Economic Growth, Climate Finance, and Green Government Spending: A Post-Kaleckian Approach

Douglas Alencar[1]

Federal University of Pará/Brazil

Frederico G. Jayme Jr.[2]

Federal University of Minas Gerais/Brazil

Eduardo Strachman[3]

UNESP, São Paulo State University/Brazil

Cláudio Puty[4]

Federal University of Pará/Brazil

ABSTRACT: This paper examines the impact of climate finance and green government spending on economic growth using a Post-Kaleckian approach. By including pollution as an endogenous variable in the investment function, the study proposes that capital accumulation and pollution are interconnected, with green finance playing a crucial role in reducing emissions and fostering sustainable growth. The analysis explores how investments directed toward the ecological transition and public policies aimed at reducing environmental impacts can generate multiplier effects in the economy. Furthermore, the study discusses the role of the government as a facilitator of green investment, demonstrating how fiscal policies and incentives can reshape the trajectory of economic growth while meeting environmental goals. This paper aims to contribute to the understanding of the interactions between the economy and the environment, proposing new ways of thinking about economic growth in an era of climate change and the urgent need for ecological transformation.

Keywords: Post-Kaleckian Model, climate finance, green government investment, economic growth.

Área 2. Distribuição de Renda, Conflito Social e Crescimento Econômico

1- Introduction

The aim of this paper is to analyze how climate finance and green government spending influence economic growth, integrating pollution as a factor in the investment function. Specifically, it aims to understand the interaction between capital accumulation, public green investment and climate finance mechanisms, and how these factors can contribute to a more sustainable economic growth. The central

[1] E-mail: dalencar@ufpa.br
[2] E-mail: gonzaga@cedeplar.ufmg.br
[3] E-mail: eduardo.strachman@gmail.com
[4] E-mail: cputy@ufpa.br

research question guiding this study is: what is the role of climate finance and green government spending in economic growth, especially when pollution is considered an endogenous variable? We intend to investigate the role of these features in economic growth, adopting a post-Kaleckian approach that focuses on the interaction between capital accumulation, aggregate demand and income distribution, and how these factors can be endogenized in a model that considers pollution as a relevant variable.

The specific objectives include incorporating the argument of pollution into the post-Kaleckian investment function, endogenizing pollution within the model, and analyzing the impact of these factors in both the short and long run. This study is justified by the need to understand how public policies directed at climate finance and the green transition can be integrated into economic models that have traditionally not explicitly considered environmental externalities. The methodology adopted will be a theoretical modeling based on an extension of the post-Kaleckian model, including variables associated with green investment, climate finance, and the effects of pollution on capital accumulation.

This article contributes to the field of post-Kaleckian economics, by offering new perspectives on how environmental policies can be integrated into economic growth models and providing a theoretical foundation for future discussions on public policies aimed at sustainable growth.

The paper is divided into three sections, in addition to the introduction and conclusions. Section two presents a literature review of climate finance and green government spending. Section three presents the model the relationship between economic growth and climate change. Section four analyses dynamics of the model.

2- The role of climate finance and green government spending in the energy transition

This section addresses the importance of climate finance for adaptation to climate change, with a focus on the needs of developing countries, particularly the most vulnerable ones, such as the least developed countries (LDCs) and the small island states. It discusses existing international mechanisms to mobilize financial resources, highlighting the contribution of global financial institutions, UN agencies, bilateral and multilateral channels, as well as the private sector. Furthermore, the section explores how new financial approaches, such as market mechanisms and green bonds, can attract private investments for adaptation. It also examines public policy proposals to integrate adaptation into sustainable development, considering the importance of government funding and the use of fiscal policies to drive green innovation and climate resilience.

Climate change adaptation is a key strategy to address global climate challenges, particularly, as underscored beforehand, for the LDCs and small island states, which are the most vulnerable to climate impacts, but lack the financial resources to effectively adapt. Thus, although it would be more economical to invest in adaptation rather than face the anticipated damage of inaction, the capital to fund adaptation is estimated to range in the hundreds of billions. Timilsina (2021) provides an overview of existing international provisions for climate finance, detailing support mechanisms through international financial institutions, United Nations agencies, bilateral and multilateral channels, and the private sector. Furthermore, the author explores how private sector finance can be attracted to invest in climate adaptation projects, emphasizing the need for innovative financial mechanisms to mobilize additional resources for this crucial effort.

Financing adaptation to cope with climate change is crucial of future climate change policy, especially for developing countries. Bouwer and Aerts (2006) propose a two-track approach: one seeks to secure adaptation funding under the United Nations Framework Convention on Climate Change (UNFCCC), while the second focuses on inserting climate risk management into the mainstream development efforts. They emphasize that the developed countries must show a much greater commitment to funding adaptation measures, if the UNFCCC is to cover a substantial portion of the costs. Additionally, they suggest that integrating climate change adaptation into disaster risk reduction strategies and 'climate-proofing' development projects, which currently do not consider climate and weather risks, could enhance the sustainability and resilience of development initiatives.

Khan and Munira (2009) highlight that financing for climate adaptation remains severely inadequate despite the growing recognition of its importance in addressing global climate change impacts. Beginning as an afterthought in the UN Framework Convention on Climate Change, adaptation has evolved significantly since 1992, however, recent years have seen an increasing frequency of extreme climate events, including cross-border climate risks. The Paris Agreement now frames adaptation as a global goal and responsibility, but financing for adaptation continues to fall short relative to the estimated needs. Khan and Munira (2009) suggest that this poor funding can be attributed to the territorial framing of adaptation under the existing regime, which largely conceptualizes it as a local or national public good, making market mechanisms ineffective. They argue that reframing adaptation as a global public good would make conceptual and political sense, potentially enhancing the scale of adaptation finance. Moreover, multilateral agencies should take the lead in promoting this reframing to boost global adaptation finance.

Dellink et al. (2009) argue that climate change disproportionately affects countries that have historically contributed the least to greenhouse gas emissions. They identify both consequentialist

and non-consequentialist ethical principles to inform a fair international burden-sharing framework for climate adaptation costs. By translating these principles into political criteria — specifically historical responsibility and capacity to pay — they propose a hybrid approach of 'common but differentiated responsibilities and respective capabilities as a foundation for international negotiations on burden-sharing schemes. Their numerical assessment of seven scenarios indicates that Annex I countries of the UNFCCC would shoulder most adaptation costs. However, contributions vary significantly depending on the chosen capacity-to-pay indicator, with less sensitivity to responsibility calculations, except those related to land-use emissions. Assuming annual climate adaptation costs of USD 100 billion, the financial contributions from Annex I countries are estimated between USD 65–70 billion, equating to approximately USD 43–82 per capita annually.

