Overview & Results of ERC Project EVOCLIM

Prof. Jeroen van den Bergh from ICTA-UAB finished a prestigious ERC Advanced Grant project on the theme of "Behavioral-evolutionary analysis of climate policy: Bounded rationality, markets and social interactions" (EVOCLIM). It amounted to almost € 2 million in funding and ran from January 2018 to June 2023. EVOCLIM covered three postdoc positions and four PhD research positions. This document gives an overview of the project and its key results.
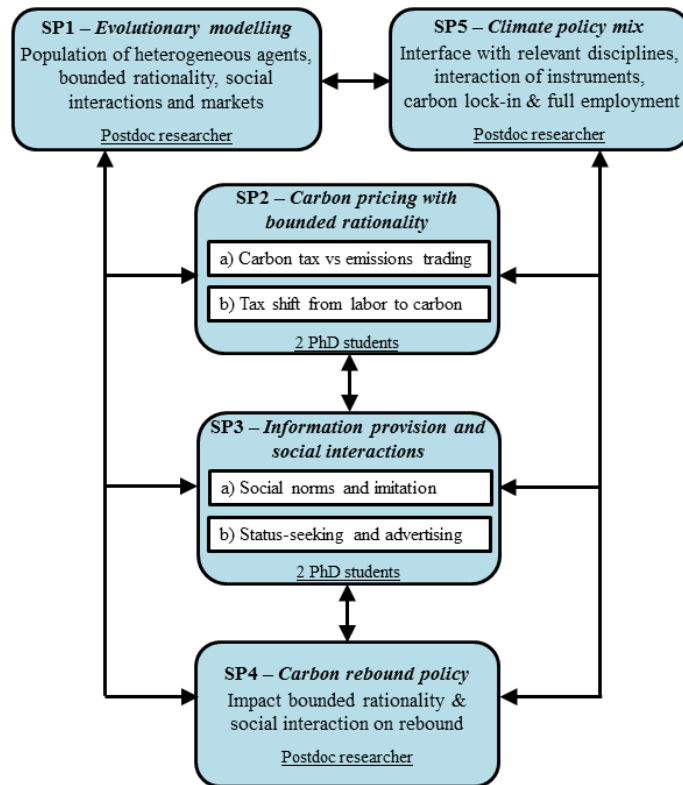
PROJECT DESCRIPTION

The EVOCLIM project aimed to develop a new set of models to assess the performance of policy instruments – such as various carbon pricing and information provision instruments – under bounded rationality and social interactions. To this end, EVOCLIM blends insights from behavioral, environmental and evolutionary economics. The key novelty is linking climate policies to populations of heterogeneous consumers and producers characterized by bounded rationality and social interactions. This offers three advantages: one can evaluate the effectiveness of very different climate policy instruments in a consistent and comparative way; one can examine policy mixes by considering interaction between instruments from a behavioral as well as systemic perspective; and one can simultaneously assess policy impacts mediated by markets and social networks.

EVOCLIM was guided by five specific goals: (i) test the robustness of insights on carbon pricing from benchmark approaches that assume representative, rational agents; (ii) test contested views on joint employment-climate effects of shifting taxes from labor to carbon; (iii) examine various instruments of information provision under distinct assumptions about social preferences, interactions and networks; (iv) study regulation of commercial advertising as a climate policy option in the context of status-seeking and high-carbon consumption; and (v) explore behavioral roots of energy/carbon rebound. The research has a general, conceptual-theoretical rather than a particular country focus. Given the complexity of the developed models, it involves numerical analyses with parameter values in realistic ranges, partly supported by insights from questionnaire-based surveys among consumers and firms. One survey examines information provision instruments and social interaction channels, another behavioral foundations of rebound, a third diversity of expert opinions on climate policy instruments, and a final one the impact of COVID-19 on climate policy support.

Organisation

The organization of EVOCLIM in terms of sub-projects (SPs) is shown in the scheme below. The project funded three postdoc positions (two of 5 years in SP1 and SP5, and one of 3 years in SP4) and four PhD researchers (each 4 years, in SP2 and SP3). Cooperation and synergies between the sub-projects will be secured by the two integrative sub-projects SP1 and SP5. The first of these develops the framework and basic models, and can be seen to assure consistency and synergy of SPs at a methodological level. Next, SP5 guides the survey questionnaires and integrates the policy insights produced by the other SPs, on the basis of which it further develops and analyses policy packages.

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┌──────────────────────────────┐        ┌──────────────────────────────┐
│ SP1 – Evolutionary modelling │        │  SP5 – Climate policy mix    │
│ Population of heterogeneous   │◄──────►│ Interface with relevant      │
│ agents, bounded rationality,  │        │ disciplines, interaction of  │
│ social interactions and       │        │ instruments, carbon lock-in  │
│ markets                       │        │ & full employment            │
│   Postdoc researcher          │        │   Postdoc researcher         │
└──────────────────────────────┘        └──────────────────────────────┘
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SP2 – Carbon pricing with bounded rationality
a) Carbon tax vs emissions trading
b) Tax shift from labor to carbon
2 PhD students

SP3 – Information provision and social interactions
a) Social norms and imitation
b) Status-seeking and advertising
2 PhD students

SP4 – Carbon rebound policy
Impact bounded rationality & social interaction on rebound
Postdoc researcher

Project team

– Project leader: Prof. Jeroen van den Bergh
– Postdocs: Dr. Stefan Drews, Dr. Filippos Exadaktylos and Dr. Ivan Savin
– PhD students: Juana Castro, Joël Foramitti, Franziska Klein and Théo Konc
– Project manager: Marta Viana Diaz

Scientific Advisory board

- Prof. Valentina Bosetti (Dept. of Economics, Bocconi University, Milan, Italy)
- Prof. Herbert Dawid (Fac. Business Adm. & Econ., Bielefeld University, Germany)
- Prof. Wouter Poortinga (School of Psychology, Cardiff University, UK)
- Prof. Steven Sorrell (Science Policy Research Unit, University of Sussex, UK)

Meeting of the EVOCLIM team and scientific advisory board

Details about the five sub-projects

Specific research questions, addressing general issues, tangible instruments of climate policy, and policy packages, are addressed in five sub-projects (SPs) (visualized in the scheme):

1. The first, overarching, integrative sub-project addresses the question: How can we best model the relationship between climate policies, markets, social interactions, innovation-and-diffusion processes, bounded rationality, and heterogeneous agents? This SP aims to develop the general framework, learn from non-environmental macro-evolutionary models, traditional market equilibrium models, climate impact assessment studies and sustainability transition models. It undertakes general, theoretical analyses with these models to understand their structure and behavior, and supports particular elaborations and policy analyses in the other SPs. SP1 is executed by a postdoc researcher who interacts with the other SPs to assure a framework that balances their needs and requests.

