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D9.1 Transitioning towards Harmonious Living: A Society-Economy-Nature model with heterogeneous agents, finite resources and politics (SEN-HARP) for Europe-27

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Authors

Pierre Funalot – Researcher of the SPES project, Bordeaux University, Bordeaux School of Economics

Eric Rougier – Team leader and researcher of the SPES project, Bordeaux University, Bordeaux School of Economics

Maïder Saint Jean - Researcher of the SPES project, Bordeaux University, Bordeaux School of Economics

Contributors and Peer reviewers

Mario Biggeri, University of Florence; Corrado Di Guilmi, University of Florence; Martin Henseler, Partnership for Economic Policy; Zsófia Kőműves, Cambridge Econometrics (Budapest); Luca Lodi, University of Florence; Elisa Omodei, Central European University.

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Disclaimer

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Abstract

The urgent need to mitigate climate change demands rapid and extensive de-carbonization of global economies. Transition to net-zero carbon is not merely technical but a complex socio-political endeavour with significant trade-offs involving inequality, well-being, sustainability, and political acceptability. If perceived as unfair, the transition risks rejection and political backlash. Still, a just and inclusive transition can also enhance social cohesion and accelerate sustainable policy adoption. In this paper, we introduce a new Agent-Based Model (ABM) called SEN-HARP which integrates biophysical and socio-political modules through original feedback loops to study how these interactions might shape the feasibility and effectiveness of different scenarios of European Union's Green Deal: market-based and innovation, augmented Green Deal, and a disruptive post-growth called “harmonious living”. SEN-HARP articulates the micro and macro levels for simulating the joint dynamics of resource use, warming impacts, livelihood dynamics and voting behaviour the latter being based on perceived gains or losses from transition policies. By combining an Agent-Based Stock-Flow Consistent (AB-SFC) approach with an environmental biophysical module, SEN-HARP can also explore how sustainability goals interact with inequality and political acceptability within fiscal and physical boundaries. While significant progress has been made in understanding the biophysical dimensions of climate change, the socio-political aspects remain largely under-explored by assessment models. This paper therefore provides a useful tool for analysing more comprehensively the trade-offs between effectiveness, fairness and political feasibility brought by the net-zero carbon transition.

Keywords: Carbon Transition; Decent living; Basic needs; Social acceptability; Political responsiveness; Agent-Based model; Stock-Flow Consistent modelling; Endogenous damage; Planetary Boundaries; Spatial Heterogeneity;

1. Introduction

The global imperative to mitigate climate change is necessitating a rapid and far-reaching de-carbonization of economies worldwide. Given the current state of affairs, even greater efforts will be required in the near future to achieve outcomes that align with the targets set for 2050. However, the prevailing trend of setbacks and opposition highlights that transitioning to a low-carbon society is not merely a technical challenge (Thalberg et al, 2024; Vohra, 2024); rather, it is a highly complex task fraught with numerous trade-offs involving inequality, well-being, sustainability, and political acceptability and carried out under significant environmental and socio-political pressure. Identifying these trade-offs and implementing policies that can transform them into synergies is the only viable and urgent path to overcoming delay or setback in Europe as in the rest of the world. Rather than being viewed as a blocking constraint, the costs of transition and their uneven distribution should be seen by European countries as an opportunity to accelerate progress toward sustainability through sound and ambitious policies.

The de-carbonization transition is inherently disruptive, as it involves deeply reconfiguring energy systems, industrial processes, and consumption patterns. Such transformations inevitably create winners and losers, exacerbating or alleviating existing inequalities (Newell and Mulvaney, 2013; Baranzini et al., 2017; Carley and Konisky, 2020; Newell et al., 2022). For instance, the phasing out of fossil fuels may disproportionately affect workers in carbon-intensive industries, while the adoption of renewable energy technologies may benefit regions with abundant solar or wind resources. Structural transformations also embody politically-sensitive trade-offs between nature conservation and material livelihood. These distributional and structural effects have profound implications for social well-being and political stability, necessitating both careful scientific analysis and political resolution (Alkin, 2024). This highlights the central challenge of improving our understanding of how climate change, economic transformation and social acceptability interact to either support or hinder transition policies. Policy challenges are also considerable if the objective is to design actions for transforming trade-offs into synergies.

