Game Theoretical Aspects Towards a Sustainable Path to Fight Climate Change

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Abstract

We provide a new form of re-globalization tackling the aspects of climate change by addressing it through a theoretical approach rooted in game theory. A first holistic game of Berlin—between the individual and the group—is presented, grounded in Isaiah Berlin's (Berlin (1961)) concepts of negative and positive liberty. Next, we generalize a non-cooperative game of climate change. Building on an evolutionary game theory approach (Caleiro et al., 2019), we propose a novel framework. We then explore cooperative games and introduce the notion of Kantian equilibrium as developed by Roemer (2019). Finally, we discuss the intertemporal political-economic approach to climate change in the context of an overlapping generations (OLG) model, as in Rocha de Sousa and Pica (2023). We conclude with conjectures on global climate governance, drawing from simulations of global ecological footprints (Araújo et al., 2025).

Keywords: Game Theory, Climate Change, Re-globalization, Kantian Equilibrium, OLG Model, Global Governance.

JEL Codes: C72, D62, H23, Q54, Q58.

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1 Introduction

Game theory is an essential tool for studying strategic and dynamic interactions. In fact, it is fundamentally defined by the presence of strategic interaction between at least two players.

The origins of game theory precede von Neumann (1921), who laid the groundwork for the formalization of the discipline by providing solutions for non-cooperative zero-sum games.

In simple terms, zero-sum games are those in which one player's loss is exactly equal to the other's gain. This concept was elegantly articulated in von Neumann and Morgenstern (1944)'s magnum opus, *The Theory of Games and Economic Behavior*.

Yet, something was still missing: there were no general solutions for non-zero sum type of non-cooperative games.

John Nash, in his early twenties, discovered such a solution through what we now call the Nash Equilibrium (Nash, 1950b,a). His method used fixed-point theorems—initially Brouwer's ((Brouwer, 1911)) and later Kakutani's((Kakutani, 1941))—to prove the existence of equilibrium.

Interestingly, although von Neumann (1921) was Nash's advisor, he reportedly dismissed the result as "a trivial fixed-point solution."

Nevertheless, Nash's contribution remains one of the most elegant and foundational results in the development of game theory.

There was immediate interest in applying non-cooperative game theory to environmental issues.

This paper explores the intersection of classical and evolutionary game theory (Caleiro et al., 2019), and the political economy of climate change—not only at the individual level but also across nation-states in need of a global governance framework.

We discuss incentive structures between individuals and groups using the lens of freedom types, as introduced by Berlin (1961), and formalize a proposal by Stiglitz (2024), as elaborated in Rocha de Sousa et al. (2025).

Finally, we propose a commons-based solution using the concept of Kantian equilibrium (Roemer, 2019). Whether additive or multiplicative in nature, it offers a foundation for resolving collective action problems in climate governance.

2 Theoretical Framework

Isaiah Berlin (Berlin (1961)) introduced two important notions of liberty: *positive liberty*, which can be understood as "what you are free to do," and *negative liberty*, or "what others are not free to do to you" — in other words, liberty that is either unrestricted (positive) or constrained (negative).

At first glance, this distinction might seem straightforward. However, classical liberals such as Adam Smith(Smith (1776)), Friedrich von Hayek(Hayek (1960)), Ludwig von Mises(von Mises (1949)), and Murray Rothbard (Rothbard (2009)) tended to favor positive liberty almost exclusively, advocating for minimal interference in the freedom of individuals and markets.

In contrast, traditions rooted in socialism or utopian leftist thought have often emphasized the importance of regulation — a role for the state in defending negative liberty, ensuring that unchecked freedoms do not infringe on the rights or welfare of others.

More recently, Joseph Stiglitz has proposed a nuanced position (Stiglitz (2024)). Reflecting on the fallout of the 2008 financial crisis — which he attributes, in part, to an "excess of liberty" — Stiglitz offers a compelling case against an overly liberal agenda. He proposes the following balanced framework:

a) Positive liberty for the group — whether individuals organized as collectives, institutions, or nation-states — in order to allow liberal systems to function effectively within a cooperative capitalist society.

b) Negative liberty for the individual — meaning that as citizens, we must accept certain general rules that may limit our individual freedom slightly, but do so in the service of the broader common good.

So, if we formalize in terms of game theory approach we might do it between at least two players (Player A= citizen; Player B= the group which he belongs to).

We next present a normal form of the game with 4 possible pay-offs, where the moves of the players A and B, occur specifically on the liberty/freedom space and might choose between positive or negative liberty.

Table 1: Alleged Theoretical Superiority of Global Capitalism Under Global Order

Individual \ Group	**Positive Liberty**	**Negative Liberty**
Positive Liberty	**(10, 10)**	(0, -5)
Negative Liberty	(-5, 0)	(-10, -10)

Source: Authors' creation (Rocha de Sousa et al. (2025)) based on interpretation of Stiglitz (2024).

And the following version presents a solution by Stigliz to solve the global capitalism crisis with an inclusive liberal order, contrasting negative liberty for the individual and positive liberty for the group.

Below, we present an updated assessment of global governance capacity, building on the framework originally proposed by Zweifel (2006). In this approach, each organization is assigned a rating of positive (1), neutral (0), or negative (-1). The original analysis, developed by this Swiss consultant across several institutions, has since been expanded and revised by the author. I first shared this updated assessment at an OECD forum and later presented it at the ESADR conference (Rocha de Sousa, 2013).

