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EAERE Magazine

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EAERE
European Association of Environmental and Resource Economists

EAERE Magazine serves as an outlet for new research, projects, and other professional news, featuring articles that can contribute to recent policy discussions and developments in the field of environmental and natural resource economics. It is published quarterly in the Winter, Spring, Summer, and Fall. Contributions from the wider EAERE community, especially senior level researchers and practitioners, and EAERE Country Representatives, are included in the magazine.

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Dear EAERE friends and colleagues,

This issue will be the last issue of this year, which has been a very complicated year and may bring more complications in the remaining two months.

This issue is dedicated to the researchers who have been awarded with an EAERE Award this year and who couldn't be celebrated at the EAERE conference as usual.

We start with **Antoine Dechezleprêtre**, Environment Directorate and Economics Department at OECD and winner of the European Award for Researchers in Environmental Economics under the Age of Forty, who writes about the challenges that the current COVID-19 crisis poses for the climate change crisis. We then have contributions from three recent ERC Grantees, **Ulrich Wagner** from the University of Mannheim, winner of an ERC Consolidator Grant, **Emanuele Campiglio** from the University of Bologna, winner of an ERC Starting Grant, and **Elena Verdolini** from the University of Brescia, winner of an ERC Starting Grant, who present their research projects. Reading about their work not only gives an impression of the research activities in our association but is also especially interesting for young researchers who toy with the idea of writing an ERC proposal. Finally, **Luis Peña-Lévano** from the University of Florida and **Farzad Taheripour** from Purdue University present their article on forest sequestration, food security and climate change, for which they received the EAERE Award for Outstanding Publication in ERE.

Enjoy reading,

Astrid Dannenberg

COVID-19 and the low-carbon transition[1]

Antoine Dechezleprêtre
OECD and London School of Economics

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The COVID-19 and climate challenges

The COVID-19 crisis is an enormous challenge to economies and societies across the world. The first priority for governments has been to deal with the health crisis and save lives and, as containment measures have resulted in a drop in economic activity without precedent in recent history, to adopt support policies that minimise the destruction of jobs and income. However, the magnitude and urgency of the crisis should not let us lose sight of other challenges. In fact, the COVID-19 crisis is a reminder of how vulnerable we are to high-impact global shocks such as natural disasters triggered by climate change, and of the important role of public policies in mitigating the risks by reducing greenhouse gas emissions. The massive drop in air pollution levels during the lockdowns also gave us a glimpse of how a cleaner world could look like. Therefore, the crisis must not derail global efforts to address climate change, but should instead encourage policymakers to shape the recovery in ways that are consistent with strategies to reduce greenhouse gas emissions.

Temporary emissions reductions

The lockdowns imposed across the planet have caused large reductions in CO_2 emissions from transportation and industrial activity. The IEA expects global CO2 emissions to decline by 8% in 2020 compared to 2019 (IEA, 2020). This temporary drop in emissions, however, will be inconsequential for climate change unless followed up with strong policy action. Past crises, including the 2008 Global Financial Crisis (GFC), show that economic recoveries are typically associated with stronger emission growth, compensating for the initial downfall (Figure 1). The behavioural changes triggered by the pandemic (such as more teleworking and teleconferencing, shortening of global supply chains), even if permanent, are unlikely to be large enough to significantly alter the climate problem.

The COVID-19 crisis puts the low-carbon transition at risk

There is a risk that the crisis might actually make things worse from the climate mitigation point of view. Reducing emissions in the long run requires large investments in low-carbon technologies – both on the innovation and the diffusion side (IPCC, 2018). But the fall in economic activity combined with high economic uncertainty means that firms may lose access to financing, reduce or postpone investment, including in innovation (Baker et al., 2020). At the same time, the COVID-19 crisis has been accompanied by a massive drop in fossil fuel prices, resulting from a collapse of demand and an oil price war. Low fossil-fuel energy prices provide weaker incentives for investment in low-carbon and energy efficiency technology at all stages, from R&D to commercial diffusion. For example, there is ample evidence that fossil fuel prices are strongly correlated with global patenting activity in low-carbon technologies (Dechezleprêtre et al., 2011), as shown in Figure 2. In addition, young and small firms, which tend

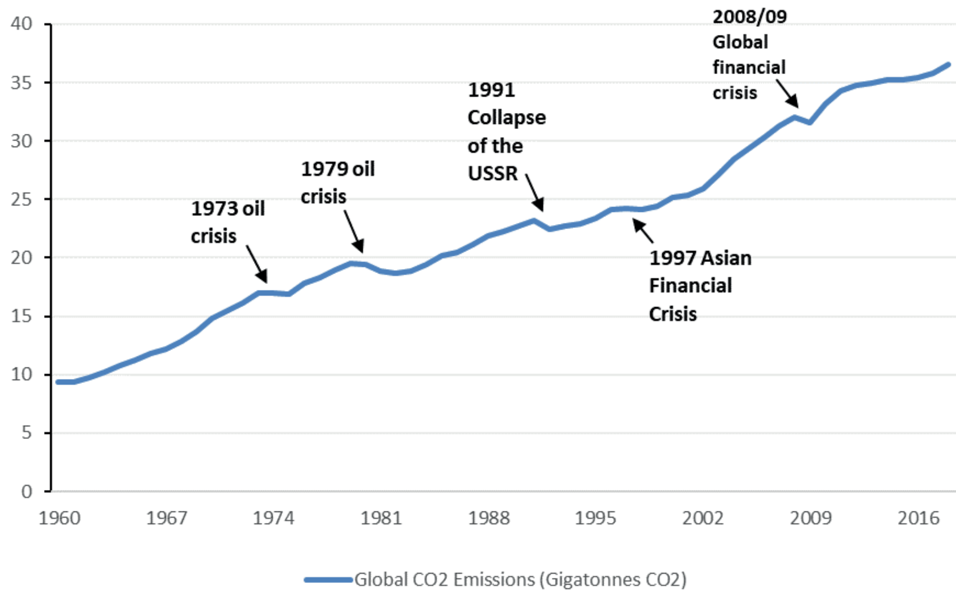

Figure 1. CO_2 emissions and past economic crises. (Source: Global Carbon Project, 2020)

to be major drivers of radical innovation, are likely to be much more severely affected by the COVID-19 crisis compared to larger or incumbent firms, as they have poorer access to capital required to smooth over transitory shocks (Bell et al., 2020).

A role for public policies

With historically low oil prices, the fossil fuel industry – especially producers exploiting costlier resources – is also under stress. Hence, policies have a particular opportunity to tilt the balance towards more sustainable energy sources. What can policy makers do? In the short run, the most important message is: do no harm. Lifeline support to firms and industries should not be combined with the dismantling or watering down of environmental policies. Both in the United States and Europe, some industry lobbies have been pushing to weaken standards or to delay the introduction of planned climate policies. But, at a time of unprecedented uncertainty, signals from carbon pricing, emissions standards, and other environmental regulations need to be maintained to provide stability for low-car-

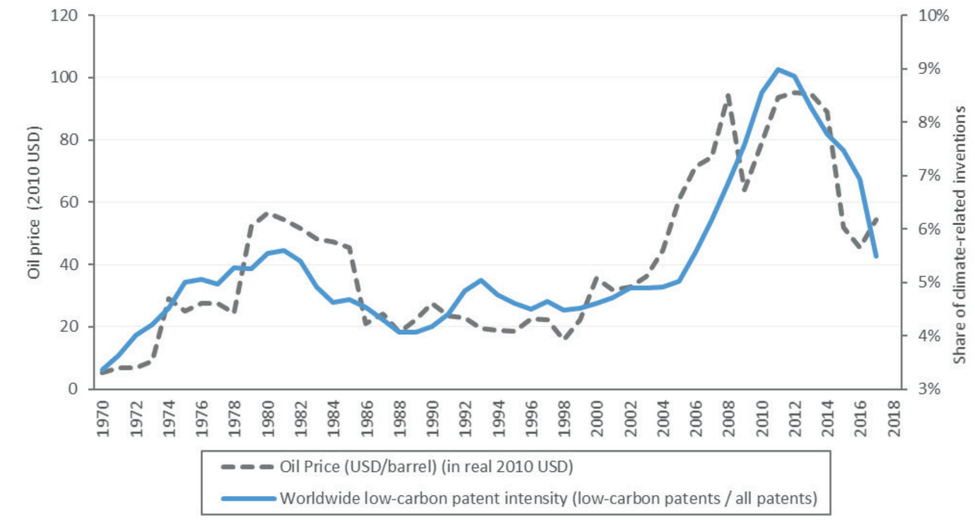

Figure 2. Worldwide low-carbon patent filings and oil prices. (Source: Based on data from the European Patent Office's Global Patent Statistical Database and Oil price data from the World Bank.)

bon activities. This is particularly important as energy investments are highly sensitive to public policies and require long-term planning horizons.

Calls have also been voiced to make direct support to firms contingent on environmental improvements. Certainly, bailouts of ailing companies provide an opportunity for governments to steer investment toward low-carbon production and emissions reductions once they are afloat again, and support workers through re-training in low-carbon technologies. Efficiency improvement conditions can further help ensure the future viability of firms in a low-carbon world. The immediate priority, however, remains to rescue as many viable businesses as possible and in practice this may not be easily compatible with the imposition of conditions such as energy efficiency improvements (Aldy, 2020). However, credible commitments to attaching such strings in the future may be feasible and would help setting incentives and expectations of investors.

