# Iseec

## [1] V. Ramanathan, Y. Xu, and A. Versaci, “Modelling human–natural systems interactions with implications for twenty-first-century warming,” Nat Sustain, vol. 5, no. 3, pp. 263–271, Dec. 2021, doi: 10.1038/s41893-021-00826-z.

由于缺乏对人类与自然系统相互作用在社会应对气候变化方面所起作用的定量处理,重新设计能源和经济系统以稳定气候变化的工作 受到了阻碍。在这里,我们提出了一个综合的社会-能源-生态-气候模型框架,用于理解人类-自然系统相互作用在气候变化中的作用。 我们重点关注全球变暖和社会行动之间的反馈对气候稳定的限制,以使能源使用脱碳和扩大大气碳提取。能源-气候反馈通过从历史数 据推断出的社会、政策和技术行动的四个变暖相关响应时间进行建模。我们表明,2030 年之后缺乏社会响应将导致全球变暖超过 3°C。 将社会反应时间和技术扩散时间加快两倍,同时大幅增加对可再生能源和大气碳提取技术的启动投资,以及到 2030 年短期缓解气候污 染物,可以将升温稳定在 1.5°C 以下。该模型的分析框架和本文提出的分析揭示了在制定和设计稳健的气候解决方案时,在向零排放 过渡的过程中,考虑人-自然系统相互作用的重要性。

The redesign of energy and economic systems to stabilize climate change is hindered by the lack of quantitative treatment of the role that human–natural systems interactions play in what society can do to tackle climate change. Here we present an integrated socio–energy–ecologic–climate model framework for understanding the role of human–natural systems interactions in climate change. We focus on constraints on climate stabilization imposed by feedbacks between global warming and societal actions to decarbonize energy use and to scale up atmospheric-carbon extraction. The energy–climate feedbacks are modelled through four warming-dependent response times for societal, policy and technological actions inferred from historical data. We show that a lack of societal response beyond 2030 would result in a warming in excess of 3 °C. Speeding up societal response times and technology diffusion times by a factor of two along with a dramatic boost in start-up investment in renewables and atmospheric-carbon extraction technologies and short-lived climate pollutants mitigation by 2030 can stabilize the warming below 1.5 °C. The model’s analytical framework and the analyses presented here reveal the fundamental importance of factoring in the role of human–natural systems interactions in the transition to zero emissions when formulating and designing robust climate solutions.

# Stand2019-ays

## [1] F. M. Strnad, W. Barfuss, J. F. Donges, and J. Heitzig, “Deep reinforcement learning in world-earth system models to discover sustainable management strategies,” Chaos: An Interdisciplinary Journal of Nonlinear Science, vol. 29, no. 12, p. 123122, Dec. 2019, doi: 10.1063/1.5124673.

I. INTRODUCTION

【在全球可持续发展的识别路径中需要考虑socio world和生物物理地球之间的互馈过程】

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Efforts invested in identifying pathways toward global sustainability need to account for critical feedback loops between the socioeconomic and sociocultural World and the biophysical Earth system.1,2

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These pathways may require novel, yet undiscovered, multilevel policies, from the local to the global scale, for the governance of this coupled World-Earth system leading toward a safe and just operating space.3,4

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Striving for a safe and just operating space, policymakers of the United Nations agreed on global political cooperation for a sustainable future at the resolution of the 17 Sustainable Development Goals (SDG)5 and the adoption of the Paris Agreement on Climate Change.6

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The safe and just operating space is based on a set of biophysical planetary boundaries (dened on dimensions such as climate change or biosphere integrity loss) as they are formulated by Rockström et al. in Refs. 3, 4, 7, and 8, extended by social foundations (e.g., poverty alleviation) by Raworth.9 If respected together, staying within these boundaries is seen as a prerequisite to ensuring sustainable human development. The eld of Earth system model ing develops computer models to show possible pathways toward a sustainable future.

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However, the identication and characterization of concrete trajectories within the planetary boundaries and above social foundations remains a problem requiring ongoing research eorts.10,1

【本文中的基本假设】

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In this paper, we consider this problem on a globally aggregated level assuming the following basic structure: An abstract single decision-maker interacts with a dynamical, in most cases, nonlinear environment to nd sustainable trajectories within certain boundaries.

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The eld of Integrated Assessment Modeling (IAM) addresses this issue via optimizing a social welfare function in order to estimate the design of sustainable management strategies.12 IAM models integrate data and knowledge from established climate models.13,14 To identify pathways in IAM, numerical solvers such as GAMS15 are frequently used.

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However, these IAM models are highly dependent on the choice of the target function of the optimization. In many cases, this choice may not be obvious and depends on the IAM developers.16

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As another approach, optimal control theory (OCT) can be used to solve problems where dynamical systems are supposed to stay within certain constraints. In these systems, OCT tries to nd an optimal choice for some control variable by optimizing a specic objective function.17 Applied to Earth system models, the focus has been set on the design of climate regulators and their impact on climate modication.18,19

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Viability theory (VT) as a subeld of OCT can be stated as an example. In this field, such problems of identifying trajectories are typically addressed by methods that rely on adiscretization of the state space, followed by the application of local linear approximations.20

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It is, however, not well applicable in systems with more than just a small number of variables due to the curse of dimensionality.2

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The use of reinforcement learning (RL)22 can also be considered as a possible approach for intelligent decision-making within World-Earth system models.23 It is designed for nding optimal policy strategies as well. However, in contrast to the previously presented approaches, RL does not detect solutions based on numerically solving an optimization problem, but by a dynamic search process via exploration and exploitation of past experiences, guided by a reward

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However, tabular methods, which are mainly used for classical RL solutions, cannot be straightforwardly applied to the systems of interest here, due to the continuous state spaces that we mostly nd in World-Earth system models.

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Since then, DRL algorithms have become increasingly popular in the eld of arti- cial intelligence.27,28 The key to the success of this approach lies in the combination of Q-learning,29 neural networks,30 and experience replay,31 which has been shown to learn policies up to a super human performance in a variety of dierent environments.24,25 Often DRL applications come up with unexpected and novel solutions.32,33 Many extensions have been proposed addressing both speed and eciency.34

【drl应用领域广泛】

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Due to its general applicability to various environments, DRL is used in a wide range of dierent elds, e.g., resources management in computer clusters,35 optimization of chemical reactions,36 playing abstract strategy games like chess and Go,32,33 autonomous driving,37 and, in particular, robotics.38–41

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Due to the wide applicability of DRL, we propose a framework that uses DRL as a tool that is both robust and easy to use at the same time to identify and classify trajectories in Earth system models eectively.

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As a proof of concept, we use our DRL framework within various stylized World-Earth system models.2,42

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These models are designed to investigate the coevolutionary dynamics of humans and nature in the Anthropocene. Some rst applications of reinforce

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but as far as we know, there are no approaches yet applying DRL to Earth system models.

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We believe this approach will open so far unused possibilities to discover so far unknown management strategies that keep the Earth system within planetary boundaries, while, at the same time, respecting social foundations of the world’s societies. Recently, various ways of how to tackle problems related to anthropogenic climate change by using machine learning techniques have been outlined.46 Our work proposes a novel strand to this list.

II. METHODS

# C-切入点-ClimateRL-theo

## [1] T. Wolf, N. Nardelli, J. Shawe-Taylor, and M. Perez-Ortiz, “Can reinforcement learning support policy makers? A preliminary study with integrated assessment models,” Dec. 11, 2023, arXiv: arXiv:2312.06527. doi: 10.48550/arXiv.2312.06527.