The framework presented here combines both approaches and introduces new insights in the context of global governance today.

Table 2: A New Vision of Global Capitalism Under Global Order — A Solution to Global Crises?

Individual \ Group	**Positive Liberty**	**Negative Liberty**
Positive Liberty	(-5, 0)	(0, -5)
Negative Liberty	**(10, 10)**	(-10, -10)

Source: Authors' creation (Rocha de Sousa et al. (2025)) based on interpretation of Stiglitz (2024).

Table 3: Comparative Capacity of International Organizations for Global Governance (Scale: -1(negative), 0 (neutral) to 1 (positive))

Dimension	**UNFCCC**	**IMF**	**WTO**	**WB**	**UNDP**	**G20**	**OECD**
Democracy / Transparency	1	-1	-1	0	1	-1	0
Accountability	0	-1	0	0	0	-1	1
Effectiveness	0	1	1	1	0	1	1
Enforcement	-1	1	1	1	-1	0	0
Legitimacy	1	0	-1	0	1	-1	0
Inclusiveness	1	-1	0	0	1	-1	-1
Total Score	**2**	**-1**	**0**	**2**	**2**	**-3**	**1**
Ranking	#1	#5	#4	#1	#1	#7	#3

Source: Authors' creation based on interpretation of Zweifel (2006) and updated Rocha de Sousa (2013).

3 Methodology

In this section, we expand our approach by analyzing three key dimensions related to **global climate governance**:

i) Evolutionary game theory
ii) Overlapping Generations (OLG) models
iii) World eco-footprint forecasting

Each of these methodological pillars builds upon previously published research, yet they collectively lay the groundwork for the **novel contribution** of this paper.

The originality of this study lies in establishing a clear and structured diagnosis of **where we currently stand as a human species** and **where we are headed** in the realm of global climate governance.

More importantly, we aim to offer a ***preliminary roadmap toward a viable solution — a path we could and should take to achieve genuine sustainable development***.

This leads us to our guiding **research question**:
How can we avert the looming ecocide through improved global ecological governance?

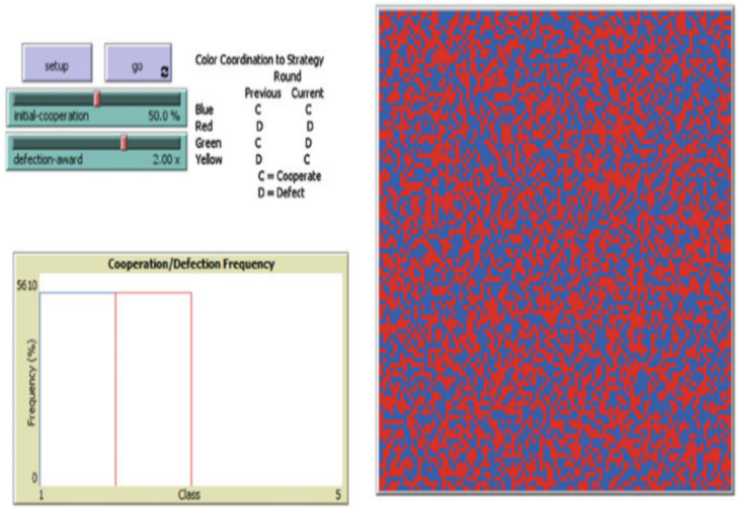

Fig. 1 The initial situation

Figure 1: The initial situation with 50% cooperatives and 50% non-cooperatives agents. Source:Caleiro et al. (2019)

We begin by offering a comprehensive diagnosis as the foundation for identifying a potential solution.

Methodologically, approach (i) applies evolutionary game theory; approach (ii) uses an Overlapping Generations (OLG) model — which is game-theoretical but deterministic in nature; and approach (iii) involves long-term projections of the global ecological footprint for the years 2050 and 2100.

These approaches are grounded in the following references: (i) is detailed in Caleiro et al. (2019), (ii) in Rocha de Sousa and Pica (2023), and (iii) in Araújo et al. (2025).

4 Results and Discussion

4.1 Evolutionary Game Theory

These approaches are grounded in the references detailed in Caleiro et al. (2019).
We consider four distinct types of agents: CC, $N_C N_C$, $N_C C$, and CN_C. These represent, respectively: agents who are cooperative and remain cooperative (CC); agents who are non-cooperative and remain non-cooperative ($N_C N_C$); agents who shift from non-cooperative to cooperative ($N_C C$); and agents who shift from cooperative to non-cooperative (CN_C).
We start from a uniform world with an even split between cooperative and non-cooperative agents — that is, 50% CC and 50% $N_C N_C$.

Next, we simulate how our world would evolve based on a risk-reward penalty premium for non-cooperation.
If this penalty premium is low, we are likely to follow an ecocidal trajectory—reaching a tipping point, a point of no return, after which our "squared" world turns entirely red. In other words, all agents become $N_C N_C$ (non-cooperative), and the Climate Change