Green stimulus packages to support the longer-term recovery

There has been much talk in recent months about how to design green stimulus packages (e.g. Birol, 2020). The objective of green recovery packages is to use expansionary policy to reignite growth while making progress on the climate agenda. For most countries, one of the many legacies of the COVID-19 crisis will be high public debt, with numerous claims on public support. This strengthens the need to spend money in ways that are most effective in reigniting growth, generating jobs while putting the economy on track to meet emission reduction pledges. For example, in many countries government support to energy efficiency retrofitting of buildings can help absorb job losses from the construction sector, while reducing emissions in the long run and providing important co-benefits in terms of energy poverty and health. Investment in infrastructure projects may be crucial for facilitating a low-carbon recovery, through improving power system flexibility (e.g. energy storage, smart grids, long-distance and cross-border power transmissions), public transport, charging stations for electric or hybrid vehicles, carbon capture facilities, and renewable energy deployment. Support to enabling technologies (such as digital technologies, artificial intelligence, communication networks) can help perpetuate the behavioural changes triggered by the crisis and improve productivity growth.

Lessons from the past

Following the GFC, over half a trillion US dollars was committed worldwide as part of green stimulus packages. Yet, emissions recovered after the GFC, and continued on an upward path. Obviously, the current crisis is very different: uncertainty is unprecedented, fiscal space is limited, debt is much higher, but on the other hand some climate-related technologies (e.g. renewables, batteries) are now vastly cheaper than ten years ago. Notwithstanding these differences, a number of lessons can be drawn from this past experience (Agrawala et al., 2020).

First, it is very difficult for green recovery packages to at the same time fix the economy and the climate crisis. Some green policies will be good for the recovery, others are not really win-win (Hepburn et al. 2020). Green stimulus packages can be effective at reshaping the economy and at delivering growth over the long-term, but not necessarily at generating jobs in the short run. For example, the Green American Recovery and Reinvestment Act (ARRA) induced large emissions reductions through renewable energy deployment and subsidies for new cars, but the job effects were modest and costly (Gayer and Parker, 2013; Popp et al., 2020). Energy efficiency retrofitting of buildings generates jobs in the short run, but emissions reductions have been generally disappointing. Trade-offs exist and green stimulus packages need to be combined with other standard short-term policy measures to revive the economy.

Second, the design of policies needs to carefully take into consideration countries' domestic settings (level of development, talents, skills, firms and infrastructure). Previous green recovery packages focused on the demand side (feed-in tariffs, car rebates) with little attention paid to the supply side and to the development of global supply chains. Matching green investments to the skill base of the local economy matters for the success of green recovery packages, so that green recovery packages should be complemented with training programmes (Chen et al., 2020).

Third, investment support is not sufficient. Post-GFC green stimulus packages often lacked the important longer-term signals provided by carbon prices – EU ETS prices were low, the US abandoned ideas to introduce a carbon tax. As a consequence, large-scale publicly supported investments such as CCS demonstration projects were all later abandoned for lack of private financing (Dechezleprêtre and Popp, 2017). We risk being in a similar situation – across 44 OECD and G20 countries, over 75% of emissions are priced below EUR 30/ tCO2, a conservative estimate for the social cost of carbon (OECD, 2018). Green recovery packages will go nowhere if not accompanied by clear trajectories of gradually increasing carbon prices over the next decades and removal of harmful fossil fuel subsidies which undermine the business case for a low-carbon transition[2].

Social acceptability considerations

Arguing for increased carbon pricing in the midst of perhaps the largest global recession in history might sound fanciful. But even a moderate carbon tax announced now but imposed only well into the recovery period can provide forward guidance to investors, reduce uncertainty and ensure that the mistakes from the past are not repeated, without immediately burdening businesses and households with new taxes (Van Dender and Teusch, 2020). It remains that carbon pricing has proven difficult to implement politically, as the Yellow Vest movement in France has shown. The political economy of carbon pricing thus needs to play an important role in the design of such policies (Carattini et al., 2018). Carbon taxes and the phasing out of fossil fuel subsidies carry the risk of disproportionally affecting lower-income households and small businesses, which would magnify the negative impact of the crisis on vulnerable populations[3]. Compensation measures through lump-sum payments to households and to the most affected firms can be used to offset the distributional impacts of higher taxes and boosting investments in green infrastructure can increase public acceptance for such policies (Douenne and Fabre, 2020). Lessons learnt from the successful introduction of the British Columbia carbon tax, where the higher carbon tax is combined with labour and business income tax reductions, could be applied to other countries (Harrison, 2013). Providing households with viable alternatives to carbon-intensive choices, such as public transport, energy efficiency improvements of buildings and appliances, can help change their behaviour, allowing them to benefit, not lose out from carbon taxes.

Conclusion

The COVID-19 crisis has temporarily reduced carbon emissions but could in fact derail global efforts to address climate change. The post-crisis recovery programmes present an opportunity to more closely align public policies with climate objectives and limit the risk of locking-in carbon-intensive infrastructure. Forthcoming stimulus packages can be designed to orient investment towards sectors and technologies that can accelerate the transition, and improve resilience to future shocks from climate change, but they will be of little help if not accompanied by strong climate policies which make the business case for low-carbon investment viable.

References

Agrawala, S., Dussaux, D., Monti, N. (2020). "What policies for greening the crisis response and economic recovery?: Lessons learned from past green stimulus measures and implications for the COVID-19 crisis", OECD Environment Working Papers, No. 164. https://doi.org/10.1787/c50f186f-en

Aldy, J. (2020). Greener Stimulus? Economic Recovery and Climate Policy. www.energypolicy.columbia.edu/greener-stimulus-economic-recovery-and-climate-policy

Baker, S. et al. (2020). "COVID-induced economic uncertainty and its consequences", VOX CEPR Policy Portal, https://voxeu.org/article/covid-induced-economic-uncertainty-and-its-consequences

Bell, B. et al. (2020). "Prepare for large wage cuts if you are younger and work in a small firm", VOX CEPR Policy Portal, https://voxeu.org/article/prepare-large-wage-cuts-if-you-are-younger-and-work-small-firm

Birol, F. (2020). "How to make the economic recovery from coronavirus an environmentally sustainable one", www.iea.org/commentaries/how-to-make-the-economic-recovery-from-coronavirus-an-environmentally-sustainable-one

Carattini, S., M. Carvalho and S. Fankhauser (2018). "Overcoming public resistance to carbon taxes", *WIRES Climate Change, Vol. 9*.

Chen, Z., Marin, G., Popp, D. and Vona, F. (2020). "Green Stimulus in a Post-pandemic Recovery: the Role of Skills for a Resilient Recovery". *Environment and Resource Economics 76*, 901–911. https://doi.org/10.1007/s10640-020-00464-7

Davis, L. and C. Knittel (2019). "Are Fuel Economy Standards Regressive?", *Journal of the Association of Environmental and Resource Economists, Vol. 6*, pp. 37-63.
Dechezlepretre, A., Glachant, M., Hascic, I., Johnstone, N. and Ménière, Y. (2011). "Invention and Transfer of Climate Change-Mitigation Technologies: A Global Analysis", *Review of Environmental Economics and Policy, Vol. 5/1*, pp. 109-130, http://dx.doi.org/10.1093/reep/req023

Dechezlepretre, A. & Popp, D. (2017). "Fiscal and Regulatory Instruments for Clean Technology Development in the European Union". Chapter 6, in Karen Pittel, Ian Parry and Herman Vollebergh, Eds, "Energy Tax and Regulatory Policy in Europe: Reform Priorities", MIT Press, Cambridge, 2017.

Dechezleprêtre, A., Elgouacem, A., Kozluk, T., Kruse, T., (2020). "COVID-19 and the low-carbon transition: Impacts and possible policy responses", OECD Policy Brief. www.oecd.org/coronavirus/policy-responses/covid-19-and-the-low-carbon-transition-impacts-and-possible-policy-responses-749738fc/

Douenne, T. and A. Fabre (2020). "French attitudes on climate change, carbon taxation and other climate policies", *Ecological Economics, Vol. 169*, p. 106496, http://dx.doi.org/10.1016/j.ecolecon.2019.106496

Gayer, T. and E. Parker (2013). An evaluation of the car allowance rebate system, Brookings Institution.

Harrison, K. (2013). "The Political Economy of British Columbia's Carbon Tax", OECD Environment Working Papers, No. 63, OECD Publishing, Paris, https://dx.doi.org/10.1787/5k3z04gkkhkg-en

Hepburn, O'Callaghan, Stern, Stiglitz, Zenghelis (2020). "Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change?" Oxford Review of Economic Policy 36(S1)

IEA (2019). World Energy Outlook 2019, OECD Publishing, Paris, https://dx.doi.org/10.1787/caf32f3b-en.

IEA (2020). Global Energy Review 2020, IEA, www.iea.org/reports/global-energy-review-2020.

IPCC (2018). "Global warming of 1.5°C. Special Report".

Levinson, A. (2019). "Energy Efficiency Standards Are More Regressive Than Energy Taxes: Theory and Evidence", *Journal of the Association of Environmental and Resource Economists, Vol. 6/S1*, pp. S7-S36.