Zhang and Maruyama (2009) highlighted that funding for greenhouse gas mitigation projects in developing countries is crucial for addressing global climate change. They examine current climate finance mechanisms, emphasizing their limited effectiveness in influencing future emissions in these nations, and advocate for increased private sector involvement in financing mitigation projects. The authors suggest that the Clean Development Mechanism (CDM), under the Kyoto Protocol, has potential to mobilize foreign direct investment (FDI), by providing commercial incentives for private sector engagement and internalizing externalities associated with mitigation projects. However, they note that due to additional risks and barriers inherent in CDM projects, appropriate public–private partnerships are essential to fully leverage its potential. They propose that public funds could complement private investments, via CDM, enhancing its market functions, and emphasize the importance of considering factors such as risk sharing, investment behavior, technology transfer, and coordination with existing trade and investment rules.

Baker et al. (2018) examine the role of green bonds, which finance environmentally friendly projects, and find that they exhibit distinct pricing and ownership characteristics, compared to conventional bonds. Their analysis reveals that green municipal bonds are issued at a premium over similar non-green bonds, indicating strong investor demand for environmentally conscious investments. Additionally, these green bonds tend to have more concentrated ownership, particularly among smaller or less risky issues, with external certification of these bonds as green enhancing these effects. These findings underscore the growing investor interest in sustainable finance and highlight the potential of green bonds to mobilize capital for climate-related initiatives.

Corfee-Morlot, Guay, and Larsen (2009) emphasize that effective financing for climate change mitigation requires stronger mechanisms for measuring, reporting, and verifying (MRV) financial flows. This study highlights the importance of transparent and consistent reporting of climate finance

to ensure accountability and proper allocation of funds. Key findings indicate that the current system for reporting climate finance, particularly through the UNFCCC, is inconsistent, with a lack of standardized frameworks for both public and private contributions. The authors emphasize the need for enhanced financial reporting systems that include clear and uniform data on the sources and uses of funds. This would allow for a better tracking of climate mitigation investments, ensuring that financial flows are directed toward high-impact projects and contributing to global mitigation goals. They conclude that improving these reporting and verification processes is essential for increasing the effectiveness and credibility of climate finance.

Hossain (2024) examines the impact of government spending on green innovation, emphasizing its critical role in the transition to a sustainable economy. Through a systematic review, the study explores how public investments in environmentally friendly technologies influence economic development and environmental sustainability. The findings suggest that such investments stimulate research and development, fostering technological advancements that mitigate environmental impacts. Additionally, government support for green sectors contributes to job creation and broader economic growth, aligning with sustainability goals. Public funding also plays a crucial role in addressing private sector limitations in financing green technologies, ensuring that environmental benefits are realized. The study underscores the importance of well-structured and targeted public policies in maximizing the impact of green fiscal initiatives.

Focusing on countries involved in the 'Belt and Road Initiative' (BRI), Yumei, Hou, et al. (2021) assess the role of government spending in enhancing green economic performance. Using panel data from 2008 to 2018 and applying the generalized method of moments (GMM), this study evaluates the effects of public expenditures on education and research and development (R&D) on the green economy performance index (GEE). The results indicate overall progress in green development across the BRI nations, although Pakistan and Bangladesh experienced a gradual decline in their GEE, between 2010 and 2018. Investments in education and R&D emerge as key drivers of green economic growth, with heterogeneous effects observed in wealthier countries. Based on these insights, the authors propose policy measures to further promote sustainable development.

Similarly, Lin and Zhu (2019) investigate the influence of fiscal spending on green economic growth, particularly through the composition and technique effects. Their analysis, covering 282 Chinese cities, from 2005 to 2016, reveals that government expenditures on education and R&D positively impact the green economic growth index (GEGI). The composition effect arises as spending on education accelerates the transition toward human capital-intensive activities, while the technique effect reflects the role of R&D investments in promoting cleaner technologies. Regional variations in

the impact of fiscal policies highlight the need for tailored strategies to optimize their effectiveness in different economic contexts.

In the post-pandemic landscape, Liu et al. (2022) explores the role of fiscal policies in advancing the transition to a green economy. Drawing on longitudinal data from China (2008–2018), the study applies ordinary least squares and quantile regression methods to assess the effects of increased government spending. The findings indicate that a 1% rise in fiscal expenditure correlates with a 0.2% reduction in cumulative carbon dioxide emissions, with notable declines in pollution from natural gas and hydrocarbon byproducts. However, coal-related emissions remain relatively unaffected. The causality analysis further suggests a one-way causal effect from fiscal policy to energy use, reinforcing the link between public spending and green economic performance.

The economic attributes of green fiscal spending, particularly in times of crisis, are the focus of O'Callaghan et al. (2022). Through a machine learning-based literature review and a structured qualitative assessment, the study evaluates the effectiveness of green stimulus policies. The results show that green investments generate higher fiscal multipliers and greater employment benefits compared to non-green alternatives, positioning them as valuable tools for economic recovery. Despite these advantages, the study identifies a disconnection between the research priorities and the actual public spending, highlighting the need for a policy realignment to fully leverage green investments.

Taking a regional perspective, Chen and Li (2024) examine the role of fiscal expenditure in promoting green economic development in heavily polluting Asian countries. Their findings challenge the conventional view that economic growth and environmental sustainability are at odds. Using panel data regression and Granger causality tests, the study establishes a strong positive link between green fiscal policies and long-term economic growth. Increased government investment in environmental protection and eco-friendly technologies proves particularly beneficial for high-pollution sectors like manufacturing and energy. The study further emphasizes the need for cross-sector and cross-national policy coordination to enhance the effectiveness of green economic initiatives.