2. The second SP examines how carbon pricing, considered by many as a core component of climate policy, functions under conditions of bounded rationality of polluters. Two main questions are addressed in two sub-projects: (2a) What are the differences in performance of carbon pricing under various types of bounded rationality of consumers and firms? This will address carbon taxes and emissions trading, to examine which is more effective under certain types of bounded rationality. The second question is: (2b) what are the innovation, employment and climate impacts of shifting taxes from labor to carbon under bounded rationality? This has been addressed with rational-agent equilibrium models in the "double dividend" literature. SP2b will assess the robustness of its findings with respect to behavioral assumptions by adapting the multi-agent models of SP1 to these questions. In particular, SP2 will assess the extent to which rational-agent studies overestimate the effectiveness and efficiency of carbon pricing. SP2a&b are tackled by 2 closely cooperating PhD students.

3. The third SP examines how information provision strategies in climate policy – like eco-labels, green awards, information campaigns, traditional media, and Internet-based social media – perform in a system characterized by bounded rationality, market processes and social interactions. Two sub-projects address two main questions associated with particular social interactions: (3a) How do different information policies compare in terms of employing imitation behavior, social norms and information diffusion to effectively spread climate-relevant information and exemplary conducts? This involves testing various features of information policies, such as appropriate framing of information provision or using "role models". The second question is: (3b) How does the interaction of commercial advertising and social comparison driven by status-seeking drive the consumption of certain carbon-intensive goods and services, like cars and holidays, and what does this mean for policy design aimed at influencing such consumption? This involves an analysis of information provision instruments interacting with both carbon pricing and advertising. Modelling in SP3a&b is undertaken by 2 PhD students. They will jointly perform a questionnaire survey to examine how opinions on climate policy, climate relevant behaviors, and social interactions are connected.

4. The fourth SP addresses the behavioral foundations of energy/carbon rebound. It is motivated by the research question: How does bounded rationality of individuals/households and firms contribute to rebound, and how does this affect the estimates of different types of rebound as well as the formulation of "rebound policy"? This involves examining the role of different types of bounded rationality, such as myopia, habits, wrong goals, and connecting these to important rebound channels, like intensity effect, market effects, technological diffusion, etc. The project integrates these elements into a behavioral-evolutionary model to address this issue, which is intended to provide better insight into the relative performance of climate policy instruments on effectiveness, in terms of controlling carbon rebound. In addition, a questionnaire survey is performed to obtain empirical information about behavioral factors underlying rebound. This research is executed by a postdoc researcher.

5. The final SP synthesizes SP2-4 and provides an interface with other disciplines offering insights on climate policy, aimed at answering the question: Which policy packages combine equity, employment and climate goals under bounded rationality and are successful in escaping

carbon lock-in? While SPs 2-4 address the performance of single instruments and the comparison of these, here combinations of instruments will be systematically studied, based on close interaction with the other SPs. Instrument complementarity and interaction is an incompletely solved issue in climate policy studies, and has not been systematically addressed in the context of bounded rationality and other-regarding preferences. Given its ambition and integrative character, SP5 is executed by a postdoc researcher.

OUTPUTS

Four PhD theses

- Théo Konc, "Carbon pricing meets social interactions: Implications for climate policy design", Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona (ICTA-UAB), 19 November 2021 (supervisors: Prof. J. van den Bergh & Dr. I. Savin).
- Joël Foramitti, "Agent-based modeling of climate policy", Institute for Environmental Studies, Vrije Universiteit Amsterdam, 6 September 2022 (supervisors: Prof. J. van den Bergh & Dr. I. Savin).
- Juana Castro, "Green advertising in a climate-change context: Experimental studies". ICTA-UAB, 20 June 2022 (supervisors: Prof. J. van den Bergh & Dr. S. Drews).
- Franziska Klein, "Who has time to be green? The 'double dividend' under bounded rationality and time constraints". ICTA-UAB, 28 November 2022 (supervisor: Prof. J. van den Bergh).

Key publications

1. Konc, T., and I. Savin (2019). Social reinforcement with weighted interactions. *Physical Review E* 100, 022305. https://journals.aps.org/pre/abstract/10.1103/PhysRevE.100.022305
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3. Drews S., I. Savin and J. van den Bergh (2019) Opinion Clusters in Academic and Public Debates on Growth-vs-Environment, *Ecological Economics* 157:141-155, https://doi.org/10.1016/j.ecolecon.2018.11.012
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5. Drews, S., F. Exadaktylos and J. van den Bergh (2020). Assessing synergy of incentives and nudges in the energy policy mix. *Energy Policy* 144, 111605. https://doi.org/10.1016/j.enpol.2020.111605
6. Savin, I., S. Drews, S. Maestre-Andrés and J. van den Bergh (2020). Public views on carbon taxation and its fairness. A computational-linguistics analysis. *Climatic Change* 162: 2107–2138. https://doi.org/10.1007/s10584-020-02842-y
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8. Foramitti, J., I. Savin and J. van den Bergh (2021). Emission tax vs. permit trading under bounded rationality and dynamic markets. *Energy Policy* 148, Part B, 112009. https://doi.org/10.1016/j.enpol.2020.112009
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Economics and Management 105, 102396. https://doi.org/10.1016/j.jeem.2020.102396

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12. Foramitti, J., (2021). AgentPy: A package for agent-based modeling in Python. *Journal of Open Source Software*, 6(62), 3065. https://doi.org/10.21105/joss.03065

13. Klein, F., S. Drews, I. Savin and J. van den Bergh (2021). How work patterns affect leisure activities and energy consumption: A time-use analysis for Finland and France. *Energy Research & Social Science* 76, 102054. https://doi.org/10.1016/j.erss.2021.102054

14. Savin, I., S. Drews and J. van den Bergh (2021). GEM: A short "Growth-vs-Environment" Module for survey research. *Ecological Economics* 187, 107092. https://doi.org/10.1016/j.ecolecon.2021.107092

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23. Foramitti (2023). A framework for agent-based models of human needs and ecological limits. *Ecological Economics* 204 part A, 107651. https://doi.org/10.1016/j.ecolecon.2022.107651

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25. Castro-Santa, J., and S. Drews (2023). Heuristic Processing of Green Advertising: Review and Policy Implications. *Ecological Economics* 206, 107760.