OECD (2018). Effective Carbon Rates 2018: Pricing Carbon Emissions Through Taxes and Emissions Trading, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264305304-en

OECD (2020). OECD Inventory of Support Measures for Fossil Fuels, www.oecd.org/fossilfuels/data/

Popp, Vona, Marin, Chen, (2020). "The Employment Impact of Green Fiscal Push: Evidence from the American Recovery Act", NBER Working Paper No. 27321

Van Dender, K. and J. Teusch (2020). "Making environmental tax reform work", *La Revue des Juristes de Sciences Po 18*, pp. 106-111, http://revuedesjuristes-desciencespo.com

End Notes

[1] This article draws on Dechezleprêtre, A., Elgouacem, A., Kozluk, T., Kruse, T., 2020. "COVID-19 and the low-carbon transition: Impacts and possible policy responses", OECD Policy Brief.

[2] The latest combined OECD and IEA estimates indicate that governments provided USD 478 billion in fossil fuel support in 2019, more than double that of support given to renewable energy (OECD, 2020; IEA, 2019).

[3] However, carbon taxes can often be less regressive than other commonly used climate-related policies such as fuel-efficiency standards (Levinson, 2019; Davis and Knittel, 2019)

ERC-Grant "Health, Labor, and Environmental Regulation in Post-Industrial Europe" (HEAL)

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Environmental regulation dates back at least as far as the thirteenth century when the King of England banned the burning of sea-coal in London in order to mitigate air pollution (Brimblecombe, 1987). Today, improving air quality is not only a priority in rapidly industrializing economies such as China and India where air pollution has been shown to shorten lives and increase morbidity, but it also continues to be a top priority for policy makers in post-industrial societies. In line with the view that the demand for environmental quality increases with economic growth (Grossman and Kruger, 1995), we observe that the richest urban agglomerations in Europe adopt very costly measures to further reduce air pollution.

As environmental economists, we teach our students that regulating air pollution and other environmental externalities is subject to trade-offs. Improving environmental quality is not a free lunch. Someone will have to pay for it. We then introduce them to the concept of socially optimal pollution, characterized by the equality of marginal social benefits of pollution and marginal social costs, as a utilitarian approach to resolving this trade-off. I am sure that many of you share my experience that this concept is often met with a healthy dose of skepticism. Some students disapprove of the notion to put a price on environmental quality, others object to the simple aggregation of environmental damages across individuals. Sometimes there are more extreme positions, such as refusal to compromise on either environmental quality or economic growth. But there is also a group of students who grow up to become policy makers and ultimately find themselves in a position where they have to allocate scarce resources between improving environmental quality and other socially desirable objectives. As researchers in environmental economics, we have a responsibility to provide them with the best possible measurements for cost-benefit analysis, in particular when it comes to estimating the damages of air pollution, for which market prices are not available.

Measuring the damages of air pollution is challenging for a number of reasons. A major obstacle to the estimation of causal impacts is that air pollution exposure is not random across individuals. In their review paper, Graff Zivin and Neidell (2013) list numerous reasons for why spurious correlations between air pollution and health outcomes could arise over time or in the cross section. Sometimes it is precisely the – rational – attempt to avoid exposure to air pollution which biases the estimation of the true dose-response function with observational data[1]. Mismeasurement of pollution exposure is another important issue. Some air pollutants travel over long distances, so that the impacts are not confined to the place of emission.

My ERC-project HEAL, submitted under the 2019 Consolidator Grant call to the SH1 panel, quantifies air pollution damages using an empirical framework that addresses these challenges in a series of empirical applications. HEAL will support evidence-based environmental policy making in Europe and elsewhere through the development of new empirical tools that bring together causal inference and spatially detailed impact analysis. Although the main focus is on air pollution, the results have straightforward and politically significant implications for climate change mitigation. This is because both global climate change and regional air pollution originate to a large extent from the combustion of fossil fuels, an activity that, in Europe as well as in other post-industrial societies, can be curbed only at steeply increasing marginal costs.

A large amount of the time and resources budgeted in HEAL is dedicated to analyzing the efficiency and distributional implications of changes in local air quality that arise as an unintended consequence of the European Union Emissions Trading Scheme (EU ETS) for carbon dioxide (CO_2). The EU ETS is the cornerstone of EU climate policy and has served as a blueprint for similar schemes in other countries[2]. There are plenty of things that we have learned about carbon trading through rigorous ex-post analysis of the EU ETS (the interested reader is referred to the symposium in REEP vol. 10(1), 2016). However, an important knowledge gap concerns the extent to which carbon trading has reallocated air pollution across Europe.

To understand why this matters, consider the map of Europe displayed in Figure 1. The map shows the spatial distributions of people and ETS regulated facilities that also emit air pollution. Since CO_2 is harmless to human health, it makes economic sense to allow market forces to allocate CO_2 emissions in ways that minimize the total abatement cost. However, the facilities displayed in Figure 1 emit CO_2 jointly with air pollutants that do have health impacts. For example, assume that firm A in Spain sells a permit to firm B in Germany. This trade is neutral in terms of CO_2 emissions, but it might not be neutral in terms of nitrogen dioxide (NO_2), an air pollutant. If, for the sake of the argument, we assume that firm B is more pollution intensive than firm A, overall pollution increases. In addition, the permit trade shifts pollution to a more densely populated area in Germany where it harms more people. While this is a hypothetical example, the vast potential for implicit pollution trades suggests that CO_2 trading could have large impacts on air quality and public health. Measuring such health damages (or benefits) is far from trivial as they are jointly determined by the heterogeneity in abatement costs and pollution intensities across thousands of polluting facilities, by complex patterns of atmospheric pollution transport, and by

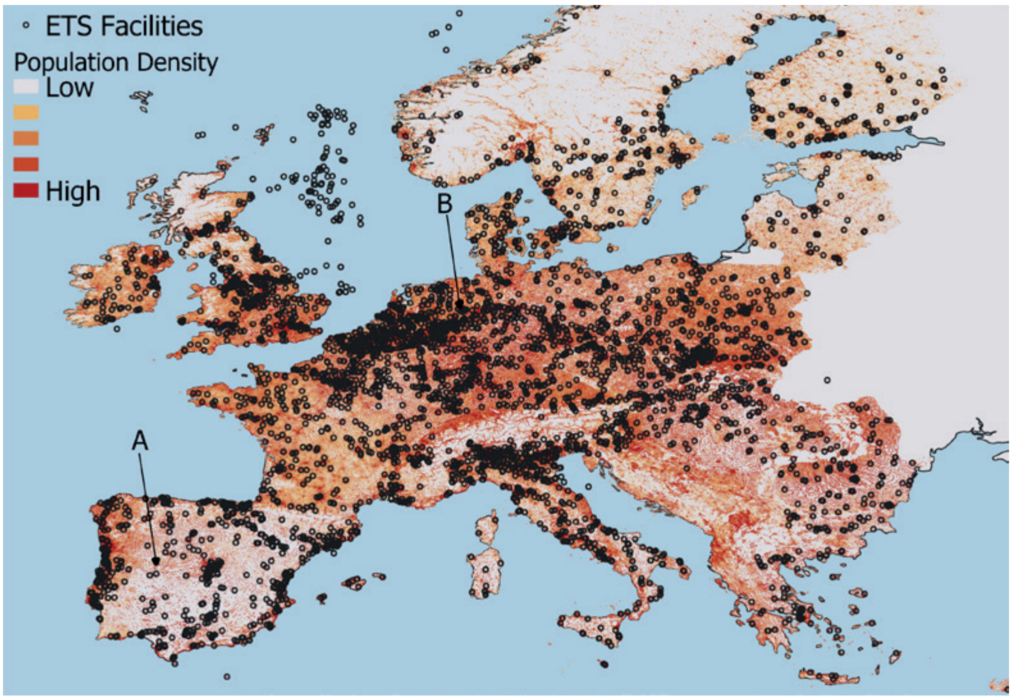

Figure 1. Polluters and Pollutees in the European Carbon Market

differences in population density.
The various work packages of HEAL contribute the buildings blocks for a spatially explicit ex-post analysis of this issue. In painstaking data work joint with Laure de Preux (Imperial College London), I have linked EU ETS installations of polluting facilities to the European Pollution Release and Transfer Register (EPRTR). Our dataset comprises 5,745 geo-referenced installations in 29 countries (cf. Figure 1), representing 92% of all CO_2 emissions in the EU ETS. These installations release up to 50 different pollutants to air, water, and land. In ongoing work with our Mannheim colleague Dana Kassem, we use this dataset to econometrically estimate the facility-level impacts of CO_2 trading on air pollution emissions. The microeconometric model allows us to predict pollution emissions by each facility in a counterfactual scenario without CO_2 trading.

To estimate health impacts in the counterfactual, we need to translate emissions into human exposure to pollution. This is a complex process governed by weather, topography and chemistry. A state-of-the-art chemical transport model will be calibrated to carry out this step. Finally, the treatment effect on public health will be calculated on a spatial grid for Europe by multiplying the counterfactual pollution exposure with monetized per-capita dose-response functions from the literature. The estimates obtained in this way allow us to analyze the efficiency and distributional consequences of implicit pollution trades under the EU ETS.