Xing et al. (2022) expand the discussion by analyzing the interplay between green finance and public spending in mitigating environmental degradation. Employing a vector error correction model (VECM), with data spanning from 2005 to 2018, their study finds that China's green finance sector, in conjunction with increased public expenditure, has contributed to lower carbon emissions and improve environmental quality. Nevertheless, challenges remain, as rising carbon intensity has

hindered the expansion of non-fossil energy sources. The findings call for further refinements in green finance policies to maximize their impact on renewable energy adoption and long-term sustainability.

Cooper (2012) argues that green government spending can effectively stimulate economic growth, while promoting environmental sustainability. Empirical evidence suggests that targeted public investments in renewable energy, energy efficiency and sustainable infrastructure contribute to both short-term economic stimulus and long-term structural transformation. Moreover, countries that allocate a significant portion of their fiscal stimulus to green initiatives tend to experience positive spillover effects, such as increased employment in emerging green industries and reduced environmental degradation. These findings underscore the potential for green public spending to serve as a dual-purpose policy instrument, fostering economic resilience while advancing environmental goals.

In conclusion, financing climate adaptation is a critical component of global efforts to address climate change, particularly for the most vulnerable countries. Despite the growing recognition of its importance, adapting financing remains insufficient, and innovative financial mechanisms must be explored to bridge the gap. The role of both the public and private sectors is essential to mobilize resources, with green bonds, market-based mechanisms, and government-led fiscal policies offering promising solutions. Moving forward, strengthening international cooperation and aligning financial flows with climate goals will be crucial to ensure that developing countries are adequately supported in their adaptation efforts, fostering long-term resilience and sustainability in the face of climate change.

3- The model

The relationship between economic growth and climate change has been widely explored within the Post-Kaleckian tradition, with several authors, such as Rezai, Taylor, and Mechler (2013), Fontana and Sawyer (2015) and Oliveira and Lima (2022) developing theoretical models that integrate environmental and macroeconomic dynamics. A key concern in this literature is how the transition to a low-carbon economy can be reconciled with sustained economic growth and financial stability. While some studies emphasize the role of sustainable consumption and investment in green infrastructure, others focus on the implications of climate policies for income distribution, labor markets, and financial dynamics. This section builds upon these contributions by incorporating climate finance and green government spending into a Post-Kaleckian growth framework. Specifically, it extends the investment function to account for the impact of pollution, highlighting how environmental factors can influence macroeconomic stability, investment decisions, and

economic growth.

Considering the Post-Kaleckian tradition, numerous authors have sought to integrate or relate climate change issues to economic growth models. Rezai, Taylor, and Mechler (2013) develop an ecological macroeconomic framework within a Keynesian growth model to analyze climate change policies. They argue that traditional neoclassical models fail to account for systemic market failures, uncertainty, and biophysical limits, which are essential for understanding climate change dynamics. Their approach adopts a demand-driven macroeconomic perspective, incorporating concepts such as sustainable consumption, reduced working hours, and energy efficiency. A key conclusion is that economic policies aimed at sustainability must consider macroeconomic constraints and feedback loops, particularly the interactions between labor productivity, energy use, and greenhouse gas emissions. Their findings suggest that smooth market adjustments assumed in neoclassical models may not adequately capture the complexities of a transition to a low-carbon economy and, thus, they advocate for policies that address both environmental sustainability and social stability.

Fontana and Sawyer (2015) develop a post-Keynesian ecological macroeconomic framework, that integrates economic, biophysical, and social factors into a demand-led growth model. Their analysis builds upon the Monetary Circuit theory and the Demand-led growth theory, emphasizing the role of financial institutions and investment in shaping economic dynamics. A key conclusion of their study is that economic growth, while crucial for reducing unemployment, also exacerbates environmental degradation if not managed properly. They challenge the neoclassical assumption of automatic market adjustments, arguing instead for policy interventions that regulate investment, credit allocation, and use of resources to ensure a sustainable growth path. Their framework highlights the need of aligning economic policies with ecological constraints, advocating for a transition toward a low-carbon economy, through structural changes in investment patterns and financial regulation.

Taylor, Rezai, and Foley (2016) present a demand-driven growth model that integrates capital accumulation and greenhouse gas (GHG) dynamics to explore macroeconomic implications of climate change. Their framework departs from supply-side models by incorporating biophysical limits and post-Keynesian growth theory, emphasizing demand and income distribution effects on output and employment. The model highlights that rising GHG levels can negatively impact profitability, investment, and productivity, leading to macroeconomic instability. A key finding is that climate change mitigation policies, such as increased investment in energy efficiency and emission reductions, can stabilize the economy, while lowering carbon intensity. However, they argue that automatic market adjustments are insufficient to address these challenges, advocating for active policy interventions to align economic growth with ecological constraints.

The model developed by Dafermos, Nikolaidi, and Galanis (2017) investigates the implications of climate change for financial stability, highlighting the physical and transition risks associated with environmental degradation and the transition to a low-carbon economy. Simulations conducted for the period from 2015 to 2115 lead to three main conclusions. First, climate change tends to destroy corporate capital, reducing profitability and liquidity, which may result in an increase in corporate default rates and jeopardize the stability of the banking sector. Second, climate damages could induce a portfolio reallocation, resulting in a gradual decline in the price of corporate bonds. Third, financial instability may negatively impact credit expansion and investment in green capital, creating feedback effects that amplify the challenges of global warming. The study also evaluates the implementation of a 'Green Quantitative Easing' (Green QE) program, as a mechanism to mitigate these impacts. The results indicate that by increasing the price of green corporate bonds, this program could reduce financial instability caused by climate change and limit the rise in global temperatures. However, the authors emphasize that Green QE alone is not sufficient to prevent the worsening of global warming and must be combined with other robust environmental policies.

The model proposed by Oliveira and Lima (2022) integrates the relationship between economic growth, functional distribution of income and pollution concentration, emphasizing the impact of the pollution-adjusted Kaldor-Verdoorn effect. The analysis suggests that while output growth enhances labor productivity, increasing pollution can mitigate or even reverse this effect, due to its negative impact on workers' health and productive capacity. The authors identify a trilemma in which economic growth, pollution concentration and income distribution interact in a complex manner, making it impossible to simultaneously maximize growth and equity, without effective environmental mitigation measures. The stability of the system depends on the growth regime: in a profit-led scenario, long-term equilibrium can be achieved, although subject to fluctuations; in a wage-led scenario, growth tends to be unstable. The study highlights that without strong environmental policies and investments in clean technologies, the economic trajectory may lead to an environmental crisis and a decline in productivity, reinforcing the need for a sustainable development model that internalizes the environmental costs of production.