26. Savin, I., F. Creutzig, T. Filatova, J. Foramitti, T. Konc, L. Niamir, K. Safarzynska and J. van den Bergh (2023). Agent-based modelling to integrate elements from

different disciplines for ambitious climate policy. *WIREs Climate Change* 14(2), E811, https://wires.onlinelibrary.wiley.com/doi/10.1002/wcc.811

27. Castro-Santa, J., S. Drews and J. van den Bergh (2023). Nudging low-carbon consumption through advertising and social norms. *Journal of Behavioral and Experimental Economics* 102, 101956. https://doi.org/10.1016/j.socec.2022.101956

28. van den Bergh, J., and I. Savin (2023). Impact of carbon pricing on deep decarbonisation: A rejoinder to Lilliestam et al. (2022). Working paper available at SSRN, 9 February 2023, https://ssrn.com/abstract=4352574 or http://dx.doi.org/10.2139/ssrn.4352574

29. Savin, I. (2023). Evolution and recombination of topics in Technological Forecasting and Social Change. *Technological Forecasting and Social Change* 194, 122723. https://doi.org/10.1016/j.techfore.2023.122723

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Additional publications in *Nature* and *Science* journals

1. Exadaktylos, F., and J. van den Bergh (2021). Energy-related behaviour and rebound when rationality, self-interest and willpower are limited. *Nature Energy* 6(12): 1104-1113 https://doi.org/10.1038/s41560-021-00889-4

2. Maestre-Andrés, S., S. Drews, I. Savin, J. van den Bergh (2021). Carbon tax acceptability with information provision and mixed revenue uses. *Nature Communications* 12, Article number 7017. https://doi.org/10.1038/s41467-021-27380-8

3. King, L., and J. van den Bergh (2022). Sugar taxation for climate and sustainability goals. *Nature Sustainability* 5: 899-905. https://www.nature.com/articles/s41893-022-00934-4

4. King, L., J. van den Bergh and G. Kallis (2022). Transparency crucial to Paris climate scenarios. *Science* 375(6583): 827-828. https://www.science.org/doi/10.1126/science.abn7998

5. King, L., I. Savin and S. Drews (2023). Shades of green growth scepticism among climate policy researchers. *Nature Sustainability*, forthcoming.

Commentaries in *Nature* and *PNAS*

1. Galbraith, E., and J. van den Bergh (2020). Carbon tax to aid economic recovery. *Nature* 581, 262, https://www.nature.com/articles/d41586-020-01500-8

2. van den Bergh, J., and W. Botzen (2020). Low-carbon transition is improbable without carbon pricing. *Proceedings of the National Academy of Sciences of the U.S.A. (PNAS)*, 117(38): 23219-23220. https://www.pnas.org/content/117/38/23219

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4. van den Bergh, J., C. van Beers, and L.C. King (2023). Climate activists — rethink fossil-fuel subsidy cuts. *Nature* 617, 465. https://doi.org/10.1038/d41586-023-01620-x

Articles in newspapers & popular-science magazines

5. Drews, S. J. van den Bergh and S. Maestre (2019). ¿Aceptaríamos en España un impuesto al carbono? *The Conversation* https://theconversation.com/aceptariamos-en-espana-un-impuesto-al-carbono-118218

6. van den Bergh, J. (2019). Más allá del Acuerdo de París para revertir el aumento de emisiones CO2. *El Periódico*, 25 Nov. 2019 https://www.elperiodico.com/es/opinion/20191125/articulo-emisiones-co2-aumento-cambio-climatico-acuerdo-paris-jeroen-van-den-bergh-7750946

7. van den Bergh, J. (2019). Zonder koolstofheffing geen stevig klimaatverdrag. *NRC Handelsblad*, 6 December 2019, https://www.nrc.nl/nieuws/2019/12/06/zonder-koolstofheffing-geen-stevig-klimaatverdrag-a3982918

8. van den Bergh, J. (2020). Doble crisis: Soluciones conjuntas para la pandemia y el cambio climático. *El Periódico*, 21/05/2020. https://www.elperiodico.com/es/opinion/20200521/articulo-jeroen-van-den-bergh-soluciones-conjuntas-pandemia-cambio-climatico-7970333

9. Drews, S., I. Savin, J. van den Bergh and S. Villamayor (2020). COVID-19: ¿Nos preocupa ahora menos el cambio climático? *The Conversation*, 30 September 2020, https://theconversation.com/covid-19-nos-preocupa-ahora-menos-el-cambio-climatico-146694

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11. Van den Bergh, J. (2021). Política climàtica eficaç a Espanya, Catalunya i Barcelona (Effective climate policy in Spain, Catalonia and Barcelona). *5centims.cat – Una visió analítica de l'economia catalana*, 9 December 2021, https://www.5centims.cat/politica-climatica-eficac-a-espanya-catalunya-i-barcelona/

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15. New models to assess climate policies. Article about the EVOCLIM project in *EU Research,* Spring 2023, pp. 30-31. https://doi.org/10.56181/MIQD2682

Other relevant outputs

- GEM – module about growth-vs-env opinions for inclusion in surveys by others (Savin/Drews/van den Bergh); for details see https://doi.org/10.1016/j.ecolecon.2021.107092
- Agentpy software to program ABM models for policy in Python (by J. Foramitti); see https://github.com/JoelForamitti/agentpy%20 and https://joss.theoj.org/papers/10.21105/joss.03065
- Team members organized an International Conference on Low-Carbon Lifestyle Changes (LCLC) at ICTA-UAB. While originally intended to be a conventional face-

to-face Conference, due to the Covid-19 crisis, it was decided to change its format to a virtual Conference. More than 800 researchers from all around the world participated. More info: https://lifestyle-changes.org/wp-content/uploads/2020/05/ICTA2020_Program.pdf, the YouTube Playlist of ICTA-UAB https://ictaweb.uab.cat/2020-playlist, and a related journal article https://doi.org/10.1016/j.jclepro.2021.126287.