The possibility of efficiency losses due to heterogenous marginal damages across space is well-known in the context of trading schemes for emissions of local and regional air pollutants (Baumol and Oates, 1988). Recent empirical research on this matter has focused on emissions trading programs for sulfur dioxide and nitrogen oxide in the U.S., and examines the economic gains from adjusting permit prices to account for heterogeneous marginal damages (Muller and Mendelsohn, 2009; Fowlie and Muller, 2019). However, there is no ex-post evidence thus far on efficiency losses in the EU ETS where CO_2 trades may give rise to multiple implicit pollutant trades without being accounted for in the permit price.

The analysis of distributional consequences is motivated by the fact that, efficiency aside, any reallocation of air pollution due to the EU ETS creates winners and losers. In the U.S., emissions trading programs have been subject to great public scrutiny regarding distributional impacts against the backdrop of environmental justice (Fowlie et al, 2012; Grainger and Rungmas, 2018). Due to its large scale and unique importance for carbon trading schemes elsewhere in the world, the EU ETS presents an excellent opportunity for studying the distributional effects of carbon trading. Beyond environmental justice, the distribution of the public health impacts of carbon trading matters because it can have repercussions on public support for climate policy and for centralized policy making in the EU more broadly.

Using the example of the EU ETS, I have described the interdisciplinary approach taken in HEAL which emphasizes both causal inference and spatial detail in the empirical analysis of air pollution damages. As part of the 5-year grant, I will employ this approach to obtain credible estimates of the pollution-health gradient while also incorporating subclinical and long-term health impacts. The methodological advances of this research agenda will directly benefit cost-benefit analysis in a broad range of policy domains where air pollution externalities matter, including energy, climate and transportation.

References

Baumol, W. and Oates, W. (1988). *The theory of environmental policy*. Cambridge University Press, Cambridge.

Brimblecombe, Peter. (1987). *The Big Smoke: A History of Air Pollution in London since Medieval Times*. Methuen, London and New York.

Fowlie, M., Holland, S., and Mansur, E. (2012). "What Do Emissions Markets Deliver and to Whom? Evidence from Southern California's NO_x Trading Program." *American Economic Review*, 102(2):965–93.

Fowlie, M. and Muller, N. (2019). "Market-based emissions regulation when damages vary across sources:What are the gains from differentiation?" *Journal of the Association of Environmental and Resource Economists,* 6(3): 593-632.

Graff Zivin, J., and Neidell, M. (2013). "Environment, health, and human capital." *Journal of Economic Literature,* 51(3): 689–730.

Grainger, C. and Ruangmas, T. (2018). "Who Wins from Emissions Trading? Evidence from California." *Environmental and Resource Economics*, 71: 703-727.

Grossman, G. and Krueger, A. (1995). "Economic Growth and the Environment." *Quarterly Journal of Economics*." 110(2): 353-377.

Martin, R., M. Muûls, and U.J. Wagner (2016). "The Impact of the EU Emissions Trading Scheme on Regulated Firms: What is the Evidence after Ten Years?" *Review of Environmental Economics and Policy*, 10(1): 129-148.

Muller, N. Z., and Mendelsohn, R. (2009). "Efficient Pollution Regulation: Getting the Prices Right." *American Economic Review*, 99(5):1714–1739.

End Notes

[1] Experimental approaches to this topic remain limited to very low exposures for obvious ethical reasons.

[2] Canada, Japan, Kazakhstan, South Korea, Switzerland, and the U.S. have also implemented (pilot) ETS for CO_2. China is in the process of rolling out its pilot ETS to a nationwide scheme. Several countries plan to adopt ETS.

Low-carbon macrofinancial transitions: What could go wrong?

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Mitigating climate change would be easy if we had a benevolent social planner, efficient markets and forward-looking economic agents. Governments would design credible coordinated policy plans so as to maximise intertemporal social welfare, and would stick to them. Physical investments would be rapidly reallocated towards an expanding set of increasingly competitive low-carbon technologies. High-carbon capital stocks would continue to be used but, since no new dirty investment would be made, they would smoothly decline as they reach their natural end of life. Banks and financial investors would react by pricing climate-related risks appropriately and gradually reallocating their portfolios, so low-carbon firms would have a stable and inexpensive access to external finance. Some sectors and agents might suffer losses, but on aggregate they would be more than compensated by the profits to be made in the rising industries. At the end of the process, we would have achieved a rapid low-carbon transition without any major disruption.

However, for better or worse, this scenario is far from being reality. Our world is fragmented and riddled with uncertainties, inertias and mistakes. Individuals take investment decisions under the influence of social norms and cognitive biases, and with limited access to information they can only partially internalise. Governments struggle to implement forward-looking policies due to public spending constraints, social opposition and regulatory capture by powerful interests. High-carbon technologies are still the most attractive investment option in a large number of productive sectors, especially in lower-income countries eager to grow. Most financial investors operate under short-term planning horizons and still perceive the risk-return profile of low-carbon investments to be unattractive. To complicate things, add the deep uncertainty created by financial crises, global pandemics and geopolitical conflicts, affecting all economic agents.

The real-world lack of a coordinated mitigation effort could have two undesirable consequences. First, it could prevent the allocation of sufficient resources to low-carbon investments, leading us well beyond the 2°C temperature threshold. Second, it could leave the transition exposed to volatility and sentiment fluctuations, creating the conditions for an abrupt and disruptive process. These two circumstances could overlap in the scenario of a 'late and sudden' transition, leading to what the former governor of the Bank of England referred to as a 'Climate Minsky moment' (Carney et al., 2019), which might then have further negative effects on the low-carbon transition process itself.

The main aim of the SMOOTH project (2020-2025) is to understand if and how it would be possible to achieve a rapid low-carbon transition in such an imperfect and evolving context, while avoiding large macroeconomic and financial disruptions.

This requires addressing three broad inter-linked research gaps.

1. *Drivers of transition-related disruptions*. What could trigger macrofinancial disruptions along the transition process? A number of suspects can be identified: technological development, the introduction of mitigation policies, changes in preferences, climatic events, and others. However, what matters

most are not the triggers themselves, but rather how these materialize. A predictable and socially accepted policy strategy, even when strong, would smoothly push economic agents to decarbonise their activities without major disruptions. An unanticipated policy shock, possibly in the wake of some unforeseen climate event, is instead likely to cause large economic losses. The alignment (or misalignment) of expectations and investment decisions with future decarbonisation pathways is therefore crucial in determining the smoothness of the transition. But what are these expectations, and how are they formed? How are investors internalizing their expectations into physical and financial investment decisions? Do they have the right economic, social and institutional incentives to perform long-term investments? While some light is recently being shed on the topic (see for instance Krueger et al., 2020), these questions still remain largely unanswered.

2. *Transmission channels and impacts of transition-related disruptions*. Wherever the exact origin of the disruption lies, sudden climate-related realisations by consumers, firms, investors or governments could trigger macroeconomic and financial spillovers. Figure 1 offers an overview of how transition risks might materialise and be transmitted to the rest of the economic system (Semieniuk et al., 2020). A particularly relevant type of transition-related cost is asset stranding, i.e. the unanticipated loss of operability or monetary value attached to different types of assets (Caldecott, 2018). Assets at risk of stranding due to a low-carbon transition include reserves of fossil fuels (the 'unburnable carbon'), fossil-dependent stocks of physical capital (e.g. coal-fuelled electricity plants), and financial assets (e.g. bonds issued by fossil extracting firms). The issue of asset stranding and associated macrofinancial disruptions along the transition process is being increasingly investigated, using a number of methodological approaches (see for instance the programme of the recent 2020 EAERE Conference). First, dynamic economic modelling of different sorts (IAM, DSGE, CAPM, SFC, ABM, and others) is being developed to capture possible aggregate transition dynamics. Second, analyses of production and financial networks are trying to assess the exposure of economies to stranding risks. For instance, Figure 2 shows how a marginal shock in the fossil sector of the countries in the sample (e.g. a

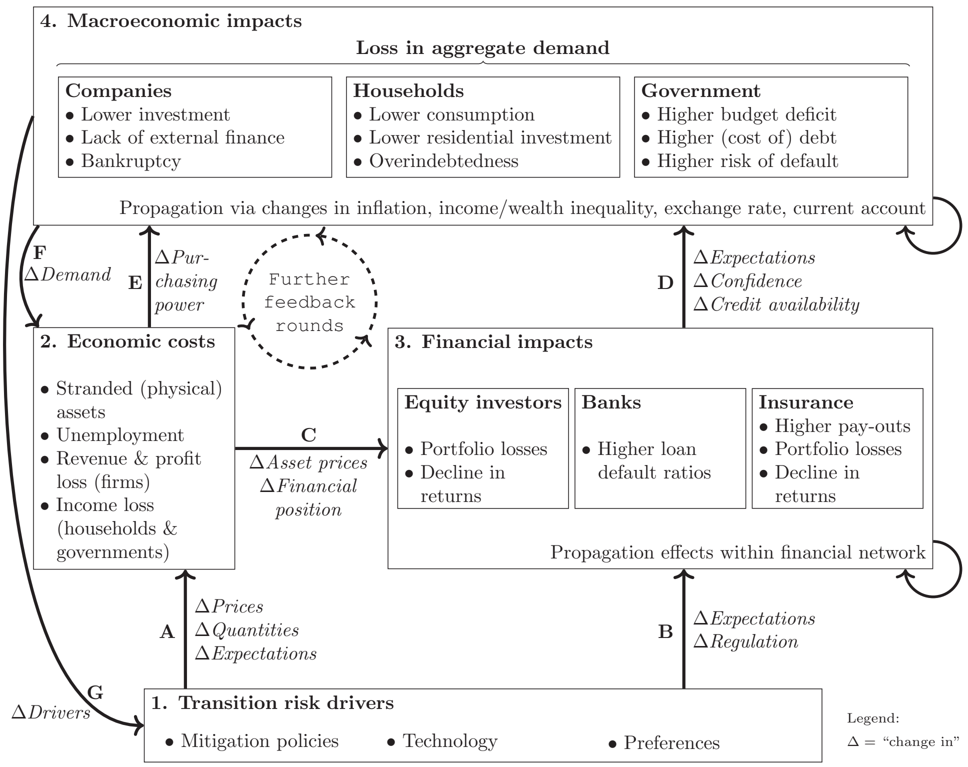

Figure 1. Drivers, transmission channels and impacts of transition-related costs (Semieniuk et al. 2020)

unitary loss of primary inputs used in the extraction of fossil fuels, or a unitary increase in taxes applied to fossil production) would trigger cross-boundary stranding of physical capital stocks (Cahen-Fourot et al., 2019). However, despite recent advancements, we are still far from having a comprehensive modelling framework capable of capturing the complex coevolution of financial, socioeconomic and environmental variables along the transition.