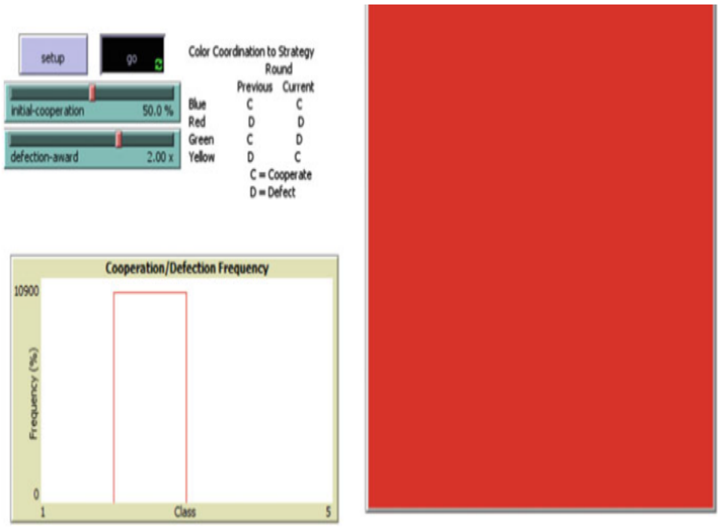

Fig. 2 The disastrous situation

Figure 2: The disastrous situation with 100% non-cooperatives agents. Source:Caleiro et al. (2019)

problem remains unsolved.
This scenario can also be referred to as a **BAU scenario**—a **business-as-usual scenario**—which clearly leads to an **ecocide** pathway.

If, however, the risk-reward penalty for non-cooperative behavior regarding climate change is increased, islands of cooperation (blue cooperative agents) begin to emerge. In the long run, this can lead to a turning point—a viable path away from an ecocidal trajectory.
Eventually, the system may evolve into a fully blue, cooperative world, where all agents act cooperatively and the problem of climate change is effectively addressed.

These scenarios might initially seem overly pessimistic in the first case and overly optimistic in the latter.
Nevertheless, they provide a solid theoretical benchmark that the literature on incentives for human cooperation and behavior should take into consideration.

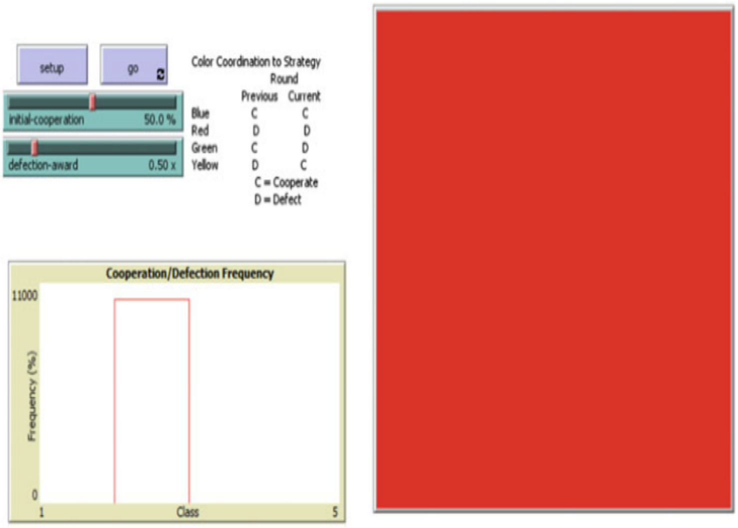

Fig. 3 The reduced defection-award situation

Figure 3: The reduced defection award situation with 100% non-cooperatives agents as a start. Source:Caleiro et al. (2019)

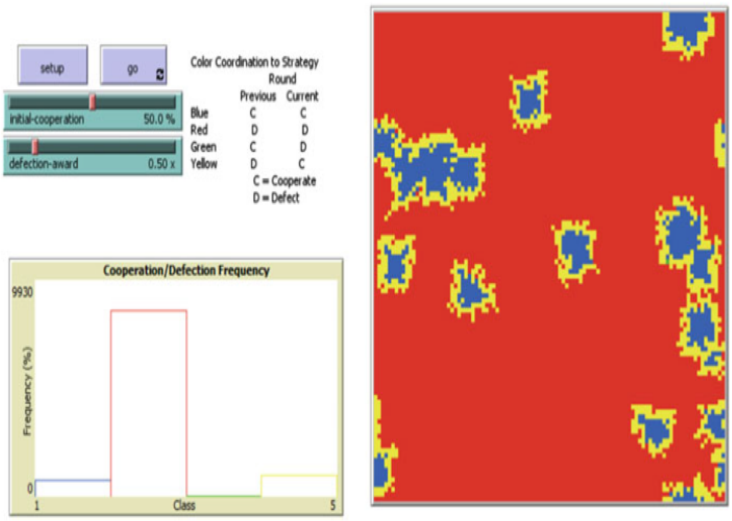

Fig. 4 A first intermediate situation

Figure 4: A first intermedite situation with islands of hope. Source:Caleiro et al. (2019)

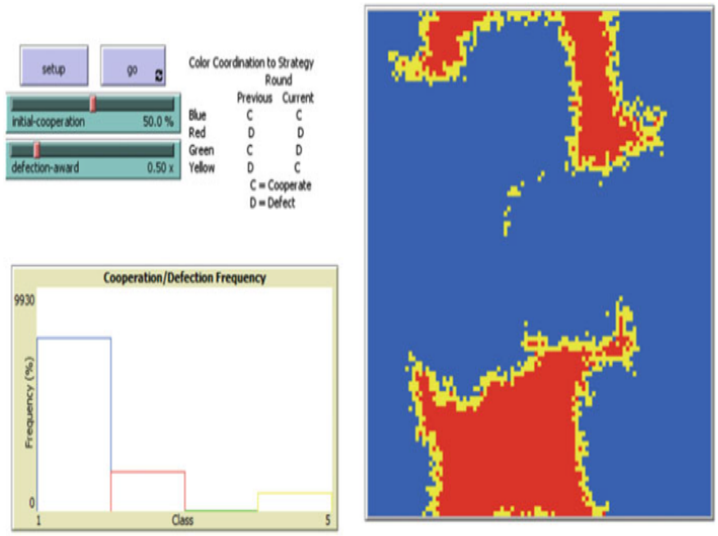

Fig. 5 A second intermediate situation

Figure 5: A second intermedite situation going well. Source:Caleiro et al. (2019)