Awards for & recognitions of EVOCLIM members

- Postdoc Dr. Stefan Drews got the "Extraordinary prize for the doctorate from Universitat Autònoma de Barcelona" (premis extraordinaris de Doctorat), course 2015/2016", in July 2019.
- Postdoc Dr. Ivan Savin received the prize of the Governor of Sverdlovsk region (Russia) for the best study on economics by a young researcher, February 2019.
- PI Jeroen van den Bergh received an honorary doctorate of the Open University of the Netherlands for pioneering contributions to the debate on environmental politics, based on combining elements of evolutionary economics and environmental and behavioural economics. The award was bestowed on him on the 26th of September 2019.
- van den Bergh was invited member of the Climate-Crisis Policy Team ("Klimaatcrisis Beleid Team" – KBT) to advise the Dutch government and parliament about appropriate design of climate policy (Dec. 2020 – Oct. 2021). Seven advisory reports: https://ce.nl/publicaties/klimaatcrisis-beleid-team-kbt/
- van den Bergh is invited member of the climate-policy advisory board of the city of Barcelona (since January 2021): https://www.barcelona.cat/barcelona-pel-clima/ca/barcelona-respon/grup-dexpertes-i-experts-demergencia-climatica-de-barcelona
- PhD student Théo Konc got an honorary mention for the best PhD thesis of EAERE 2022 – the European Association of Environmental and Resource Economists: https://www.eaere.org/best-european-doctoral-dissertation-award/
- PhD student Joël Foramitti won a second place in the 2022 research paper prize for "complexity in macroeconomics" of the UK ESRC project Rebuilding Macroeconomics: https://www.rebuildingmacroeconomics.ac.uk/copy-of-prize-complexity-macro

KEY RESULTS AND INSIGHTS

(Key policy findings are in red)

The ***dissertation by Théo Konc*** combined equilibrium and agent-based modelling to study optimizing agents in a setting of social interactions. The results suggest that by ignoring the social environment in which agents make decisions, conventional climate economics models lead to incomplete or biased conclusions about the composition, effectiveness and public support of climate policy. By contrast, considering social interactions in design of climate policy could help to design more effective and acceptable instruments and thus create better policy responses to the urgency of climate change.

The essential and novel element in his study is that social influence on consumption of high- versus low-carbon goods/services is the channel for secondary effects of pricing instruments. This interdependence of agents' preferences is found to create dynamic, endogenous preferences, in turn giving rise to a "social multiplier" of climate policy. Model analysis shows that policy outcomes depend on the strength of social influence, preference polarization, social network topology, and income inequality. Numerical analysis, informed by realistic parameters for Spain, indicates that the social multiplier of taxation allows to reduce the effective carbon tax rate by

38%. The approach further suggest that the social multiplier can be increased through appropriate information and social-network policies, such as comparative information, social marketing and awards.

In an additional study examines dynamic opinions of socially-influenced agents for climate policy support. This was done by developing a *co-evolution model of public opinion and climate policy stringency*, by combining sequentially a general equilibrium model to assess effects of climate policy with an ABM to calculate associated policy support. Such support depends on both individual political preferences (which are diverse) and influence by others in a social network, until convergence. *So as opposed to the previous study, here social interactions do not influence consumption decisions but opinions and indirectly voter/political support.* One finding is that agents' tendency to resist opinion change translates into higher support for a tax trajectory with a lower initial tax that increases fast in later periods, to achieve a sufficiently ambitious policy that meets emissions/climate targets. Additionally, transfers to households are found to help gaining maximum support for climate policy, more so then green spendings. When social influence plays a stronger role in shaping agents' opinion about the policy, transfers to low-income households tend result in lower policy support as social influence helps gathering public support for (regressive) policies that are favourable to well-connected and those relatively influential richer households. The approach further finds that carbon taxation with progressive redistribution consistently generates more public support than standards, which resemble in support more carbon taxation with proportional redistribution.
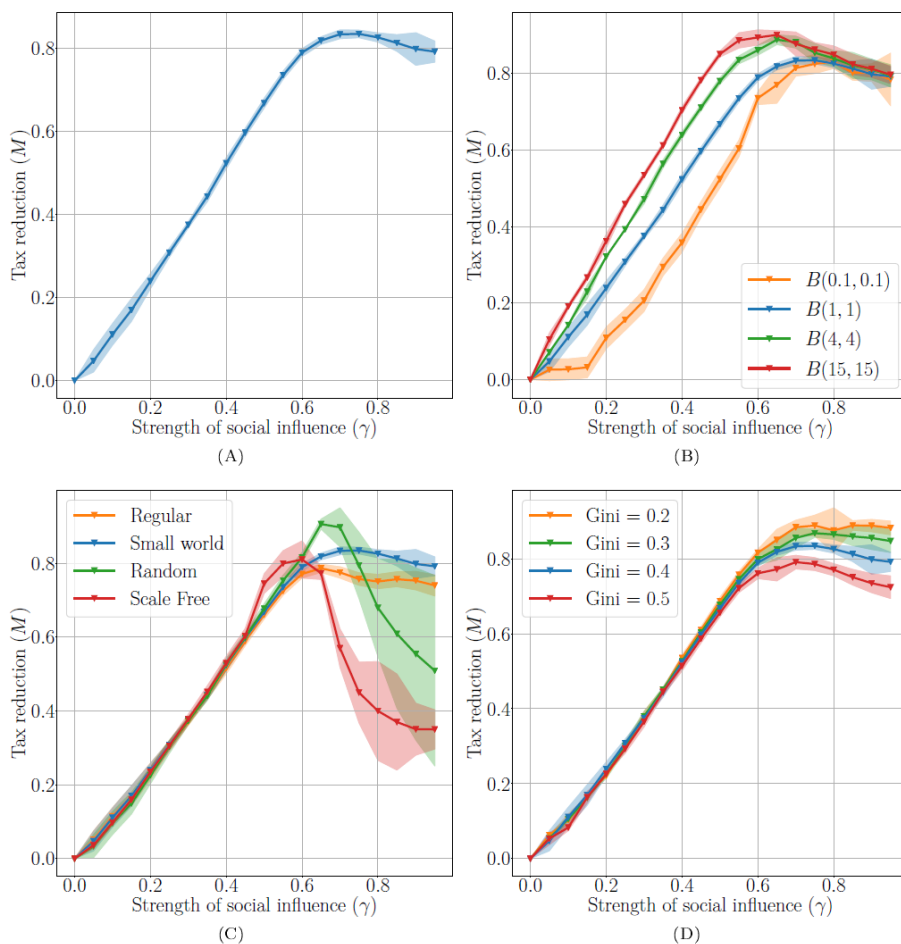

Figure 3.5: Reduction in effective carbon tax due to social multiplier effect for varying strength of social influence and (A) Baseline parameters; (B) different intrinsic taste distributions; (C) different network topologies; (D) different income distributions.
Note: Unless specified differently, the parameters are chosen according to the baseline scenario specified in Table 3.1. The shaded area represents +/- 1 standard deviation around the average.