3. *Policies and institutions for a smooth transition*. Even assuming we were able to develop reliable transition risk assessment techniques, financial investments, such as climate-related disclosure requirements, differentiated prudential regulations, sectoral credit quotas, and others (Campiglio et al., 2018). However, we still lack a good understanding of the effectiveness and possible side effects of the various policy options. Second, could these policies be implemented if thought to be beneficial, and by whom? Since the 2007 global financial crisis, many regions have experienced shifts in the distribution of powers and responsibilities between governments, central banks and financial regulators, sometimes coupled with institutional fragmentation and frictions.

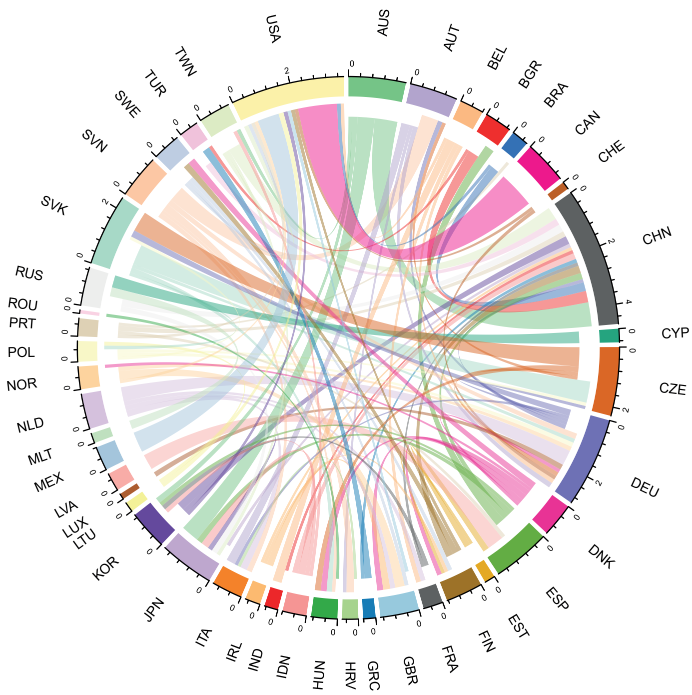

Figure 2. Cross-boundary physical capital stranding triggered by defossilisation (Cahen-Fourot et al., 2019)

the question of how we would mitigate (or adapt to) these risks remains open. Two main questions arise. First, what policies should be implemented? All economists agree on the need for a carbon price to shift consumption and investment choices, but it is unclear whether i) a sufficiently strong price signal will ever be implemented; ii) it would be able to address all existing market failures, including the ones present in financial markets; iii) it could actually exacerbate transition risks, if implemented too abruptly. Additional policies have been proposed or applied (especially in emerging economies) to target more directly physical and This process affected also the climate mitigation policy sphere, where central banks have become very active (see for instance the creation of the Network for Greening the Financial System - NGFS) triggering both enthusiasm and concerns over their legitimacy and the lack of democratic control. So what is the most appropriate governance framework configuration to deliver a consistent and comprehensive policy effort for a smooth transition? What are the institutional obstacles to its achievement, and what second-best options are available within current configurations? Additional work is needed to answer these questions.

Addressing the research gaps above is crucial, but also very challenging. It will require going beyond economics to incorporate insights from finance, behavioural sciences, transition theory, political economy and other disciplines. Within the economics discipline itself, it will require revamping traditional modelling techniques, as well as complementing them with non-equilibrium and complexity modelling (Mercure et al., 2019). The role of evolving and heterogenous expectations, in particular, appears to be crucially important in determining the shape and speed of the low-carbon transition and its macroeconomic and financial consequences. However, despite the strong rise of the literature linking sentiments, animal spirits and heterogenous expectations to aggregate fluctuations (see for instance Bordalo et al., 2018), these approaches have yet to be systematically used to study climate and transition macrofinancial implications.

Over the course of five years, SMOOTH will attempt to address these shortcomings and offer new insights on how to achieve a rapid and non-disruptive low-carbon transition. The project will be conducted by an interdisciplinary team based at the University of Bologna and at the RFF-CMCC European Institute on Economics and the Environment in Milano. All research outputs, events and call for applications will be posted on the project website: https://site.unibo.it/smooth/. We are looking forward to interacting with the EAERE research community and presenting our results at future EAERE conferences!

References

Bordalo, P., Gennaioli, N., & Shleifer, A. (2018). Diagnostic Expectations and Credit Cycles. *The Journal of Finance*, *73*(1), 199–227. https://doi.org/10.1111/jofi.12586

Cahen-Fourot, L., Campiglio, E., Dawkins, E., Godin, A., & Kemp-Benedict, E. (2019). *Capital stranding cascades: The impact of decarbonisation on productive asset utilisation* (Working Paper No. 18). WU Institute for Ecological Economics.

Caldecott, B. (Ed.). (2018). *Stranded Assets and the Environment: Risk, Resilience and Opportunity*. Routledge.

Campiglio, E., Dafermos, Y., Monnin, P., Ryan-Collins, J., Schotten, G., & Tanaka, M. (2018). Climate change challenges for central banks and financial regulators. *Nature Climate Change*, *8*(6), 462–468. https://doi.org/10.1038/s41558-018-0175-0

Carney, M., Villeroy de Galhau, F., & Elderson, F. (2019). *Open letter on climate-related financial risks*. Bank of England. https://www.bankofengland.co.uk/news/2019/april/open-letter-on-climate-related-financial-risks

Krueger, P., Sautner, Z., & Starks, L. T. (2020). The Importance of Climate Risks for Institutional Investors. *The Review of Financial Studies*, *33*(3), 1067–1111. https://doi.org/10.1093/rfs/hhz137

Mercure, J.-F., Knobloch, F., Pollitt, H., Paroussos, L., Scrieciu, S. S., & Lewney, R. (2019). Modelling innovation and the macroeconomics of low-carbon transitions: Theory, perspectives and practical use. *Climate Policy*, *19*(8), 1019–1037. https://doi.org/10.1080/14693062.2019.1617665

Semieniuk, G., Campiglio, E., Mercure, J.-F., Volz, U., & Edwards, N. R. (2020). Low-carbon transition risks for finance. *WIREs Climate Change*, *Forthcoming*.

2D4D - Disruptive Digitalization for Decarbonization

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Technological change plays a dual role in deep decarbonization pathways. On the one hand, the diffusion of already available low-carbon technologies and the invention of novel carbon-neutral options is necessary to achieve and surpass the Paris Agreement target of limiting mean global temperature increase to 2C degrees with respect to 1900 levels (IPCC 2018). Indeed, one of the key differences across the alternative decarbonization pathways explored in the literature is the nature and timing of innovation, technology diffusion and transfer. On the other hand, innovation is an enabler of the sustainable transition because it can turn the decarbonization challenge into a wide set of social and economic opportunities. Specifically, innovation promotes competitiveness, can have positive labor market impacts, and can increase the access to services and resources for all citizens (EC 2018a). Innovation is at the core of "A clear planet for all", the European vision for a prosperous, modern and climate-neutral economy by 2050 (EC 2018b), and technological diffusion also plays and important role in supporting the achievement of sustainable development goals (Anadon et al. 2016; IPCC 2018).

Given their importance, the phases, drivers and potential impact of innovation in low-carbon technologies are subjects of much academic investigation (Carraro et al. 2010, Popp et al. 2010, Popp 2019). Available literature explores, for instance, the level, growth and productivity of public and private R&D funding (i.e. Goldstein et al 2020, Mazzucato 2013) and their complementarity (i.e. Popp and Newell 2012), the way in which innovators build on the shoulders of the giants by benefiting from intertemporal, intersectoral and international spillovers (i.e. Popp 2002, Nemet 2012, Verdolini and Galeotti 2011), the inducement effect of both demand pull or technology push policies on either the level or the direction of (low-carbon) energy innovation (i.e. Nesta el al. 2014, Aghion et al. 2016) ; the potential impact of low-carbon technology diffusion on competitiveness i.e. (i.e. Rubashkina et al. 2015), labour market impacts (Marin and Vona 2019) and the dynamics of trade and embodied emissions (i.e. Sato and Dechezleprêtre 2015, Meng et al. 2018).

