficacy of research endeavors.

References

[1] Mohammad Ahmadpoor and Benjamin F Jones. "The dual frontier: Patented inventions and prior scientific advance". In: *Science* 357.6351 (2017), pp. 583–587.

[2] Antoine Dechezleprêtre, Ralf Martin, and Myra Mohnen. *Knowledge spillovers from clean and dirty technologies: A patent citation analysis*. Grantham Research Institute on Climate Change and the Environment, 2013.

[3] Santo Fortunato et al. "Science of science". In: *Science* 359.6379 (2018), eaao0185.

[4] Daniel P Gross and Bhaven N Sampat. "The economics of crisis innovation policy: A historical perspective". In: *AEA Papers and Proceedings*. Vol. 111. 2021, pp. 346–50.

[5] Ryan Hanna et al. "Emergency deployment of direct air capture as a response to the climate crisis". In: *Nature communications* 12.1 (2021), pp. 1–13.

[6] Jonas Meckling and Bentley B Allan. "The evolution of ideas in global climate policy". In: *Nature Climate Change* 10.5 (2020), pp. 434–438.

[7] P.R. Shukla et al. *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. 2022.

[8] Detlef P Van Vuuren et al. "Open discussion of negative emissions is urgently needed". In: *Nature energy* 2.12 (2017), pp. 902–904.

[9] Yian Yin et al. "Coevolution of policy and science during the pandemic". In: *Science* 371.6525 (2021), pp. 128–130.

[10] Yian Yin et al. "Public use and public funding of science". en. In: *Nature Human Behaviour* (July 2022). Publisher: Nature Publishing Group, pp. 1–7. ISSN: 2397-3374. DOI: 10.1038/s41562-022-01397-5. URL: https://www.nature.com/articles/s41562-022-01397-5 (visited on 07/11/2022).

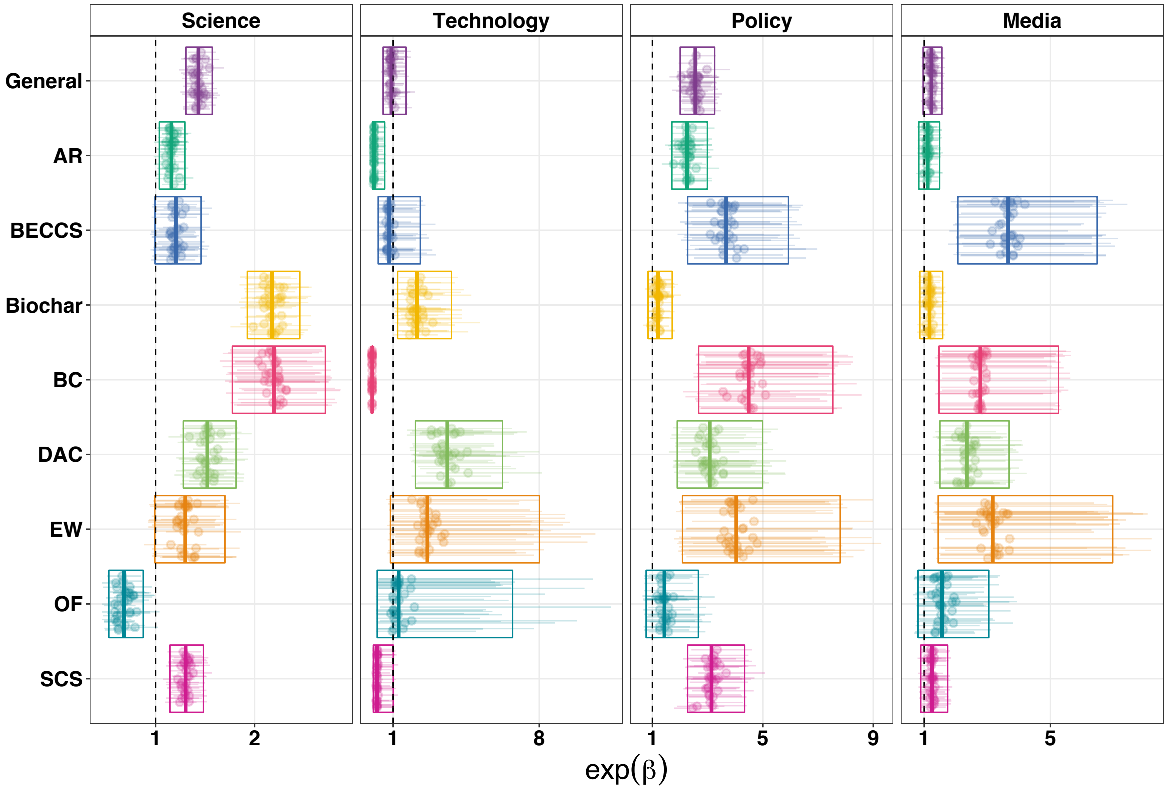

Figure 1: **NETs spillovers to science, technology, policy and media**. Coefficients (exponentiated) of the regression models. Results are obtained by fitting 30 negative binomial regressions (**Science**) and 30 logistic regressions (**Technology-Policy-Media**) on one-to-one matched samples with year dummies and control variables. **(Science)** Incident Rate Ratio (IRR) for each NET on the number of scientific citations. **(Technology)** Odds Ratio (OR) for each NET on the probability of being cited by a patent (BC estimates set to zero since there is no patent documents citing BC papers). **(Policy)** Odds Ratio (OR) for each NET on the probability of being cited by a policy document. **(Media)** Odds Ratio (OR) for each NET on the probability of being cited by a media (or social media) outlet.