9

The research objective of the **thesis by Joël Foramitti** was to evaluate the relative performance of climate policies when realistic assumptions are adopted regarding the behaviour of polluters. Three key instruments are analysed: a carbon tax, a permit market, and direct regulation in the form of an emission quota. Emission quotas do not involve a price for emissions but will of course affect prices of goods and services as well. Each of these instruments can be applied either upstream, where fossil fuels are extracted, or downstream, where emissions are caused. Two chapters compares policy performance on the supply-side, while two others give attention to the demand-side, looking at how climate policy affects human needs and well-being.

The main policy insights are as follows. The comparison between a carbon tax and permit trading indicates as an important difference that successful mitigation will reduce the demand for permits, which leads to a fall in permit prices. This creates a competitive disadvantage for firms who adopted low-carbon technology when permit prices where high. Such a dynamic can lead to unstable permit prices and inconsistent incentives, resulting in higher abatement costs than under an equivalent carbon tax.

A key difference between upstream and downstream regulation is that the latter reduces demand, and thus also the price, of fossil fuels. Results show that this makes it possible for unregulated firms to buy fuels at a cheap price, leading to an increase in emissions outside the policymaker's jurisdiction. Upstream regulation, in contrast, increases the overall price of emissions by reducing the global supply of fuels – thus preventing this kind of emission leakage.

Direct regulation, in the form of a uniform emission quota, is found to lead to similar profit rates as under grandfathering, since firms will charge scarcity rents to compensate for production restraints. However, since quotas cannot be traded, if applied downstream it obstructs the shift of production towards firms with low abatement costs, leading to less efficient outcomes than under a carbon tax or permit trading. This confirms traditional insights based on rational agents.

To study the performance of climate policy from a demand-side perspective, the Needs and Limits (N&L) framework was developed to offer a theoretical and computational foundation for agent-based simulations. It considers the behaviour and well-being of individuals with multiple human needs, which are satiable, adaptive, and interdependent with the social and bio-physical environment. Analysis suggests carbon pricing to be combined with progressive revenue recycling and effective improvements of low-carbon infrastructure. Again, findings are in line with rational-agent models, suggesting that traditional economic insights about climate policy are fairly robust.

Based on psychological research, human needs are described as satiable, adaptive, and interdependent with the social and bio-physical environment. The N&L framework represents a generic foundation that can be applied to a broad range of socio-economic and ecological scenarios. A comparison is provided with classical utility approaches. The framework is illustrated for the topics of income inequality and climate policy. In general it is found that bounded rationality does not alter basic insights from mainstream equilibrium approaches with rational agents.

Finally, markets have the advantage that they will respond to bounded rationality such as habits by creating a price sufficiently high to assure the cap is met. Carbon taxation, lacking this endogenous price, will be less effective under bounded rationality. Of course, carbon markets have other advantages, such as harmonization & easy integration of national policies – witness EU-ETS which covers 31 countries and has by far the highest price of all carbon pricing initiatives worldwide. So the future of carbon pricing seems to be cap-and-trade or carbon markets.
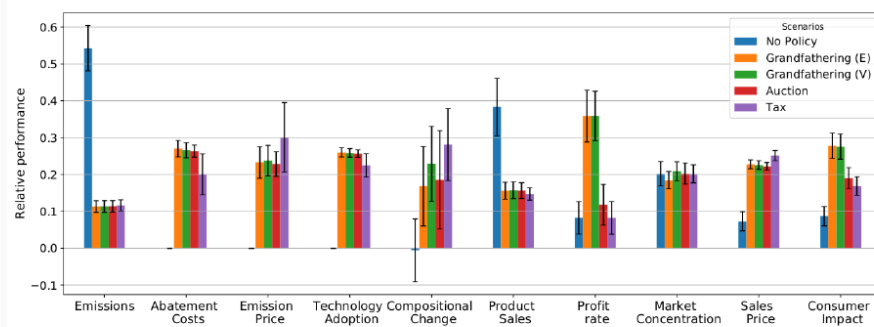
Figure 3: Aggregate evaluation measures that are calculated over multiple runs with different parameter combinations to compare policy scenarios.

The ***dissertation by Juana Castro*** examined, using an experimental approach, how advertising interacts with social norms in terms of consumer choice of low- versus high carbon products. This involved attention for spillovers from low-carbon purchases to other relevant pro-environmental behaviours. The approach allows unravelling the heuristics that people use to process green advertising messages.

A first experiment presented participants with a pro-environmental social norm and green advertising in a simulated Facebook homepage to test their effectiveness in enhancing green choices over high-carbon alternatives. While the social norm had a positive effect on encouraging low-carbon choices, the results show a greater influence of green advertising on choice as it influences perceptions of all product attributes, namely, quality, popularity, and environmental perceptions. Moreover, when presented together, green advertising and social norm do not show positive interaction effects. Rather, advertising for either high- or low-carbon products determined choice. This suggests that communicating a pro-environmental social norm in the presence of commercial advertising might have little or no effect as advertising plays a dominant role.

A second study examined the potential negative spillovers from initial green purchases to subsequent green purchases and climate policy support. In an experiment, participants were randomly assigned to select products from a shop with mostly conventional or green products. This was followed by a similar behaviour, namely purchase of a green versus conventional product, or a very different one like support for costly climate policies. The results show that spillovers are moderated by dissimilarity of subsequent choices and by the price of green products. When initial green products were cheap, the spillover was positive for subsequent green purchases and negative for policy support. These results mean novel evidence for a trade-off in climate policy: incentivizing green purchases through lower (e.g., subsidized) prices may have adverse effects on policy support (perhaps people think that climate change can be mitigated without strong policies), yet positive ones for subsequent green purchases.