The innovative aspect of the approach presented in our article is that climate finance and green government spending can serve as key factors to mitigate environmental degradation, while also acting as instruments for the transition to a low-carbon economy. Accordingly, following the investment function of Bhaduri and Marglin (1990), investment (I) is modeled as a function of the profit share (π) and the capacity utilization level (u):

$$I = I(\pi, u) \qquad (1)$$

To incorporate the impact of pollution (P), we can extend this function as follows:

$$I = I(\pi, u, P) \qquad (2)$$

Where P represents the level of environmental pollution, which can be measured by CO_2 emissions, air pollution, or other environmental indicators. The effect of P can be negative ($\frac{\partial I}{\partial P} < 0$) if pollution increases regulatory costs, reduces productivity, or creates uncertainty. Conversely, the effect can be positive ($\frac{\partial I}{\partial P} > 0$) if there are incentives for investments in clean technologies or climate change adaptation. Thus:

$$g^i = \gamma + \gamma_u u + \gamma_\pi \pi + \gamma_P P \qquad (3)$$

Where g^i stands for growth rate, γ is an autonomous term, γ_π and γ_u are, respectively, coefficients that capture the effects of income distribution and demand on investment, and γ_P measures the impact of pollution on investment (it is expected that $\gamma_P < 0$, if investment in the climate transition is not sufficient to offset the negative effects of pollution).

The inclusion of pollution in the investment function can be justified by several economic and institutional mechanisms. Pollution can generate additional regulatory costs for firms, including environmental taxes, fines, and the need to comply with stricter regulations. These costs can reduce the expected profitability of investment, decreasing the incentive to expand production (Porter and van der Linde, 1995; Stokey, 1998). Uncertainty about the evolution of environmental policies can lead firms to delay investment decisions (Pindyck, 1991). If economic agents perceive that future environmental regulations will be more restrictive, they may choose to reduce or redirect investments toward sectors less exposed to regulatory risk (Aghion et al., 2016).

Pollution can also negatively affect labor productivity due to health issues, as demonstrated by Hanna and Oliva (2015). Additionally, it can increase production costs through higher maintenance of machines and equipment, due to environmental degradation (Graff Zivin and Neidell, 2012). The current level of pollution concentration depends on the entire history of emissions up to that point in time. It is assumed that the concentration of pollution negatively impacts labor productivity, which is supported by the growing empirical literature. Graff Zivin and Neidell (2012) provided early evidence on the causal relationship between changes in ozone concentration and labor productivity, using a sample of agricultural workers in the Central Valley of California. The channel through which labor productivity is negatively affected by pollution operates via observable and unobservable effects, such as health conditions, cognitive abilities, and effort on the job, which change according to the specific pollutant and its time horizon of influence (Graff Zivin and Neidell, 2013; Nauze and

Severnini, 2021).

High levels of pollution, nonetheless, can stimulate investment in clean technologies, aligning environmental innovation with economic growth (Acemoglu et al., 2012). This effect can be observed in countries with well-structured environmental policies that encourage the transition to a low-carbon economy (Johnstone et al., 2010). Highly polluting companies may face credit constraints from investors and financial institutions that adopt ESG (Environmental, Social and Governance) criteria in their decisions (Krueger et al., 2020). This can limit the financing of new projects, negatively impacting aggregate investment. The adoption of strict environmental policies can reduce the competitiveness of polluting sectors in open economies, negatively affecting investment in those sectors (Copeland and Taylor, 2004). However, in countries that lead the transition to clean technologies, investment may increase due to higher global demand for sustainable products.

Thus, pollution can be determined as follows:

$$P = g - F_v - G_v \qquad (4)$$

Where (P) is pollution, (g) is the variation in the growth rate of the economy or investment growth, (F_v) is climate financing, and (G_v) is government spending directed toward the transition to a low-carbon economy. Climate financing is essential for accelerating the transition to a low-carbon economy, as it enables investments in clean technologies, energy efficiency and sustainable infrastructure.

The Role of Climate Financing (F_v) in reducing pollution can ease energy transition, as climate financing reduces the cost of capital for investments in renewable energy, making them more competitive compared to fossil fuels. Studies show that financial incentive policies, such as subsidies and green financing, significantly increase the adoption of renewable sources (Polzin, 2017; Ketterer and Kock, 2018). Furthermore, green credit lines allow companies to invest in less polluting production processes, reducing industrial emissions (Calel and Dechezleprêtre, 2016). Additionally, climate financing can mitigate regulatory uncertainties by directing resources to sectors aligned with long-term environmental goals (Campiglio, 2016).

Public spending on pollution reduction (G_v) directed towards the transition to a low-carbon economy plays a crucial role in reducing pollution through Direct Investment in Green Infrastructure. This State investment in sustainable public transportation, renewable energy, and energy efficiency directly reduces CO_2 emissions (Somanathan et al., 2014), generates a Multiplier Effect on the Private Sector, as public financing can leverage private investments in clean technologies, creating synergies in the energy transition (Mazzucato and Semieniuk, 2018). Governments can reduce pollution through

subsidies for green innovation and emissions taxes (Acemoglu et al., 2012) and, on the other hand, the decrease in pollution (through public policies aimed at environmental mitigation) improve public health and reduce economic costs associated with environmental degradation (Nordhaus, 2019).

Following the saving function of Kalecki (1937), Kalecki (1954), Bhaduri and Marglin (1990), Dafermos, Nikolaidi and Galanis (2018), Hein (2014), Lavoie (2014), Rezai, Foley, and Taylor (2013) and Taylor (2004), we get:

$$g^s = s_p \pi u / v \qquad (5)$$

Where g^s is the growth rate of savings, s_p is the marginal propensity to save of capitalists, π is the profit share in income, u is the degree of capacity utilization, and v is the capital-output ratio (the ratio between capital and output, $v = K/Y$). In the Kaleckian model (Kalecki, 1937; Kalecki, 1954), it is assumed that workers consume most of their income, while capitalists have a higher propensity to save. If the profit share increases (π rises), aggregate savings tend to grow, provided the propensity to save of capitalists (s_p) is positive. When the degree of capacity utilization (u) increases, there is higher production and more profits, which raises aggregate savings. The capital-output ratio (v) indicates the amount of capital required to generate a certain level of output. A high v suggests a capital-intensive economy, where accumulation may be slower due to the need for larger investments.