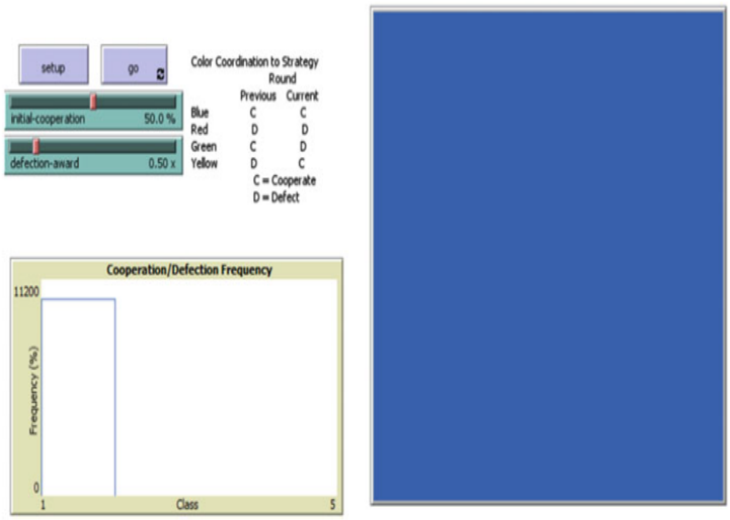

Fig. 6 The final situation

Figure 6: An ideal solution in the long run. Source:Caleiro et al. (2019)

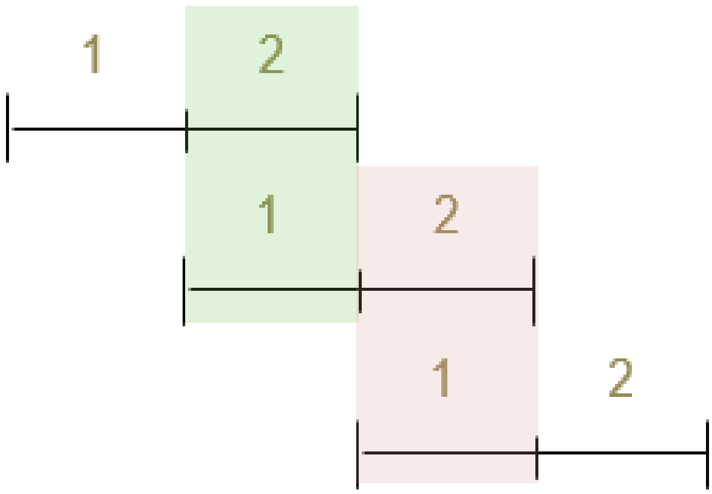

Figure 7: The two cohorts in an OLG model. Source:Rocha de Sousa and Pica (2023)

4.2 An OLG model

These approaches are grounded in the references, particularly in Rocha de Sousa and Pica (2023).
Although this model is deterministic, it enables us to evaluate how individuals—living through two life stages, as young and elderly—respond to the need for energy replacement and show willingness to invest in renewable energy.
At any given point in time, the model considers two overlapping cohorts: the young and the elderly.

In the next period, $t+1$, today's young become the elderly, and the current elderly exit the model.
The novelty of our approach lies in introducing a continuous chain of intergenerational concern—not only as a matter of the elderly caring about the environmental legacy they leave behind, but as a deeper ethical commitment to future generations, even after one's death.
This resonates with a Christian sense of belonging and responsibility for others, reflecting a moral duty that transcends one's own lifetime.
It aligns with the concept of intergenerational concern formalized by economist Nicholas Stern in 2009 through the η parameter.
As this sense of belonging to others—and of responsibility for what we leave behind—increases, so does the potential to resolve the climate crisis.
In Rocha de Sousa and Pica (2023), we present this via a deterministic model inspired by Udalov, extended to incorporate posthumous care and the dynamic interaction between present-day actions and future environmental bequests.
Even within a deterministic framework, the emphasis on caring for others opens a pathway toward climate solutions.
This aligns with Stern's conclusions and literature on "warm glow" altruism and Michael Tomasello's research on prosocial behavior.
Without delving too deeply into technicalities, we derived an interaction surface between

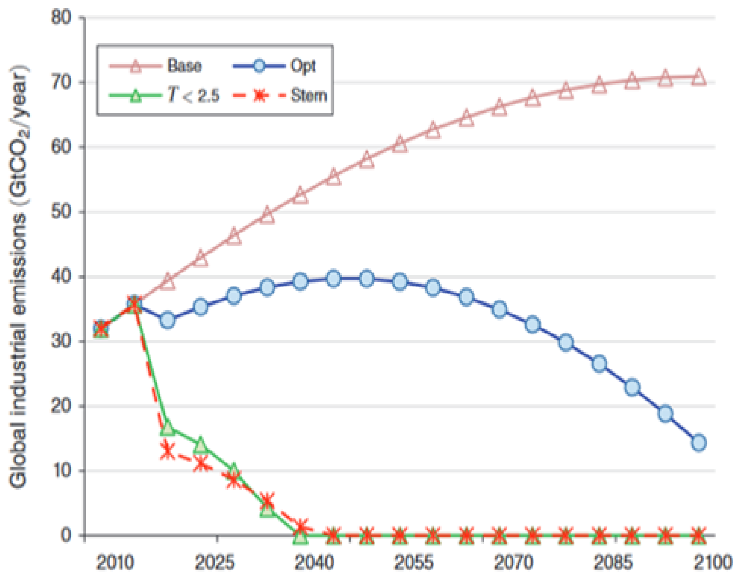

Figure 8: The trajectory accordingly to Nordhaus(2019). Source:Rocha de Sousa and Pica (2023)

current and future generations, shaped by concern for others. This is parameterized by β, the intertemporal discount rate, and r, the market interest rate or return on capital investment.