So it is found that advertising is effective in influencing consumer choice, both positively (low-carbon) and negatively (high-carbon). Far from being only an information channel, green advertising uses emotional persuasion mechanisms to influence consumer preferences that trigger non-rational biases in the processing of information. This may involve inattention to information about social norms, or inaction in support for climate policies. All in all, we need to regulate advertising for its own sake and to assure information policies will have more impact.
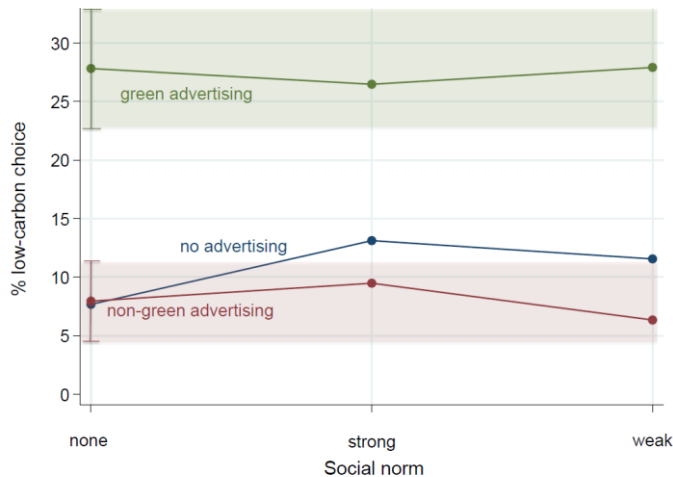
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Figure 3. Combined Effects: Green and Non-Green Advertising Counteract Social-Norm Nudges. The dots in the graph display the share of low-carbon choice for advertising and social-norm nudges, and its combinations. Green and red coloured dots display treatments presenting green and non-green advertising respectively, while treatments without any advertising (baseline and social norm only) are depicted in blue. The x-axis indicates the presence of a social norm nudging towards low-carbon consumption and its type (weak/strong). Shaded regions depict 95% confidence intervals for green and non-green advertising only treatments.

The **thesis by Franziska Klein** explored the potential for an employment double dividend (DD) using a behavioural-evolutionary modelling approach. This involved thinking about how to model decisions in labour and goods markets.

One study undertook empirical analysis of the relationship between work time, leisure activities and resulting energy use for different types of employees, with applications to two countries, namely France and Finland. It differentiated between part-time and full-time employees and used detailed information about energy intensities of activities. It found that the combination of work and leisure activities differs between the two countries, with variations between part-time and full-time workers being more pronounced in France than in Finland. This may be due to cultural and institutional differences. Both countries exhibit significant non-linear links between work and certain activities. The comparison of two energy use metrics (total energy versus direct energy) suggests the importance of accounting for energy use in both production and consumption.

Next, an agent-based model (ABM) was developed to replicate the results of a general equilibrium model (GEM) of ETR by Aubert and Chiroleu-Assouline (2019). This methodological study thus tested the potential for "agentization" of a GEM. This confirmed that most propositions derived from the GEM study were robust except for results relying on precise equilibrium conditions, which were hard to reproduce with an ABM. Dynamics, job search time, and hidden monetary flows such as potential profits appeared to create model challenges and differences in results.

Subsequently, this model was extended to arrive at a comprehensive ABM of ETR. To this end, a number of features were added: heterogeneous households in terms of education/skills, gender, location, and employment sector; consumption goods with distinct energy intensities and consumption time, and produced with varying energy and labour intensities; and households and firms acting habitually.

Without social interaction and uniformly distributed preferences, the preliminary model results are in line with expectations from the traditional literature. We find that a per capita climate dividend paid to all households turns out particularly beneficial to the purchasing power of individuals who are outside of the workforce, but does not enable reductions in energy consumption. Tax reform may benefit men's employment in the high-wage rural service sector and men's purchasing power in the high-wage urban service sector disproportionately, compared to women in the same category. We further find that stronger leisure preferences in a non-social setting

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yield qualitatively similar results for an employment double dividend as lower leisure preferences. However, the reduction in unemployment under stronger leisure preferences goes along with lower purchasing power.

With social interactions, notably imitation of wealthier and higher-status peers, increased labour supply and consumption result. The potential for an employment double dividend is then compromised, as average work time increases, which substitutes for job creation. Furthermore, we find that in a social setting, wage dynamics can in fact lead to less labour and more energy use in production. This is the case for high-wage workers in the non-competitive service sector. Higher prevalence of green preferences in a social setting raises the chances for an environmental dividend but not for an employment dividend.

The findings confirm many results of equilibrium-model based studies of the DD, indicating they are robust to different settings. Yet, taking a time-based perspective with multi-dimensional heterogeneity delivers a number of novel insights. Especially gendered patterns of consumption and labour supply have not received much attention in the study of the DD. More attention for heterogeneity beyond income is thus likely to advance policy advise about ETR. Specifically household heterogeneity in multiple dimensions is relevant as combinations of household features matter, such as being a woman who lives in a rural area and works in a particular sector, rather than just gender as such.
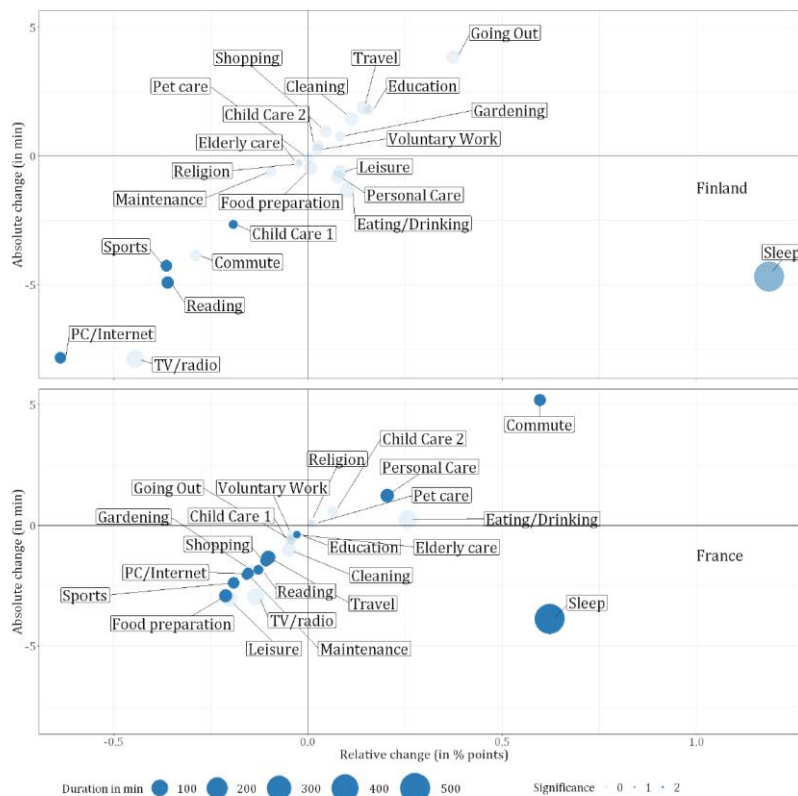