Regarding the rate of profit (r), following Hein (2014), we have:

$$r = \pi u \frac{1}{v} \qquad (6)$$

Where r is the rate of profit, defined as the ratio between aggregate profits and the capital stock. The rate of profit increases when the profit share in income rises, as higher profit margins raise the profitability of capital. In Post-Kaleckian models, the income distribution between wages and profits influences both the growth and stability of the economy (Lavoie, 2014). The rate of profit is positively related to the degree of capacity utilization. A higher level of capacity utilization generates more production and profits, boosting the profitability of capital (Bhaduri and Marglin, 1990). The rate of profit is inversely proportional to the capital-output ratio (v). Capital-intensive economies (with a high v) tend to have lower profit rates, as they require greater investments in relation to the output (Taylor, 2004).

In equilibrium, savings equals investment. Solving equations 3 and 5 for capacity utilization, we have:

$$u^* = \frac{\gamma + \gamma_\pi \pi + \gamma_P P}{s_p \pi / v - \gamma_u} \qquad (7)$$

The degree of capacity utilization (u) depends on the marginal propensity to save (s_p), the profit share (π), pollution (P), and the investment parameters ($\gamma, \gamma_u, \gamma_\pi, \gamma_P$). If pollution has a negative effect on investment ($\gamma_P < 0$), this can reduce capacity utilization. An increase in the profit share (π) can have ambiguous effects, depending on the relationship between investment and income distribution.

Substituting equation 7 into equation 6, we have:

$$r^* = \frac{\pi(\gamma+\gamma_\pi\pi+\gamma_P P)}{s_p\pi-v\gamma_u} \qquad (8)$$

The relationship between the profit share and the rate of profit depends on how income influences investment and savings. If $\gamma_P < 0$, an increase in pollution can reduce the rate of profit, indicating adverse effects on productivity and costs. An increase in s_p tends to raise the rate of profit, while an increase in v (capital per unit of output) reduces r, reflecting an inverse relationship between capital intensity and profitability.

Substituting equation 7 into equation 5, we have the equilibrium equation between savings and investment:

$$g^* = \frac{s_p\pi(\gamma+\gamma_\pi\pi+\gamma_P P)}{v(s_p\pi/v-\gamma_u)} \qquad (9)$$

The equilibrium equation between savings and investment shows the relationship between the flows of savings and investment in the economy, considering the profit share π, pollution P, and the parameters s_p, γ_π, γ_P, etc. The relationship between the variables reflects how the level of investment (or savings) depends on the factors that influence capacity utilization and environmental impact. Equilibrium is reached when total savings equals total investment.

The extended Post-Kaleckian framework presented in this section highlights the critical role of climate finance and green government spending in shaping macroeconomic dynamics, in the context of environmental constraints. By incorporating pollution into the investment function, the model illustrates how environmental degradation can negatively impact capital accumulation, capacity utilization and the rate of profit, while also creating incentives for investment in clean technologies. The equilibrium conditions emphasize the interdependence between income distribution, investment behavior, and environmental policies. Asuccessful transition to a low-carbon economy requires coordinated policy interventions. Ultimately, the findings reinforce the argument that relying solely on market mechanisms is insufficient to address the economic and ecological challenges posed by climate change, underscoring the need for proactive fiscal and financial policies to ensure both environmental sustainability and macroeconomic stability.

4- Short-term and Long-term behavior

This section examines both the short-term and long-term dynamics of the model, which integrates pollution, economic growth, and policies aimed at transitioning to a low-carbon economy. The short-term behavior is analyzed by exploring how pollution influences key economic variables, such as capacity utilization, profit rates, and growth. In the long term, the model incorporates the interaction between pollution, economic growth, climate finance, and government investments, in green actions, highlighting the impact of these aspects on the overall system. The analysis also investigates the stability of the system through the Jacobian matrix, identifying the necessary conditions for a stable equilibrium and emphasizing the crucial role of effective policies in ensuring sustainable growth and a successful transition to a low-carbon economy.

Studying the short-term impacts in relation to P (pollution), we have the derivative of the capacity utilization equation with respect to pollution as follows:

$$\frac{du^*}{dP} = \frac{\gamma_P}{s_p\pi/v - \gamma_u} \qquad (10)$$

Assuming that $\frac{s_p\pi}{v} > \gamma_u$, the value of γ_P can be either negative or positive. If $\gamma_P < 0$, pollution has a negative effect on investment, suggesting that an increase in pollution will reduce the degree of capacity utilization. This indicates that pollution harms capital accumulation or productivity, leading to lower utilization of productive capacity. If $\gamma_P > 0$, pollution has a positive effect on investment, possibly due to incentives for technological innovation or investments in green solutions. In this case, pollution would increase the degree of capacity utilization.

Differentiating equation 8 with respect to pollution, we have:

$$\frac{dr^*}{dP} = \frac{\gamma_P\pi}{s_p\pi - v\gamma_u} \qquad (11)$$

Assuming that $s_p\pi > v\gamma_u$, the value of γ_P can be either negative or positive. If $\gamma_P < 0$, the derivative will be negative. In this case, an increase in pollution reduces r^*, meaning the rate of profit decreases as pollution increases. This result is expected in many economic circumstances, where the negative effects of pollution raise costs and reduce productivity, thereby decreasing the profitability of capital.

Differentiating equation 9 with respect to pollution, we have:

$$\frac{dg^*}{dP} = \frac{s_p\pi.\gamma_P}{v(s_p\pi/v - \gamma_u)} \qquad (12)$$

Once again, assuming that $\frac{s_p\pi}{v} > \gamma_u$, if $\gamma_P < 0$ the numerator $s_p\pi.\gamma_P$ will be negative, since s_p and π

are positive. In this case, the derivative $\frac{dg^*}{dP}$ will be negative, indicating that an increase in pollution P leads to a decrease in growth g^*. On the other hand, if $\gamma_P > 0$, the numerator $s_p \pi . \gamma_P$ will be positive, as both s_p and π are positive. In this case, the derivative $\frac{dg^*}{dP}$ will be positive, indicating that an increase in pollution P leads to an increase in growth g^*.