Systemic approaches have also characterized the complexity of energy innovation systems, and of the set of actors and institutions that shape low-carbon technology innovation processes (Sagar and Holdren 2002, Anadon et al., 2016). The interaction of the different elements in an energy innovation system is complex, as connections among actors and institution occur at many stages of the technology innovation process, in multiple sectors and countries, and at different scales. Recent research also points to the key role of behavioral change to support low carbon deployment and diffusion (i.e. d'Adda et al. 2017), and to the complex web of institutions and actors involved in the development and diffusion of low carbon technologies (i.e. Hughes and Urpelainen 2015; Geels at al. 2017). This extensive body of evidence inform the design of environmental and climate policies (i.e. EC 2018a; Chan et al. 2017). It also points to the importance of appropriately modelling and calibrating technical change dynamics in both top-down long-term integrated assessment models and bottom up models (i.e. Iyer et al. 2015 and van Sluisveld et al. 2018).

Yet, the framework conditions within which both low-carbon innovation and decarbonization are pursued are constantly changing. Decarbonization is only one of several other mega-trends our societies are facing, which include asymmetric global population explosion, globalization, multiple revolutions in healthcare and accelerating, exponential information technology development (Hammond 2018). Therefore, many new questions arise on how these mega-trends will impact the innovation and technology diffusion needed to support the achievement of the low-carbon transition in future decades.

The 2D4D "Disruptive Digitalization for Decarbonization" ERC project specifically tackles the interaction between digitalization and climate mitigation, with a specific focus on Europe. Digital technologies will have disruptive socio-economic implications for decarbonization narratives and pathways. By 2040, all major energy-demand sectors will be deeply affected by the digital revolution. Transportation will be dominated by electric, automated vehicles fully integrated with the electricity system, home environments will be filled with smart devices and most manufacturing processes will rely on digital technologies (EC 2014; IEA 2017; Hammond 2018). In the same time frame, the European Union aims to be well ahead on the road towards 2050 climate neutrality (EC 2011). Yet, current mitigation policies, which are disjoint from consideration about the impacts of digitalization on energy use and all other socio-economic outcomes, will likely be inefficient and/or ineffective in a deeply digitalized world.

At present, whether the digital revolution will be an enabler or a barrier for decarbonization is a matter of debate. Forecasts suggest that disruptive change will happen fast, and experts recognize this transition will create several challenges (Hammond 2018). The understanding of the disruptive potential of digital technologies, which is a function of both technical characteristics and non-technical aspect, is still limited (Aghion and Jones 2018). This is partly due to their ground-breaking and disruptive nature, which makes it hard to extrapolate from previous history/experience. Indeed, digital technologies are still highly concentrated. In 2014 (latest available data), roughly 750,000 industrial robots were estimated to be operational in OECD countries, constituting more than 80% of the global stock. Indeed, Japan, the United States, Korea and Germany alone account for almost 70% of the total number of operational robots. Yet, the People's Republic of China leads in the adoption of robots, with an operational stock of over 86 000 units (OECD 2017).

Digitalization will impact decarbonization through several channels. Digital technologies consume large amounts of energy (Jones 2018, Horner et al. 2016) but they contribute to (energy) efficiency in economic and human systems through material input savings and increased coordination (IEA 2017, Huang et al. 2016). Furthermore, the digital transformation will have profound distributional effects: it will affect competitiveness (Varian 2018), trade (Goldfarb and Trefler 2018), and employment (Acemoglu and Restrepo 2018; Trajtenberg 2018). Digitalization may benefit certain regions/areas/socioeconomic groups more than others, as in the case of integrated mobility services, which benefit cities more than rural and peripheral areas (OECD 2017). Digital technologies may also make it easier and cheaper (or harder and costlier) to implement stringent climate policies across sectors and countries (i.e. enhancing policy enforcement).

While digitalization is expected to be a fast process, this transformation takes place against entrenched individual behaviors, existing infrastructure, the legacy of time frames, vested interest and slow institutional processes. It also requires trust from consumers, producers and institutions. Finally, digital technologies have sector-specific potentials and barriers. The former includes, for instance, costs, material input and infrastructure requirements, technological maturity, sector-specific potential. The latter relate to the knowledge base (who invents what), market structure, social acceptance by crucial actors, regulatory requirements, incentives, administrative barriers, among others.

Unveiling the link between digitalization and decarbonization is crucially important for industry, transportation and buildings because these sectors face the biggest mitigation challenges (Luderer et al 2018). In 2014, they were responsible for 26, 25 and 33 percent of the European final energy consumption, respectively (EEA 2017). Globally, these sectors are crucial contributors to GHG emissions, facing important barriers to decarbonization. At the same time, digital technologies will drastically reshape these three sectors in the decades to come.

With this in mind, over the next five years 2D4D aims at carrying out comprehensive, systematic, large-scale assessments of the macro-economic implications emerging from a joint consideration of digitalization and decarbonization needs and pathways. The project will deploy a rich toolkit of complementary data-based and qualitative research approaches (including data science, case studies, surveys expert elicitations and integrated assessment modelling, among others) to assess the disruptive technical and socio-economic effects of digitalization in different sectors of the economy, the resulting impact on energy, economic growth, social development and, consequently, its implications for decarbonization. This understanding will be crucial to inform the design and implementation of "no-regret" decarbonization policies and portfolios ensuring that digitalization and decarbonization are mutually enhancing in the achievement of climate targets and sustainable development goals.

The 2D4D – Disruptive Digitalization for Decarbonization project runs from October 1st 2020 to September 30th, 2025. Stay tuned by following it on twitter: @2D4D_ERC*!*

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References

Acemoglu, D., P. Restrepo (2018). "Artificial Intelligence, Automation and Work", NBER Working Paper No. 24196

Aghion, P., A. Dechezleprêtre, D. Hémous, R. Martin, J. Van Reenen (2016). "Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence from the Auto Industry," *Journal of Political Economy, University of Chicago Press, vol. 124*(1):1-51.

Aghion, P., B. F. Jones, and C. I. Jones (2018). "Artificial Intelligence and Economic Growth", NBER Working Paper No. 23928

Anadon, L.D., G. Chan, A. G. Harley, K. Matus, S. Moon, S. L. Murthy, W. C. Clark (2016). "Making innovation work for sustainable development", Proceedings of the National Academy of Sciences Aug 2016, 201525004; DOI: 10.1073/pnas.1525004113

Carraro C., De Cian E., Nicita L., Massetti M., Verdolini E. (2010). "Environmental Policy and Technical Change: A Survey", *International Review of Environmental and Resource Economics, 4*:163-219

Chan, G., Goldstein, A.P., Bin-Nun, A., Anadon, L.D., Narayanamurti, V. (2017). 'Six principles for energy innovation.' Nature 552: 25-27. Doi:10.1038/d41586-017-07761-0.

d'Adda, Capraro and Tavoni (2017). "Push, don't nudge: Behavioral spillovers and policy instruments", *Economics Letters, 154*:92–95

EC (2011). "A Roadmap for moving to a competitive low carbon economy in 2050", Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions of 8 March 2011, COM (2011) 112.

EC (2014). "Advancing Manufacturing - Advancing Europe" - Report of the Task Force on Advanced Manufacturing for Clean Production Brussels, COMMISSION STAFF WORKING DOCUMENT SWD(2014) 120 final, 19.3.2014

EC (2018a). "Final Report of the High-Level Panel of the European Decarbonisation Pathways Initiative", Directorate-General for Research and Innovation, Directorate I - Climate Action and Resource Efficiency, https://ec.europa.eu/info/publications/final-report-high-level-panel-european-decarbonisation-pathways-initiative_en

EC (2018b). "A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy", Communication from the Commission to the European Parliamente, the European Counting, The Council, The European Economic and Social Committee, the Committee of the regions and the European Investment Bank, COM/2018/773 final

EEA (2017). Final energy consumption by sector and fuel, last accessed October 16th, 2018. https://www.eea.europa.eu/data-and-maps/indicators/final-energy-consumption-by-sector-9/assessment-1

Geels, F.W., B. K. Sovacool, T. Schwanen, S. Sorrell (2017). "Sociotechnical transitions for deep decarbonization", *Science 357*(6357): 1242-1244. DOI: 10.1126/science.aao3760

Goldfarb, A. and D. Trefler (2018). "AI and International Trade". NBER Working Paper No. 24254

Goldstein, A., Doblinger, C., Baker, E. et al. (2020). "Patenting and business outcomes for cleantech startups funded by the Advanced Research Projects Agency-Energy". Nat Energy. https://doi.org/10.1038/s41560-020-00683-8

Hammond, R. (2018). "Megatrends of the 21st century", Report commissioned by Allianz Partners available at: https://www.allianz-partners.com/content/dam/onemarketing/awp/azpartnerscom/reports/futorology/Allianz-Partners-Megatrends-of-the-21st-Century-ENG.pdf

Horner, N., A. Shehabi and I. L. Azevedo (2016). "Known unknowns: indirect energy effects of information and communication technology", *Environ. Res. Lett. 11* (2016) 103001 doi:10.1088/1748-9326/11/10/103001

Huang, R., et al. (2016). "Energy and emissions saving potential of additive manufacturing: the case of lightweight aircraft components". *Journal of Cleaner Production 135*:1559-1570 http://doi.org/10.1016/j.jclepro.2015.04.109

Hughes, L., J. Urpelainen (2015). "Interests, institutions, and climate policy: Explaining the choice of policy instruments for the energy sector". *Environ. Sci. Policy54*, 52-63 (2015).