The present research develops an original and innovative Agent-Based framework for assessing the conditions of economic and socio-political feasibility of different scenarios of European Green Deal and identify policy scenario that allow mitigating the main transition trade-offs. Even if the model is developed to assess different policy scenarios of net-zero carbon transition at the 2050 horizon for the EU27 as an aggregate, the mechanisms described are general and informative of situations ion other regions. For the sake of realism, the model is stock-flow consistent in terms of monetary flows and it incorporates biophysical feedbacks from nature to the economy and society (in terms of matter scarcity and of warming). Another crucial innovation bringing more realism to the simulations is the endogenous determination of transition policy dynamics through poll results and the high degree of granularity that allows addressing spatial heterogeneities in the costs and benefits of transition.

As rightly emphasized by Peng et al (2021: 174), the computer models used by analysts to assess the routes to achieve de-carbonization goals "are missing a crucial factor: politics". This paper seeks to address the existing gap by developing an ABM that integrates a biophysical module with a political module to study the interplay between critical dimensions of the transition. The type of IAM used by institutions strongly shapes their policies. Not all models represent the economic costs of ecological action and inaction in the same way, heterodox models being judged more efficient in describing complex interactions between the society, the economy and nature (Souffron and Jacques, 2023). Among these heterodox models, we follow an ever-increasing strand inscribed in the stock-flow consistent (SFC, Lavoie and Godley 2001, 2007) tradition. More recent works (Dafermos, Nikolaidi and Galanis 2017), like the DEFINE model (Dafermos and Nikolaidi 2022) introduced a complex environmental module.

By incorporating a biophysical module that simulates resource use and environmental impacts, alongside a socio-political module that models different sources of agent heterogeneity as well as voting behaviour based on agents' perceived gains or losses in terms of jobs and consumption from transition policies, our ABM offers a novel framework for analyzing the trade-offs and synergies inherent in the de-carbonization transition. In our model (that we call SEN-HARP for the Society Economy Nature-Heterogeneous Agents (finite) Resources and Politics)[1], the economic, social and political spheres are linked through endogenous variables that arise from the dynamics of the model and cover nine out of the twelve social thresholds identified by Raworth (2017).

Limited account of Energy-economy feedbacks is a literature gap identified by different reviews (Keppo et al., 2021; Ven Eynde et al, 2024) of existing climate policy assessment models. SEN-HARP's biophysical module draws on ecological economics principles to simulate the interactions between human activities and natural systems. It accounts for the finite nature of resources, the environmental impacts of resource extraction and use, and the potential for technological innovation to decouple economic growth from environmental degradation. However, resource availability limits, as well as pollution problems, may endanger the health of the ecological system itself and limit adaptive and innovative response strategies (Daly, 1996; Rockström et al., 2009). The bio-physical element of SEN-HARP model provides the foundation for assessing the sustainability of different de-carbonization pathways, as well as their implications for resource availability and ecosystem health.

Lack of heterogeneity and of consideration of distributive and political dimensions of the transition have also been emphasized as potential limitations of the existing models (Keppo et al., 2021; Ven Eynde et al, 2024). SEN-HARP's political module describes agents as voters who evaluate transition policies based on their perceived impacts on their well-being, which is influenced by factors such as income, employment, and access to resources. Households thus have three roles in the model: they work, consume and vote. In addition, our model includes different types of households (urban *vs* non-urban, skilled *vs* unskilled) endowed with heterogeneous behavioural characteristics and facing heterogeneous constraints. Agents who perceive themselves as winners in the transition are more likely to support de-carbonization policies, while those who perceive themselves as losers are more likely to oppose them. This module allows considering the potential for policy design to mitigate opposition by addressing distributional concerns (Baranzini et al., 2017; Carattini et al., 2019). After Piketty and Cagé's analysis (2023) of geo-classes and electoral structure by differentiating households with respect to their space of residence: urban households are those living in large cities and peripheral households live in secondary cities and rural spaces. A third type of household, which we call "top-income", influences political life by shaping the positions of parties and the overall political climate of our society (Otto et al, 2019).