Now, we examine the long-term dynamics of the model, which integrates the impact of pollution, economic growth, and policies aimed at transitioning to a low-carbon economy. The behavior of pollution over time is modeled by a differential equation that describes the interaction between economic growth, climate finance, and government investments in green actions.

According to the model, pollution is influenced by both changes in economic growth and mitigation policies, such as climate finance and public spending on green infrastructure. The analysis also includes the dynamics of economic growth, considering the interaction between investment, inflation, the effects of pollution, and economic policies. The growth equation reveals how the system's equilibrium is affected by these variables, including the non-linear impact of pollution on economic growth and the crucial role of green policies in mitigating this impact.

The long-term dynamics integrate the impact of pollution, economic growth, and policies aimed at transitioning to a low-carbon economy. The behavior of pollution over time is modeled by a differential equation that describes the interaction between economic growth, climate finance and government investments in green actions.

This model is grounded in Post-Keynesian economic theory, where the dynamics of investment, consumption, and policy decisions are central to understanding the long-term trajectory of economic growth. As Lavoie (2014) and Rochon (2020) argue, the role of government spending, particularly in green investments, is crucial to sustaining demand and ensuring long-term stability in an economy transitioning to a low-carbon future. Furthermore, including climate finance in the model echoes the work of authors like Hein (2013) and Storm (2017), who emphasize the importance of public investment in driving structural change towards sustainability.

We also explore the stability of the model through the analysis of the Jacobian matrix and indicate the necessary conditions for the system to reach a stable equilibrium point. The interaction between the variables is analyzed to identify the conditions for a sustainable growth, where the benefits of green policies outweigh the negative impacts of pollution, enabling a successful transition to a more sustainable economy.

In relation to the dynamics of pollution, we have:

$$\dot{P} = \alpha(g - \bar{g}) - \beta(F_v - \bar{F_v}) - \varphi(G_v - \bar{G}_v) \qquad (13)$$

In which $\bar{g}$ is the average economic growth rate, $\bar{F_v}$ is the average climate finance, and $\bar{G}_v$ is the average government investment in actions related to the transition to a low-carbon economy. The parameters are: α is the effect of the deviation of economic growth from average economic growth on pollution; β measures the impact of climate finance on reducing pollution; and φ measures the impact of government green spending on reducing pollution. If $\alpha > 0$, $\beta > 0$ and $\varphi > 0$, an increase in the growth rate raises pollution, while the growth in climate finance and government green spending reduce pollution.

The dynamic equation of the economic growth rate follows:

$$\dot{g} = \rho\left(\frac{s_p\pi(\gamma+\gamma_\pi\pi+\gamma_P P)}{v\left(\frac{s_p\pi}{v}-\gamma_u\right)} - g\right) - \delta P^m + \eta_1 F_v + \eta_2 G_v \qquad (14)$$

The first term, $\rho\left(\frac{s_p\pi(\gamma+\gamma_\pi\pi+\gamma_P P)}{v\left(\frac{s_p\pi}{v}-\gamma_u\right)} - g\right)$, represents growth as a function of the investment rate ($s_p\pi$), the impact of inflation (π), pollution (P), and the parameter γ_π, which influences the capacity utilization. The term $\rho\left(\frac{s_p\pi(\gamma+\gamma_\pi\pi+\gamma_P P)}{v\left(\frac{s_p\pi}{v}-\gamma_u\right)} - g\right)$ highlights the adjustment mechanism of growth in response to economic policies and external shocks. The system seeks to converge to an equilibrium value, which is affected by economic variables such as climate financing and pollution levels. This term reflects how growth adjusts to its equilibrium value, considering economic policies and external shocks. The equilibrium equation for economic growth (g^*) is given by the part inside the parentheses, and the factor (ρ) models the speed of adjustment to the equilibrium value.

The term $-\delta P^m$ stands for a negative impact of pollution on economic growth. If $m > 1$ the effect of pollution on growth may be non-linear, meaning that as pollution increases, the negative impact on growth becomes more intense. This effect can reflect issues such as reduced productivity, damage to public health and/or adverse impacts on infrastructure and the business environment. Meanwhile, $\eta_1 F_v$ and $\eta_2 G_v$ represent the positive impacts of investments in green initiatives. Climate financing and government spending directed towards the transition to a low-carbon economy have positive effects on economic growth. These investments can result in several benefits, such as the creation of jobs in sustainable sectors, increased energy efficiency, the development of clean technologies, and the reduction of adverse effects of pollution. These factors can partially counterbalance the negative effects of pollution on growth, accelerating the transition to a more sustainable and resilient economy.

The equation suggests that, to achieve sustainable economic growth, it is crucial to balance

investments in clean technologies (represented by F_v and G_v), with the reduction of pollution (P). The presence of δP^m implies that, without the implementation of green policies, growth will be hindered as pollution increases, since the costs associated with pollution augment in a non-linear fashion.

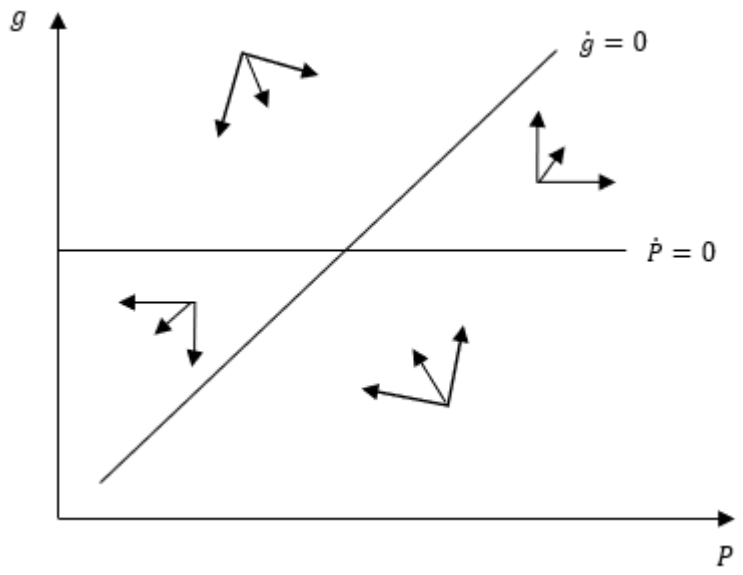
To analyze the dynamic stability of the model, we will construct the Jacobian matrix. Then, we will study the determinant and trace of the Jacobian matrix.