This figure 12 relates three different time domains and Nash equilibrium between youngsters and elderlies, η vertical axis, represents intergenerational concern among individuals, and r as capitalization of time, that is market value for the future investments, and δ represents for the individual an actualization from the future discounted till the present.

4.3 World eco-footprint forecasts

These approaches are grounded in the following references as in Araújo et al. (2025).
In this analysis the authors predict using the world formula for eco-fooprint a scenario analysis till 2050 and 2100.
The referred BAU scenario is catastrofic and only a smart sustainability scenario (a kind of nordic/scandinavian scenario is an inspiration) can tackle a lead to effective sustainable path in 2050 and 2100.

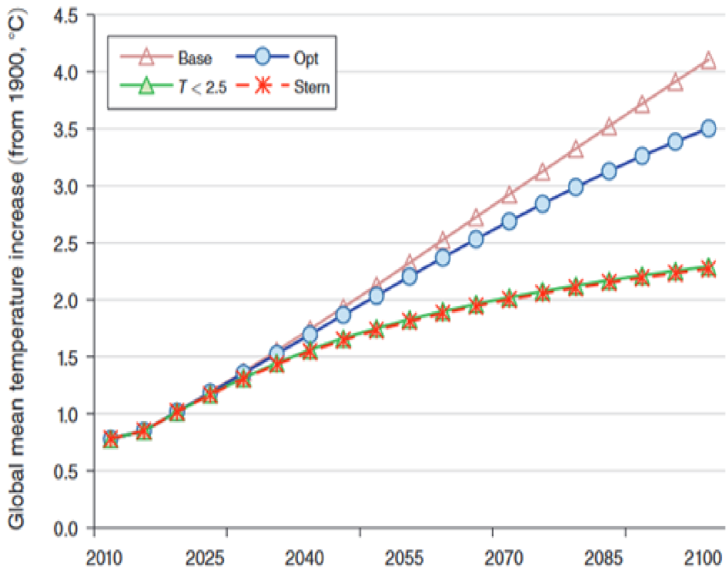

Figure 9: The trajectory of global mean temperature accordingly to Nordhaus(2019). Source:Rocha de Sousa and Pica (2023)

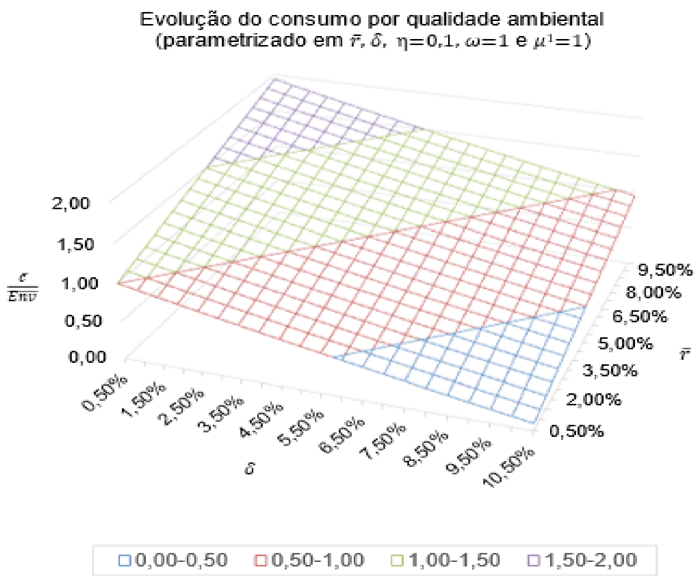

Figure 10: Consumption evolution by environmental quality as a function of δ intertemporal concern, and r interest rate, by youngsters on extended OLG model. Source:Rocha de Sousa and Pica (2023)

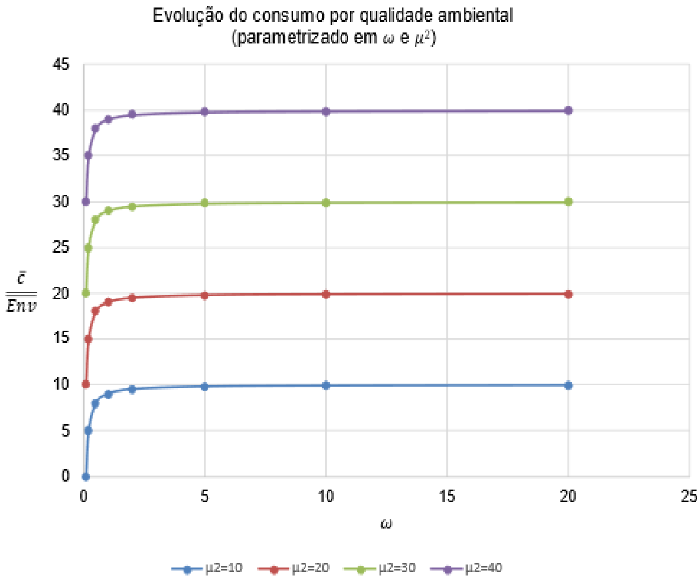

Figure 11: Consumption evolution by environmental quality as a function of δ intertemporal concern, and r interest rate, by elderly on extended OLG model. Source:Rocha de Sousa and Pica (2023)