IEA (2017). Digitalization and Energy. OECD/IEA Publishing, Paris

IPCC (2018). Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C.Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield(eds.)].

Iyer, G., N. Hultman, J. Eom, H. McJeon, P. Patel, and L. Clarke (2015). "Diffusion of low-carbon technologies and the feasibility of long-term climate targets". *Technol. Forecast. Soc. Change, 90*, 103–118, https://doi.org/10.1016/j.techfore.2013.08.025.

Jones, N. (2018). "How to stop data centres from gobbling up the world's electricity". *Nature 561*, 13 September 2018.

Luderer, G. et al. (2018). "Residual fossil CO2 emissions in 1.5–2 °C pathways". *Nature Climate Change 8*, 626–633

Marin, G., Vona, F. (2019). "Climate Policies and Skill-Biased Employment Dynamics: evidence from EU countries". *Journal of Environmental Economics and Management 98*: 102253

Mazzucato, M. (2013). The Entrepreneurial State: debunking public vs. private sector myths, Anthem Press: London, UK, ISBN 9780857282521

Meng, J, Zhang, Z, Mi, Z, Anadon, LD, Zheng, H, Zhang, B, Shan, Y, Guan, D. (2018). "The role of intermediate trade in the change of carbon flows within China". *Energy Economics (2018) 76*:303-312. Doi: 10.1016/j.eneco.2018.10.009

Nemet, G. F. (2012). "Inter-technology knowledge spillovers for energy technologies," *Energy Economics 34*(5):1259-1270

Nesta, L., F. Vona, F. Nicolli (2014). "Environmental policies, competition and innovation in renewable energy", *Journal of Environmental Economics and Management 67*(3): 396-411.

OECD (2017), OECD Digital Economy Outlook 2017, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264276284-en

Popp, D. (2002). "Induced technical change and Energy Prices", American Economic Review 92(1):160-180

Popp, D. (2019). "Environmental Policy and Innovation: A Decade of Research", National Bureau of Economic Research Working Paper Series No. 25631, March 2019, http://www.nber.org/papers/w25631

Popp, D. and R. Newell (2012). "Where Does Energy R&D Come From? Examining Crowding out from energy R&D," *Energy Economics 34*(4):980-991.

Popp, D., R. Newell and A. Jaffe (2010). "Energy, the Environment, and Technological Change", Handbook of the Economics of Innovation, eds B. H. Hall and N. Rosenberg, Volume 2, Pages 873–937

Rubashkina, Y., Galeotti, M., Verdolini, E., (2015). "Environmental Regulation and Competitiveness: Empirical Evidence on the Porter Hypothesis from European Manufacturing Sectors", *Energy Policy 83*:288–300

Sagar, A. D. and Holdren, J. P., (2002). "Assessing the global energy innovation system: some key issues", *Energy Policy, 30*(6):465-469.

Sato, M., A. Dechezleprêtre (2015). "Asymmetric industrial energy prices and international trade", *Energy Economics 52*(1): S130-S141

Trajtenberg, M. (2018). "AI as the next GPT: A Political-Economy Perspective". NBER Working Paper No. 24245

van Sluisveld, M. A. E., et al. (2015). "Comparing future patterns of energy system change in 2°C scenarios with historically observed rates of change". *Glob. Environ. Chang. 35*: 436-449.

Varian, H. (2018), "Artificial Intelligence, Economics, and Industrial Organization". NBER Working Paper No. 24839

Verdolini E., Galeotti M. (2011). "At Home and Abroad: An Empirical Analysis of Innovation and Diffusion in Energy Technologies", *Journal of Environmental Economics and Management, 61*(2): 119-134

Forest sequestration, food security and climate change

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Climate change: trends, mitigation and impacts

Climate change is the biggest global externality, exacerbated by the increasing trend in anthropogenic greenhouse gas (GHG) emissions in the last decades (Kouhestani et al., 2016). Energy, transportation and agriculture are the largest contributors (IPCC-WGIII, 2014). Recently, these emissions temporarily decreased as a result of the lockdown mandates to reduce the spread of the COVID-19 pandemic (Peña-Lévano & Escalante, 2020). Nevertheless, Le Quéré et al. (2020) shows that GHGs may reach their pre-pandemic levels as the daily activities go back to usual.

Climate change may affect productivity in many regions, depending on location and crop cultivated (IPCC, 2007; Ouraich et al., 2014). Lower yields may negatively affect food security by limiting food resources in many nations and higher food prices (Stern, 2007).

The existing literature recognizes forest carbon sequestration (FCS) as a cost-effective method to mitigate climate change due to the ability of trees to absorb CO_2 naturally as part of the photosynthesis process (Daniels, 2010). Notwithstanding, FCS incentives may have adverse impacts on the global food supply by increasing food commodity prices (Golub et al., 2012), and exacerbating poverty in developing economies (Hussein et al., 2013). Sohngen (2009) argues that targeting a maximum temperature increase of 2 degrees Celsius, FCS should expand by 178% in the 2010-2100 period with a social price of carbon of \$130/tCO_2e to cover the opportunity cost of afforestation and reforestation.

Our study expands the findings of these seminal articles by evaluating the consequences of an aggressive FCS policy in global food security under the presence of climate change effects on agricultural productivity (Peña-Lévano et al., 2019). This article highlights the interaction between climate change, mitigation, and their global economic implications, addressing important policy questions: what is the cost of emission reduction with and without FCS incentives? What are the impacts of FCS policies on global food security? What are the implications of including crop yield induced climate change in the analysis? And, is there economic benefits from abating losses in agricultural productivity?

Many governments are now considering climate change as a priority in their business agendas. In November 2021, about thirty thousand representatives from countries all over the world are scheduled to participate in the Glasgow talks, the most important convention on climate change since the Paris Agreement, which will discuss the future actions to address climate change (UK Government, 2020). Thus, our research comes at a crucial time of debate focused on the climate change effects in the global economy and financial markets. Recently, the 2020 September report of the U.S. Commodity Futures Trading Commission stated: "A world wracked by frequent and devastating shocks from climate change cannot sustain the fundamental conditions supporting our financial system" (Davenport & Smialek, 2020).

The methodology

To fulfill the objectives of this study, we developed an advanced version of a computable general equilibrium (CGE) model entitled GTAP-BIO-FCS, which provides a suitable numerical framework for the analysis of climate change policies under different emission reduction targets. Specifically, this model includes CO_2 and non-CO_2 GHG emissions, forest carbon stocks and biofuels. We address our policy questions by implementing five alternative yield/climate scenarios (presented in Figure 1) into the GTAP-BIO-FCS model.

From the five scenarios, one illustrates a business-as-usual pathway (RCP8.5) with no mitigation effort but crop yields shocks induced by climate change. The other four represent a mitigation pathway (RCP4.5) which targets a global emission reduction by 50%, according to the Paris agreement, under four alternative policy and yield setups: (i) A global uniform carbon tax ignoring the impacts of climate change on yields (dubbed *TAX*), (ii) a global carbon tax plus an equivalent subsidy on FCS ignoring the impacts climate change on yield (called *TAX-SUBSIDY*), (iii) *TAX* policy taking into account climate induced yield changes, and (iv) *TAX-SUBSIDY* policy taking into account climate induced yield changes. For each emission reduction target and policy, the GTAP-BIO-FCS model endogenously calculates the required tax/subsidy rates (in $/$tCO_2$e). The data for the future crop yields shocks were collected from the existing projections developed by the Agricultural Model Intercomparison and Improvement Project (AgMIP) (Villoria et al., 2016). These estimates together with the emission reduction targets were

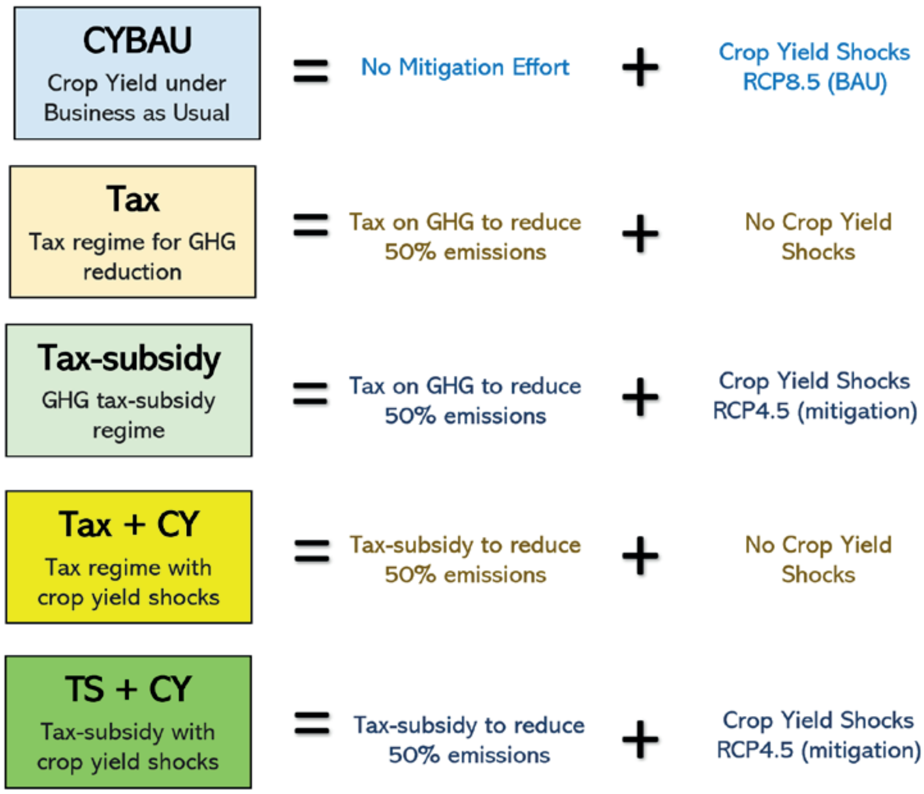

Figure 1. Scenarios of the study

inserted as exogenous shocks to the CGE model for each alternative policy (either tax or tax-subsidy).