$$J = \begin{pmatrix} \frac{\partial \dot{P}}{\partial P} & \frac{\partial \dot{P}}{\partial g} \\ \frac{\partial \dot{g}}{\partial P} & \frac{\partial \dot{g}}{\partial g} \end{pmatrix} = \begin{pmatrix} 0 & \alpha \\ \frac{s_p \pi \gamma_P}{v\left(\frac{s_p \pi}{v} - \gamma_u\right)} & -\rho \end{pmatrix} \qquad (15)$$

To ensure the determinant is negative, the term within the parentheses must be positive. For this to occur, the following condition must hold: $\frac{s_p \pi \gamma_P}{v\left(\frac{s_p \pi}{v} - \gamma_u\right)} > \delta m P^{m-1}$. The impact of pollution P^{m-1} cannot be large enough to outweigh the effect of investment and climate financing represented by the first term of the expression. Specifically, the growth of $P^{m-1}$with $m > 1$ needs to be controlled so that the term $\frac{s_p \pi \gamma_P}{v\left(\frac{s_p \pi}{v} - \gamma_u\right)}$ dominates. The value of (P) must be sufficiently small, so that the effect of pollution in the term $\delta m P^{m-1}$ does not surpass the effect of investment and climate financing. Otherwise, the determinant will become positive, which could indicate instability in the model. This implies that the increase in climate financing and green government spending must be large enough to ensure that the economy grows in a balanced manner.

Therefore, assuming that s$\frac{s_p \pi \gamma_P}{v\left(\frac{s_p \pi}{v} - \gamma_u\right)} > \delta m P^{m-1}$, the determinant and the trace of the matrix, $det(J) < 0,\ tr(J) < 0$, are negative.This result shows that the equilibrium is a saddle point, which means the system is unstable in some directions and stable in others. Figure 1 shows the phase diagram is:

Figure 1: Phase Diagram



The phase diagram illustrates the dynamics between economic growth (g) and pollution (P), highlighting the conditions for a sustainable equilibrium. The horizontal line represents the isocline where $\dot{P} = 0$, signifying the growth levels at which pollution remains constant. The upward-sloping line corresponds to the isocline $\dot{g} = 0$, which defines the points where economic growth does not vary. The intersection point of these curves represents a potential equilibrium of the system, identified as a saddle point, suggesting instability in some directions and stability in others. The arrows on the diagram show that, above the isocline $\dot{P} = 0$, pollution tends to increase, while below it, pollution decreases. Similarly, to the right of the isocline $\dot{g} = 0$, growth slows down, while to the left, it expands. This behavior reflects the need for effective policies to keep the system on a sustainable trajectory, where investments in clean technologies and climate financing can offset the negative effects of pollution on growth.

In conclusion, the dynamic analysis presented in this section reveals the complex interaction between economic growth, pollution, and green policies. Equations highlight the crucial role of investment in clean technologies and climate finance in mitigating the negative impacts of pollution on growth. Through the analysis of the Jacobian matrix, we identified the necessary conditions for a stable equilibrium point and emphasized the importance of effective public policies to ensure a successful transition to a low-carbon economy. The results suggest that, to achieve a sustainable growth, it is essential for the positive effect of green initiatives to outweigh the adverse impacts of pollution, allowing the economic system to adjust in a balanced and resilient manner over time.

5- Conclusions

The current study explored the interaction between climate finance, green government spending, and economic growth within a post-Kaleckian framework, incorporating pollution as an endogenous

variable. The proposed theoretical analysis suggests that both climate finance and government investments aimed at the transition to a low-carbon economy have the potential to positively impact economic growth, while mitigating the adverse effects of pollution.

The main contribution of this article is to demonstrate how the inclusion of pollution and the role of public policies in the investment function can be endogenized in a post-Kaleckian economic model. As we showed, the impact of pollution on investment can be either negative or positive, depending on the intensity of mitigation efforts, such as climate finance and green government spending. Pollution, by increasing costs and reducing productivity, tends to harm economic growth in the short term. However, when appropriate policies are implemented, such as incentives for clean technologies, the impact of pollution can be mitigated, contributing to more sustainable growth in the long term.

The analysis revealed that the effects of climate finance and green government spending depend on the balance between aggregate demand, capital accumulation, and income distribution — key elements of the post-Kaleckian approach. In the short term, pollution can reduce the utilization of productive capacity and the rate of profit, which would hinder economic growth. However, by directing resources toward green investments, the government can stimulate the transition to cleaner technologies, thereby boosting competitiveness as well as a sustainable growth.

The theoretical modeling presented here helps to pave the way for the development of public policies that encourage a proper and efficient energy transition. Integrating environmental variables into economic growth models allows for a more comprehensive understanding of the dynamics of capital accumulation and its effects on the environment. Future research can expand this model, exploring the impact of different fiscal and financial policies in green economy transition scenarios and more deeply assessing the distributive effects of these policies. Besides, perform an empirical evaluation of those relationship.

In conclusion, this study reaffirms the need for an economic framework that recognizes the interaction between economic growth, environmental sustainability and public intervention. When adequately applied, climate finance and green government spending have the potential to transform environmental challenges into growth opportunities, fostering a more equitable and sustainable development.

Referências

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). "The environment and directed technical change." *American Economic Review, 102*(1), 131-166.

Aghion, P., Dechezleprêtre, A., Hemous, D., Martin, R., & Van Reenen, J. (2016). Carbon taxes, path dependency, and directed technical change: Evidence from the auto industry. *Journal of Political*

Economy, 124 (1), 1-51.

Baker, M., Bergstresser, D., Serafeim, G., & Wurgler, J. (2018). *Financing the response to climate change: The pricing and ownership of US green bonds* (No. w25194). National Bureau of Economic Research.

Bansal, P., & Roth, K. (2000). Why companies go green: A model of ecological responsiveness. *Academy of Management Journal, 43*(4), 717-736.

Bhaduri, A., & Marglin, S. (1990). *Unemployment and the real wage: The economic basis for contesting political ideologies*. Cambridge Journal of Economics, 14(4), 375-393.