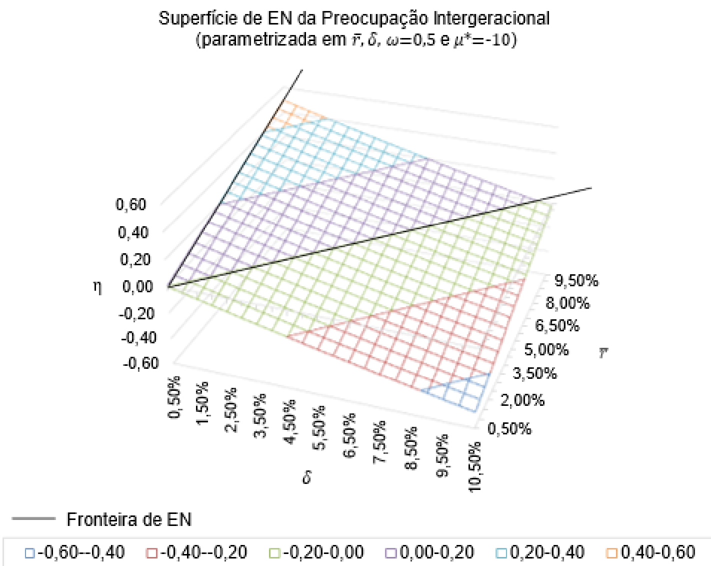

Figure 12: Nash equilibria surface (NE) of intergenerational concern η by elderly and youngsters on extended OLG model as a function of δ intertemporal concern, and r interest rate, on extended OLG model. Source:Rocha de Sousa and Pica (2023)

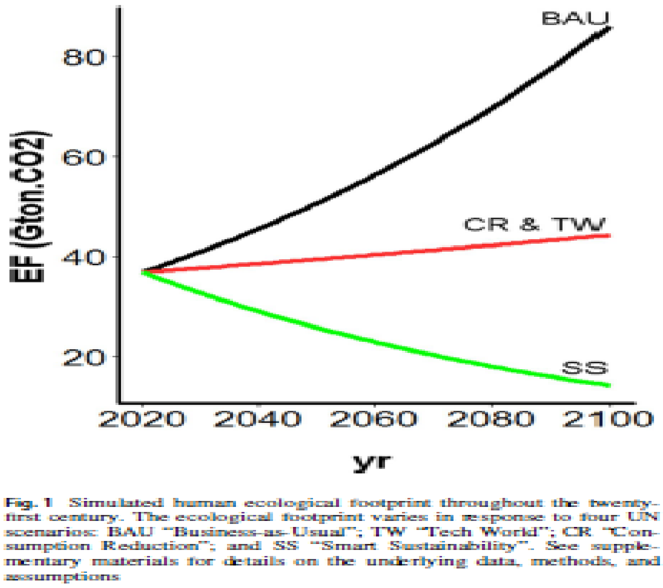

Figure 13: Ecofootprint accordingly to different UN scenarios 2050 to 2100 Source:Araújo et al. (2025)

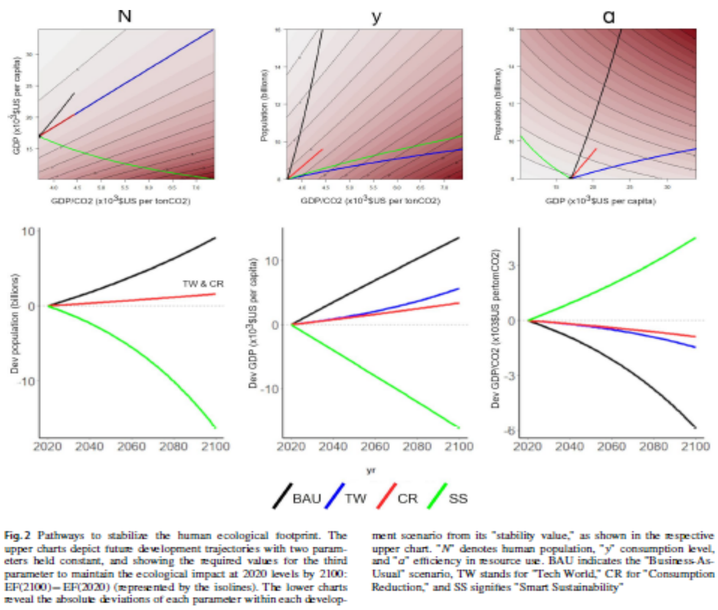

Figure 14: Ecofootprint accordingly to different UN scenarios 2050 to 2100: sensitivity analysis Source:Araújo et al. (2025)