Emission reduction and land use change

In the *TAX* scenario, implementing an emission tax to reduce global emissions by 50% requires a carbon price of \$150/tCO_2e, this policy forces to either adopt cleaner technologies or reduce production in carbon-intensive industries. Particularly, the electricity sector would need to account for 41% of this reduction. Because the absence of incentive for FCS, there is no significant land movement among cover types (agriculture, forest, pasture). However, there is area variation across crops. Because land growing rice releases methane to the atmosphere, paddy rice production declines (especially in China, India and South East Asia), expanding area for other crops. The tax also encourages biofuels use, which requires further crop expansion of corn and soybeans in the U.S., rapeseed in the European Union, palm in Malaysia and Indonesia, and sugar crops in Brazil.

The inclusion of a subsidy on FCS to this regime would lower the carbon price to \$80/tCO_2e. The *TAX-SUBSIDY* policy shows that CO_2 capture by forest is crucial in mitigating climate change, accounting for one-fifth of the emission reduction. This would motivate reforestation globally by 700 Mha, especially in South America (i.e. the Amazon), Central America, Sub Saharan Africa, United States and India. This is induced by the additional revenue for forest landowners of \$342 per hectare considering that an average hectare of forest sequesters annually 4.28 MtCO_2. As a result, cropland decreases by 378 Mha globally, driving up land rent in multiple locations. This may affect land intensive economies. However, technological adaptation improvements (breeding animals for heat resistance, better management practices and new machinery) and substitution towards labor and capital may partially offset this cropland reduction and lower the crop outputs drop.

The inclusion of crop yield shocks induced by climate change increase the tax-subsidy rate to \$100/tCO_2e. With lower agricultural productivity, the only feasible channel is through extensification of crop production, rising land competition with forest. This occurs for all crops, including paddy rice. Furthermore, land becomes more valuable which is reflected in a rise in land rent. Thus, global afforestation is not as high as before, shifting part of the mitigation towards carbon-intensive industries. As consequence, FCS becomes a less attractive alternative.

Food security and welfare

The penalty of the tax is mostly reflected in price increases in carbon intensive products (coal, oil, gas). The addition of the adverse crop yield shocks induce prices rises for all agricultural products, with more prominent impacts (+50% of original price) for paddy rice and livestock. This leads a decline in GDP and private consumption, especially in developing economies. The \$100/tCO_2e tax-subsidy policy provokes larger price increases of even three times their original values. This sharp price rise in combination with lower output acts a major threat for food security. This is a dramatic outcome, especially for people living in less developed countries who spend large portion of their income on food products. Thus, this decreases welfare costs. GDP in many regions on a range of 0.1%-9.9%, with the largest impacts in places with large dependence on agriculture (Sub-Saharan Africa, Latin America, China, India, Central and Eastern Europe).

In terms of economic well-being (taking into account changes in the economic gains and losses of producers and consumers and ignoring potential environmental benefits), the *TAX-SUBSIDY* policy is more cost-effective (\$457 billion welfare losses) than only imposing an emission tax (\$760 billion welfare losses) at the global scale. This outcome is supported by the literature (Adams et al., 1999; Golub et al., 2010; Richards & Stokes, 2004; Sheeran, 2006; Sohngen & Mendelsohn, 2003; Stavins, 1999). Nevertheless, when considering the adverse climate change effects on agriculture outputs, the conclusion is reversed, due to negative impacts on (i) crop productivity across the world, and (ii) lower efficiency in input and resource allocation. Accounting for these impacts represents additional welfare losses of $154 billion and $650 billion for the *TAX and TAX-SUBSIDY* policies, respectively. This occurs in both developed and developing economies. These figures are smaller than the global welfare losses for the case of business as usual, $726 billion. This confirms that costs of mitigation policies are smaller than the costs making no mitigation. This conclusion does not include further benefits from health, biodiversity or infrastructure. Thus, even in isolation, the results provide a strong support for mitigation.

Conclusions and final remarks

Climate change is expected to negatively affect agricultural productivity. Mitigation policies such as carbon tax or FCS policies can be used to control these effects. An aggressive FCS policy could be more costly than a simple carbon tax policy. The former policy may be a major threat for food security due to dramatic rises in commodify prices, in many cases higher than 200%, especially in countries that significantly depend on agriculture. Finally, this research shows that the examined mitigation policies are less costly than making no mitigation.

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References

Adams, D. M., Alig, R. J., McCarl, B. A., Callaway, J. M., & Winnett, S. M. (1999). Minimum cost strategies for sequestering carbon in forests. *Land Economics*, 360-374.

Daniels, T. L. (2010). Integrating forest carbon sequestration into a cap-and-trade program to reduce net CO2 emissions. *Journal of the American Planning Association, 76*(4), 463-475.

Davenport, C., & Smialek, J. (2020, Sept. 10). Federal Report Warns of Financial Havoc From Climate Change. *The New York Times,* Section B, p. 1. www.nytimes.com/2020/09/08/climate/climate-change-financial-markets.html?searchResultPosition=4

Golub, A. A., Henderson, B. B., Hertel, T. W., Gerber, P. J., Rose, S. K., & Sohngen, B. (2010). Effects of the GHG Mitigation Policies on Livestock Sectors. *GTAP Working Paper No. 62*.

Golub, A. A., Henderson, B. B., Hertel, T. W., Gerber, P. J., Rose, S. K., & Sohngen, B. (2012). Global climate policy impacts on livestock, land use, livelihoods, and food security. *Proceedings of the National Academy of Sciences*, 201108772.

Hussein, Z., Hertel, T., & Golub, A. (2013). Climate change mitigation policies and poverty in developing countries. *Environmental Research Letters, 8*(3), 035009.

IPCC-WGIII. (2014). *WGIII Assessment Report 5 - Mitigation of Climate Change*. http://www.ipcc-wg3.de/

IPCC. (2007). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. C. Cambridge University Press, United Kingdom and New York, NY, USA,.

Kouhestani, S., Eslamian, S. S., Abedi-Koupai, J., & Besalatpour, A. A. (2016). Projection of climate change impacts on precipitation using soft-computing techniques: A case study in Zayandeh-rud Basin, Iran. *Global and Planetary Change, 144*, 158-170.

Le Quéré, C., Jackson, R. B., Jones, M. W., Smith, A. J., Abernethy, S., Andrew, R. M., De-Gol, A. J., Willis, D. R., Shan, Y., & Canadell, J. G. (2020). Temporary reduction in daily global CO 2 emissions during the COVID-19 forced confinement. *Nature Climate Change*, 1-7.

Ouraich, I., Dudu, H., Tyner, W. E., & Cakmak, E. (2014). *Could free trade alleviate effects of climate change? A worldwide analysis with emphasis on Morocco and Turkey* (9292308211).

Peña-Lévano, L., & Escalante, C. (2020). Oil consumption, air quality, and health risks during the COVID-19 pandemic. *Environmental and Resource Economics, 76*, 447–517. https://doi.org/https://doi.org/10.1007/s10640-020-00493-2

Peña-Lévano, L. M., Taheripour, F., & Tyner, W. E. (2019). Climate change interactions with agriculture, forestry sequestration, and food security. *Environmental and Resource Economics, 74*(2), 653-675.

Richards, K. R., & Stokes, C. (2004). A review of forest carbon sequestration cost studies: a dozen years of research. *Climatic change, 63*(1-2), 1-48.

Sheeran, K. A. (2006). Forest conservation in the Philippines: A cost-effective approach to mitigating climate change? *Ecological Economics, 58*(2), 338-349.

Sohngen, B. (2009). *Analysis of Forestry Carbon Sequestration as a Response to Climate Change*. Copenhagen Consensus Center.

Sohngen, B., & Mendelsohn, R. (2003). An optimal control model of forest carbon sequestration. *American Journal of Agricultural Economics, 85*(2), 448-457.

Stavins, R. N. (1999). The costs of carbon sequestration: a revealed-preference approach. *The American Economic Review, 89*(4), 994-1009.

Stern, N. (2007). *The economics of climate change: the Stern review*. Cambridge University press.

UK Government. (2020). *UN Climate Change Conference UK 2021*. Retrieved Sept 18 from www.ukcop26.org/

Villoria, N. B., Elliott, J., Müller, C., Shin, J., Zhao, L., & Song, C. (2016). Rapid aggregation of global gridded crop model outputs to facilitate cross-disciplinary analysis of climate change impacts in agriculture. *Environmental Modelling & Software, 75*, 193-201.

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