Figure 3.2: Relative and absolute changes in activity duration associated with a one-hour increase of work

Note: Finland (upper plot) and France (lower plot). Coordinates reflect the total marginal effect of a change in work time (including interaction term and squared term). Transparency of the points indicates whether the respective β_1 coefficients in the two models, M1 and M2, are at least statistically significant at the 5% level.
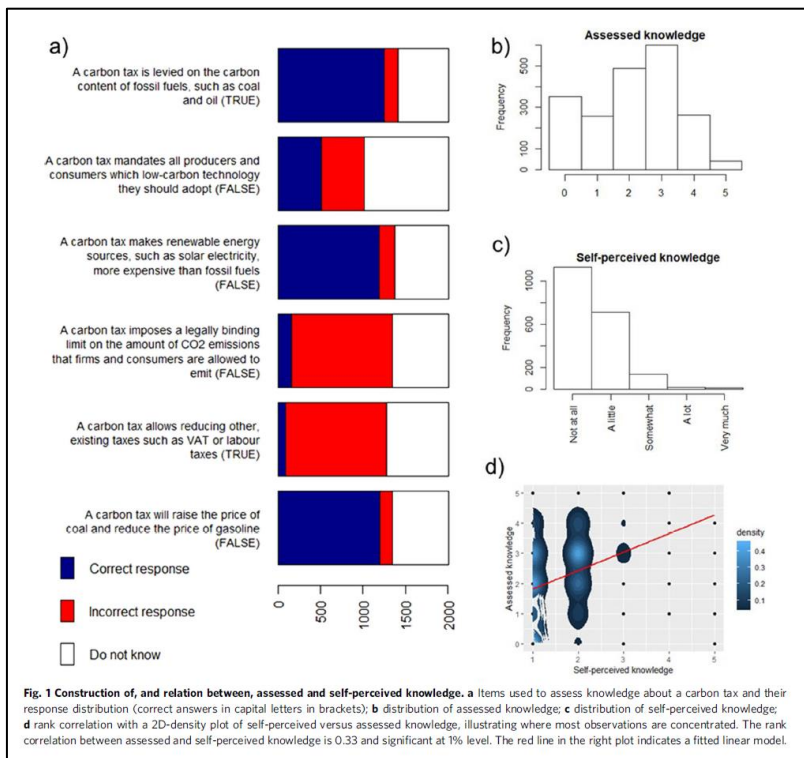
In addition, we realized various studies with postdocs in a leading role.
A first one, led by Exadaktylos and published in *Nature Energy*, studied energy rebound under bounded rationality, self-interest, and willpower. The extent to which adopting energy-efficient technologies results in energy savings depends on how

such technologies are used, and how monetary savings from energy efficiency are spent. Energy rebound occurs when potential energy savings are diminished due to post-adoption behaviour. We reviewed empirical studies on how six behavioural regularities (inattention/misconceptions, mental accounting, defaults/habits, present bias, pro-environmental values/moral licensing, peer influence) affect three energy-relevant decisions and ultimately rebound: adoption of energy-saving products or practices, their intensity of use and spending of associated monetary savings. The findings suggest that behaviours that reflect limited rationality and willpower may increase rebound, while the effects of behaviours driven by bounded self-interest are less clear. We then described how interventions associated with each of the behavioural regularities can influence rebound and thus serve to achieve higher energy savings. Our recommendation is that future research studies energy-relevant decisions in a more integrated manner, with a focus on re-spending as this presents the greatest challenge for policy.

A second study, by a team of three postdocs and the PI, published in *Nature Communications*, studied the public acceptability of carbon taxation for Spain, examining in particular the role of revenue use and information provision. This was motivated by unclarity about which single or mixed revenue use is most appropriate, and which perceptions of policy effectiveness and fairness explain this. In addition, it is uncertain how people's prior knowledge about carbon taxation affects policy acceptability. We, therefore, conducted a survey experiment to test how distinct revenue uses, prior knowledge, and information provision about the functioning of carbon taxation affect policy perceptions and acceptability. We provide evidence that spending revenues on climate projects maximises acceptability as well as perceived fairness and effectiveness. This may, however, mix up a behavioural purpose of carbon taxation with a financing purpose. A mix of different revenue uses is also popular, notably compensating low-income households and funding climate projects. In addition, providing information about carbon taxation is found to increase acceptability for unspecified revenue use and for people with more prior tax knowledge. Furthermore, policy acceptability is more strongly related to perceived fairness than effectiveness.

Fig. 1 Construction of, and relation between, assessed and self-perceived knowledge. a Items used to assess knowledge about a carbon tax and their response distribution (correct answers in capital letters in brackets); **b** distribution of assessed knowledge; **c** distribution of self-perceived knowledge; **d** rank correlation with a 2D-density plot of self-perceived versus assessed knowledge, illustrating where most observations are concentrated. The rank correlation between assessed and self-perceived knowledge is 0.33 and significant at 1% level. The red line in the right plot indicates a fitted linear model.