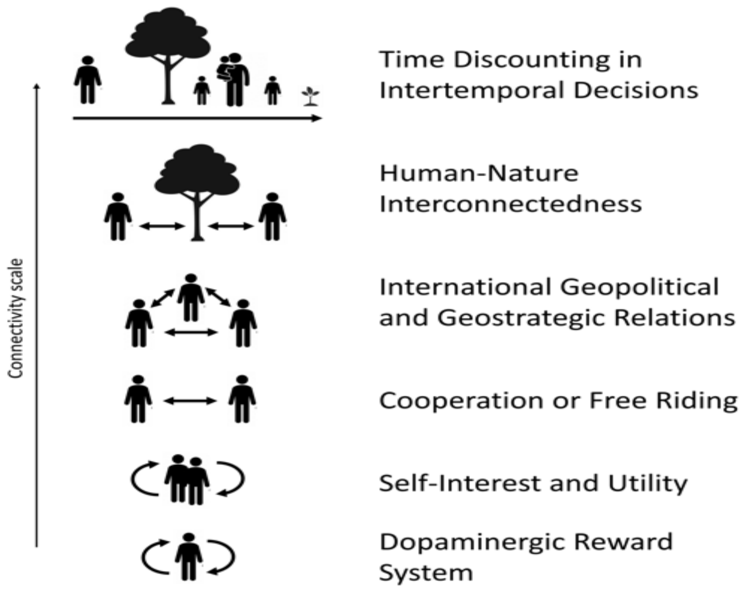

Figure 15: Six sustainability Boundaries. Source:Santos et al. (2024b,a) adapted by Avelar

4.4 Putting It All Together: Going Kantian

There is an ongoing debate regarding the individual incentive-based nature of sustainability and the associated barriers that make achieving it particularly challenging (e.g., Santos et al. (2024b,a, ming)).

Some studies address the real trajectory toward a genuine green transition. For example, Rocha de Sousa and Goucha Soares (2024) demonstrates how a model for green transition can be effectively implemented. If we begin with earlier approaches to global governance (e.g., Brites Pereira et al. (2021)) and update them to reflect the goal of resilient societies (e.g., Rocha de Sousa et al. (2025)), we still find a long and difficult path ahead to overcome unsustainable trajectories.

Recent research focusing on EU regional development once again highlights the importance of distinguishing between economic growth and true development. While this distinction is not yet fully integrated into practice, it remains a crucial element for a holistic and authentic development process (e.g., Borrega et al. (2025)).

We must also recognize the persistent tension between the Hobbesian view of self-interested individuals and the Kantian ideal of well-intentioned moral agents.

Santos et al. (2024b,a) identify six critical sustainability boundaries that hinder the path to sustainability—these are illustrated in the following figures.

Our only way to address the non-cooperative solutions and behaviors observed in climate change negotiations is to move from Nash equilibria to a Kantian equilibrium—see the following section and ongoing work by Rocha de Sousa (2025).

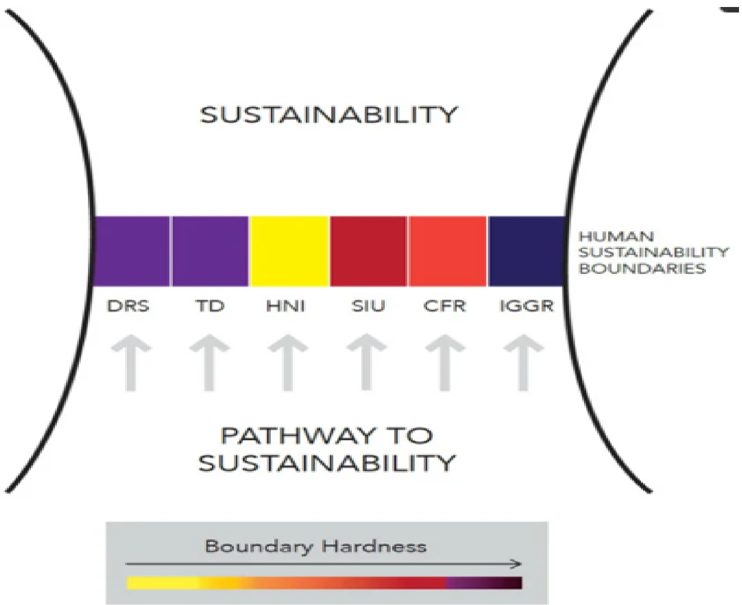

Figure 16: Six sustainability Boundaries Hardness. Source:Santos et al. (2024b,a)

4.5 Definition of Kantian Equilibrium vs Nash Equilibrium

We first depart from Nash equilibrium concept (Nash (1950b,a)):

Nash Equilibrium. *Let S be the set of possible strategies for a given climate policy (e.g., emission reductions, climate finance contributions).*
A Nash equilibrium satisfies:

$$U_i(s_i^*, s_{-i}^*) \geq U_i(s_i, s_{-i}^*) \quad \forall s_i \in S.$$

However, as discussed throughout other papers, Nash equilibrium might not be efficient under public goods provision.
So, presenting Kantian equilibria, based upon Roemer (2019):

Kantian Equilibrium. *A strategy profile s^* is Kantian if:*

$$u_i(\lambda s_i^*, \lambda s_{-i}^*) \leq u_i(s^*) \quad \forall \lambda > 0.$$

Unlike Nash equilibrium, where players unilaterally optimize given others' fixed choices, Kantian equilibrium assumes proportional adjustments, leading to more cooperative behavior.

Let's provide a more intuitive approach:
To illustrate the difference between Nash equilibrium and Kantian equilibrium, we provide a graphical representation in Figure 17. The Nash equilibrium represents a strategic outcome where each player maximizes their utility assuming others' strategies remain fixed. This often results in suboptimal cooperation, especially in public goods problems such as climate change mitigation.