In terms of the policy sets, we define three main transition policy scenarios: market-based and innovation (close to the first version of the Green Deal), augmented Green Deal, and post-growth. For each scenario, we evaluate the performance of the provisioning systems, that is to say the ways in which the economy is able to satisfy the social and human needs of the households, while preserving Nature. This allows us to evaluate the socio-ecological efficiency of the economy for each scenario, complying with the need of "systematically assessing and comparing provisioning systems and their stock-flow-service efficiencies and outcomes" (Plank et al 2021, p.11). SEN-HARP model is innovative in terms of the outcomes observed, as it bridges social outcomes, notably those defining decent life, and environmental footprints for defining the concept of harmonious living.

[1] Even though the name may suggest it, we do not refer to Amartya Sen in our work.

Harmonious living is inspired by both the eco-development approach (Sachs 1977) and the Donut framework (Raworth, 2017). In this framework, the economy is seen as purely instrumental and is conceived as a web of provisioning factors for attaining social thresholds within biophysical limits.

An additional key foundation of our model is its Stock-Flow Consistent (SFC) framework, which provides a robust foundation for analysing the economic and financial implications of de-carbonization policies by ensuring macroeconomic consistency. This approach, rooted in the post-Keynesian tradition (Godley & Lavoie, 2007), allows us to simulate the macroeconomic effects of policy instruments—such as carbon taxes, subsidies for renewable energy, or green investment programs—while maintaining consistency in the balance sheets of households, firms, governments, and financial institutions. The SFC framework is particularly valuable for analysing the fiscal and financial implications of de-carbonization policies, as it captures the interplay between income distribution, debt dynamics, and economic growth. For example, it enables us to assess how carbon tax revenues can be recycled to mitigate inequality or finance public investments in sustainable infrastructure, and how these measures influence aggregate demand and employment.

To our knowledge, the SEN-HARP model is the first to gather an AB-SFC approach with an environmental bio-physical module and an accounting of provisioning systems as well as voting behaviour. By integrating the biophysical and socio-political modules within a Stock-Flow Consistent framework, our model allows us to explore scenarios in which the pursuit of sustainability goals interacts with the dynamics of inequality and political acceptability in the context of EU27. For example, we can examine how different policy instruments—such as carbon taxes, subsidies for renewable energy, or universal basic income—affect the distribution of costs and benefits, and how these distributional outcomes influence political support for the transition. We can also investigate the conditions under which synergies between sustainability, well-being, and political acceptability emerge, as well as the trade-offs that may arise when these objectives conflict. The model is also fitted to simulate scenarios of carbon transition in democracies, that is under the pressure of votes (Lindvall, 2021; Jordan et al, 2022). As the model is calibrated for EU27, it allows jointly assessing the conditions of socio-political feasibility and environmental effectiveness of the European Green Deal[2] in the context of a European democracy modelled as a two-party (pro- and anti-transition) system. In a context of high (geopolitical) turbulence, it is utterly important to save the European Green Deal by providing ways forward compatible with what European populations are likely to accept in terms of social model, political liberties and economic objectives.

In the following sections, we first detail the positioning in and contributions of our research to the existing literature (Section 2). Thereafter, we undertake a review of the main advances and gaps in climate-economy-society ABMs, with a focus on the innovative dimensions of our model: agents' heterogeneity, distributional impacts and political support, policy design and the integration of well-being and planet boundaries through basic needs and provisioning systems (Section 3). Then, we present the theoretical foundations and objectives of our model and describe in detail its architecture and calibration (Section 4). The main outcomes selected are presented in Section 5, and the subsequent steps of the model development are outlined in Section 6.

[2] The European Green Deal, launched in December 2019, constitutes the European Union's (EU) strategy to make Europe the first climate-neutral continent by 2050. It is a set of policies and initiatives designed to promote sustainable economic growth while reducing greenhouse gas emissions. Key objectives have been established, including achieving climate neutrality by 2050 (i.e. reducing net greenhouse gas emissions to zero), achieving a 55% reduction in emissions by 2030 compared to 1990 levels, promoting a transition to renewable energy sources (e.g. wind, solar, and hydrogen energy), and fostering a circular economy (i.e. reducing waste and encourage recycling), sustainable agriculture (introduce greener farming practices through the Farm to Fork strategy), clean transport (phase out petrol and diesel cars, increase electric vehicles and rail transport), biodiversity protection (restore ecosystems and plant 3 billion trees by 2030), just transition (support regions and workers affected by the green transition).

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