Bulut, U., Ongan, S., Dogru, T., Işık, C., Ahmad, M., Alvarado, R., ... & Rehman, A. (2023). The nexus between government spending, economic growth, and tourism under climate change: testing the CEM model for the USA. *Environmental Science and Pollution Research*, *30*(36), 86138-86154.

Calel, R., & Dechezleprêtre, A. (2016). "Environmental policy and directed technological change: Evidence from the European carbon market." *Review of Economics and Statistics, 98*(1), 173-191.

Campiglio, E. (2016). "Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy." *Ecological Economics, 121*, 220-230.

Chen, Ge, and Qiu Sheng Li. "Fiscal spending and green economic growth: evidence from highly polluting Asian economic." *Environmental Science and Pollution Research* 31.1 (2024): 834-844.

Copeland, B. R., & Taylor, M. S. (2004). Trade, growth, and the environment. *Journal of Economic Literature, 42*(1), 7-71.

Corfee-Morlot, Jan, Bruno Guay, and Kate Larsen. "Financing climate change mitigation: Towards a framework for measurement, reporting and verification." (2009).

Dafermos, Y., Nikolaidi, M., & Galanis, G. (2018). *Climate change, financial stability and monetary policy*. Ecological Economics, 152, 219-234.

Dellink, R., Den Elzen, M., Aiking, H., Bergsma, E., Berkhout, F., Dekker, T., & Gupta, J. (2009). Sharing the burden of financing adaptation to climate change. *Global Environmental Change*, *19*(4), 411-421.

Fontana, G., & Sawyer, M. (2016). Towards post-Keynesian ecological macroeconomics. *Ecological Economics*, *121*, 186-195.

Graff Zivin, J., & Neidell, M. (2012). The impact of pollution on worker productivity. *American Economic Review*, 102(7), 3652-3673.

Hanna, R., & Oliva, P. (2015). The effect of pollution on labor supply: Evidence from a natural experiment in Mexico City. *Journal of Public Economics*, 122, 68-79.

Hein, E. (2013). *The Macroeconomics of Finance-dominated Capitalism and Its Crisis*. Edward Elgar Publishing.

Hein, E. (2014). *Distribution and Growth after Keynes: A Post-Keynesian Guide*. Edward Elgar Publishing.

Hossain, Belayet. "Do government spending on pollution abatement and targeted environmental policies promote green growth in Canada?." *Journal of Cleaner Production* 434 (2024): 140391.

Johnstone, N., Haščič, I., & Popp, D. (2010). Renewable energy policies and technological innovation: Evidence based on patent counts. *Environmental and Resource Economics*, 45(1), 133-155.

Kalecki, M. (1937). *The Principle of Increasing Risk*. Economica, 4(16), 440-447.

Kalecki, M. (1954). *Theory of Economic Dynamics: An Essay on Cyclical and Long-Run Changes in Capitalist Economy*. George Allen & Unwin.

Ketterer, J. C., & Kock, C. J. (2018). "Green banking and climate change: New challenges and opportunities." *Journal of Sustainable Finance & Investment, 8*(1), 1-5.

Khan, M. R., & Munira, S. (2021). Climate change adaptation as a global public good: implications for financing. *Climatic Change*, *167*(3), 50.

Krueger, P., Sautner, Z., & Starks, L. T. (2020). The importance of climate risks for institutional investors. *Review of Financial Studies*, 33(3), 1067-1111.

Lavoie, M. (2014). *Post-Keynesian Economics: New Foundations*. Edward Elgar Publishing.

Lin, Boqiang, and Junpeng Zhu. "Fiscal spending and green economic growth: Evidence from China." *Energy Economics* 83 (2019): 264-271.

Mazzucato, M., & Semieniuk, G. (2018). "Financing renewable energy: Who is financing what and why it matters." *Technological Forecasting and Social Change, 127*, 8-22.

Nordhaus, W. (2019). "Climate change: The ultimate challenge for economics." *American Economic Review, 109*(6), 1991-2014.

Oliveira, G., & Lima, G. T. (2022). Economic growth as a double-edged sword: The pollution-adjusted Kaldor-Verdoorn effect. *Ecological Economics*, *199*, 107449.

Pindyck, R. S. (1991). Irreversibility, uncertainty, and investment. *Journal of Economic Literature*, 29(3), 1110-1148.

Polzin, F. (2017). "Mobilizing private finance for low-carbon innovation–A systematic review of barriers and solutions." *Renewable and Sustainable Energy Reviews, 77*, 525-535.

Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, 9(4), 97-118.

Rezai, A., Foley, D. K., & Taylor, L. (2013). *Global warming and economic externalities*. Economic Theory, 49(2), 329-351.

Rezai, A., Taylor, L., & Mechler, R. (2013). Ecological macroeconomics: An application to climate change. *Ecological Economics*, *85*, 69-76.

Rochon, L.-P. (2020). *Theories of Money and Banking in Post-Keynesian Economics*. Routledge.

Somanathan, E., Sterner, T., Sugiyama, T., Chimanikire, D., & Tanaka, K. (2014). "National and sub-national policies and institutions." In *Climate Change 2014: Mitigation of Climate Change*. Cambridge University Press.

Stokey, N. L. (1998). Are there limits to growth? *International Economic Review*, 39(1), 1-31.

Storm, S. (2017). *Why Keynesian Economics Was Right and Why It Failed to Capture the Policy*

Agenda. Edward Elgar Publishing.

Taylor, L. (2004). *Reconstructing Macroeconomics: Structuralist Proposals and Critiques of the Mainstream*. Harvard University Press.

Taylor, L., Rezai, A., & Foley, D. K. (2016). An integrated approach to climate change, income distribution, employment, and economic growth. *Ecological Economics*, *121*, 196-205.

Timilsina, G. R. (2021). Financing climate change adaptation: International initiatives. *Sustainability*, *13*(12), 6515.

Yumei, H., Iqbal, W., Irfan, M., & Fatima, A. (2021). The dynamics of public spending on sustainable green economy: role of technological innovation and industrial structure effects. *Environmental Science and Pollution Research*, 1-19.

Zhang, Z., & Maruyama, A. (2001). Towards a private–public synergy in financing climate change mitigation projects. *Energy Policy*, *29*(15), 1363-1378.