In contrast, Kantian equilibrium assumes that players proportionally adjust their strategies, leading to higher collective payoffs. Graphically, Nash equilibrium is represented as the intersection of individual best-response functions, while Kantian equilibrium aligns with a more cooperative and Pareto-efficient outcome. The shift towards Kantian equilibrium reduces free-riding and fosters stronger commitments in climate policy. The figure below visually contrasts these two equilibria, emphasizing how Kantian strategies encourage optimal public goods provision.

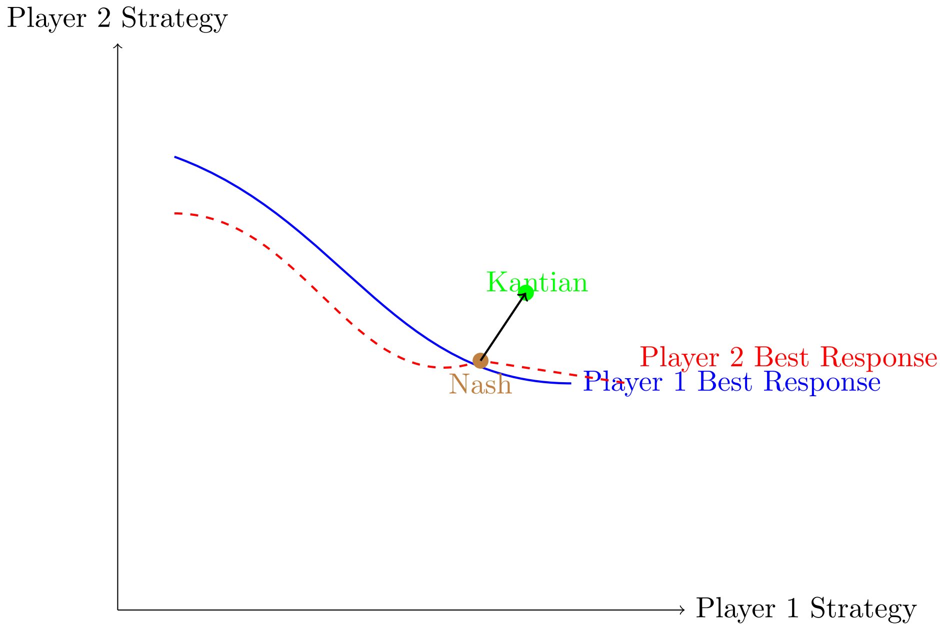

Figure 17: Comparison of Nash and Kantian Equilibria. The Nash equilibrium (brown) occurs at the exact intersection of Player 1's and Player 2's best response functions. The Kantian equilibrium (green) is a proportional shift towards greater cooperation and efficiency. Source:Rocha de Sousa (2025)

5 Conclusion

Several aspects of global governance have been scrutinized throughout this paper: the need for a reordering of the global order and the importance of rethinking the world system through new conceptual lenses. One such concept is "reglobalization," which involves examining both positive and negative liberty/freedom in the sense articulated by Isaiah Berlin (Berlin (1961)). We have shown that, to optimize incentive schemes within the global capitalist system, a slight restriction on individual liberty may be necessary, while full positive liberty should be granted to groups or associations.

In Table 3, we demonstrate that establishing a global governance ranking can serve as a useful diagnostic tool for evaluating global climate challenges.

We then examined three complementary approaches. First, we discussed evolutionary game theory (as in Caleiro et al. (2019)), which illustrates how incentives can be designed by considering tipping points and dynamic shifts in agent behavior—from cooperation to non-cooperation and vice versa.

Second, we analyzed an overlapping generations (OLG) model (as in Rocha de Sousa and Pica (2023)), which introduces intergenerational concerns across time. However, this model is not immune to criticism, particularly regarding the fact that unborn generations cannot advocate for present-day action. How, then, can we address this issue?

One way forward is to incorporate a moral framework based on caring for others even after one's death—a concept aligned with Tomasello's or Gilligan's ethics of care, or even a Christian stewardship ethic. Such an approach may help prevent ecological collapse.

The third approach examines the consequences of inaction—the "business-as-usual" (BAU) scenario—which presents a grim and catastrophic outlook for the planet (as in Araújo et al. (2025)).

Finally, we revisited the foundational work of Santos et al. (2024b,a, ming), which originally identified six critical boundaries to sustainability. We have since added a seventh: the human–technology interconnectedness barrier, particularly relevant to the discussions of RC35 on technology and development.

These studies offer a clear and urgent warning about the need to craft a holistic, coherent, and sustainable future.

The Hobbesian view of humanity—as "man is a wolf to man"—has underpinned much of neoclassical economics, from Smith to Malthus to Ricardo. Yet, if we turn to Smith's *Theory of Moral Sentiments*, we may find a path toward a more sustainable world. In this framework, the decision-making agent acts as an impartial spectator of their own actions, guided by values such as tolerance, virtue, and empathy.

Building on this moral foundation, we returned to incentive theory and argued that the market failure represented by climate change can only be addressed through Kantian cooperation—as opposed to the egocentric individualism inherent in Nashian strategies.

Thus, we must transition from a Nashian world to a Kantian one. This involves negotiations between agents—bilateral or multilateral—leading to a common equilibrium grounded in proportional effort and shared goals.

Such cooperation points the way toward a collective solution to the climate crisis. As Belbute and Pereira (2022) has shown, if the world's most polluting countries were to agree on a common policy framework, over 75% of global CO_2 emissions could be effectively addressed.

6 Limitations of analysis and Perspectives

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