The previous survey was done just before the outbreak of COVID-19. Hence, we decided to repeat the survey with additional questions after the first outbreak, leading to two publication, led by Drews and Savin, and published in *Ecological Economics* and *PLOS One*, respectively. This second survey was aimed at testing how COVID-19 affected public engagement with the climate crisis. According to the finite-pool-of-worry hypothesis, concern about climate change should have decreased after the pandemic, in turn reducing climate-policy acceptance. We test these and several other conjectures by using survey data from 1172 Spanish participants who responded before and after the first wave of COVID-19, allowing for both aggregate and within-person analyses. Findings indicate that on average climate concern has decreased, while acceptance of most climate policies has increased. At the individual-level, adverse health experiences are unrelated to these changes. The same holds for negative economic experiences, with the exception that unemployment is associated with reduced acceptance of some policies. Complementary to the finite-pool-of-worry test, we examine three additional pandemic-related issues. As we find, (1) higher climate concern and policy acceptance are associated with a belief that climate change contributed to the COVID-19 outbreak; (2) higher policy acceptance is associated with a positive opinion about how the government addressed the COVID-19 crisis; (3) citizens show favourable attitudes to a carbon tax with revenues used to compensate COVID-19-related expenditures. Overall, we conclude there is support for addressing the global climate crisis even during a global health crisis. The second and related publication uses computational linguistics to analyse the open-ended questions in the survey. This involves by applying topic modelling to textual responses from the survey. The identified topics tend to be more negative than positive, and more optimistic concerning future climate action by citizens. Positive views involve increasing pro-environmental behaviour and are more common among younger, higher educated and male respondents as well as among those who perceive climate change as a serious threat or positively assessed COVID-19 confinement. Negative topics express concern that financial resources for climate action will be limited due to a focus on healthcare and economic recovery. In addition, they mention government mismanagement and waste due to use of protective measures like masks and gloves as impediments to effective climate action.

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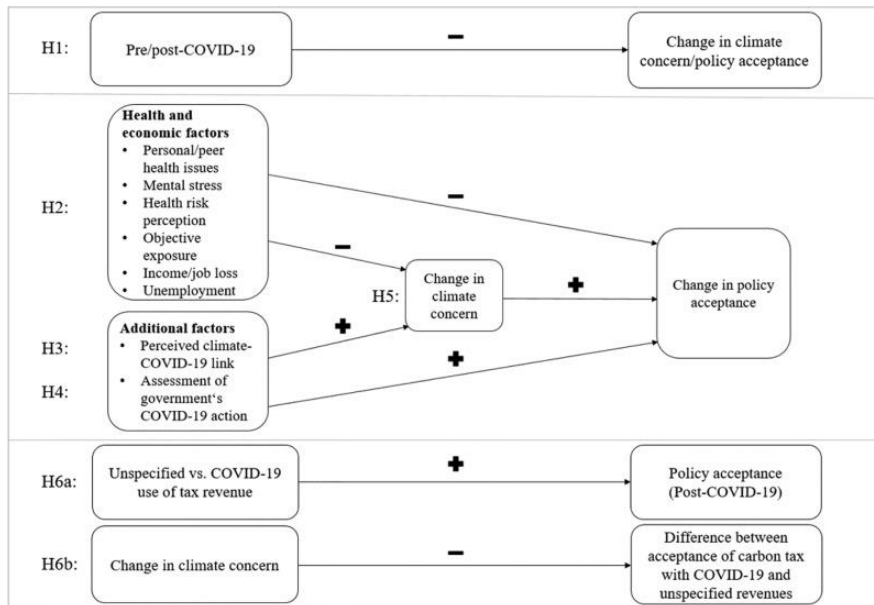
	Topic label	Most discriminating terms and illustrative responses	Topic proportion
2T1	More awareness and less consumption	take, go_out, consume, awareness, pollution, displace, even, home, aware, need	6.4%
		"People are becoming more aware of it, the bicycle is used much more, it is consumed with more awareness"	
2T2	People act as before	do, follow, same, a_bit, influence, citizen, topic, explain, action, covid	9.8%
		"They will continue acting the same as they did before covid"	
2T3	Priority for economy and health	change, affect, economy, relationship, situation, health, habit, environment, economic, thing	7.1%
		"That we prioritize health or the economy if we decide for health we do not generate money if we prioritize the economy the virus spreads who cares about climate change"	
2T4	Lack of government support	government, duty, help, put, means, environmental, citizenship, environmental, motive, unemployment	6.1%
		"Because people are not sufficiently aware of the damage we are causing and it should be governments that force people to act through education"	
2T5	Confinement fosters environmental care	know, take_care, improve, world, realize, air, have, human, city, great	9.8%
		"The pandemic has taught us the importance of respecting and caring for the environment and how vulnerable we are"	
2T6	Change is inevitable	change, want, time, a_lot, carry, new, virus, appearance, suffer, activity	5.1%
		"People have spent time at home, time to reflect, time in which we realize that we cannot buy what is important with money and anything goes, I think we will learn a lot from this pandemic"	
2T7	Old habits die hard	think, life, how_much, normality, habit, reason, sense, believe, always, attitude	7.4%
		"I think in the long run they will forget and return to their routines"	
2T8	People are myopic	now, equal, important, import, good, concern, attention, pending, resource, protect"	7.8%
		"People live day by day and they don't care what happens tomorrow as long as they are fine now"	
2T9	COVID-19 adds to waste	mask, glove, plastic, use, throw_away, residue, soil, generate, street, public	13.1%
		"The massive use of masks and gloves will end up as garbage in our oceans"	
2T10	People are occupied by other problems	climate_change, problem, worry, majority, worried, spanish, priority, exist, position, population	12.0%
		"Because it is another problem and we already have too many problems"	
2T11	Teleworking and less travel	less, car, respect, travel, catch, count, decrease, trip, see, energy	9.2%
		"Transportation by car and motorcycle will be reduced and more will be done by bicycle and scooter, teleworking will be promoted avoiding unnecessary travel"	
2T12	People consume more responsibly	aware, nature, though, awareness, behavior, impact, response, power, reflect, better	6.2%
		"This forced confinement has made people internalize that there is a transition to a world that is more respectful of our environment and with"	

Note: The terms shown are those that are the most frequent as well as exclusive to each topic. Illustrative responses are chosen from the ten responses with the highest topic prevalence. The original text was in Spanish. Here we report only the English translation, while the original Spanish words and phrases are presented in S4 Table in S1 File.

For more information about the EVOCLIM project, please contact Prof. Jeroen van den Bergh: jeroen.bergh@uab.es

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