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Research papers

# Thinking macro-economic vulnerabilities in the context of low-carbon transition

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**Thinking macroeconomic vulnerabilities in the context of low-carbon transition**


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**Résumé**
La transition vers une économie à faible émission de carbone et résiliente au changement climatique est un processus d'importante restructuration du réseau productif où des industries vont décliner et parfois disparaître et où des industries vont émerger et prospérer. Ce processus aura un impact sur tous les aspects de l'économie : de la demande à l'offre, du secteur public au secteur privé, de la finance à l'économie informelle. Alors qu'il existe une littérature croissante sur les conséquences macroéconomiques de ces transitions, il manque un cadre analytique permettant de percevoir de manière globale et systématique les vulnérabilités de ces dynamiques de changement structurel, particulièrement pour les économies en développement et émergentes. Cet article propose un tel cadre en soulignant comment les dimensions fiscales, monétaires, financières et externes peuvent être intégrées. Le cadre peut ensuite être utilisé pour questionner la robustesse des dynamiques de transition et identifier les points sur lesquels une attention particulière doit être portée.



**Mots-clés**
Transition bas carbone, vulnérabilités macro-économiques, trajectoires de développement



**Abstract**
The transition to a low-carbon and climate resilient economy is a process of important restructuring of the productive network where sunset industries will decline and sometimes disappear and where sunrise industries will emerge and flourish. As this process takes place, all aspects of the economy will be impacted: from demand to supply, from public to private sectors, from finance to the informal economy. While there is a growing literature on the macroeconomic consequences of these transitions there lacks an analytical framework that allows perceiving in a comprehensive and systematic way the vulnerabilities of such structural change dynamics, particularly in the context of developing and emerging economies. This paper proposes such a framework highlighting how fiscal, monetary, financial and external dimensions can be integrated. The framework can then be used to question the robustness of transition dynamics and pinpoint where extra attention should paid.



**Keywords**
Low carbon transition, macroeconomic vulnerabilities, development trajectories

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# Introduction

The perspectives on the future evolution of climate change have increased interest in studying not only its impacts on physical and biological systems, but also its socio-economic implications. The increase in global temperature and the intensification of extreme weather events are expected to affect the productive capacity of the economies, to disrupt trade flows and investment decisions, to increase volatility in prices and financial markets, to deteriorate the balance-sheet of the different institutional sectors, as well as to exacerbate poverty and inequality especially in developing economies, see *e.g.* Seminiuk *et al.* (2021).

In this sense, transition strategies to mitigate greenhouse gases (GHG) emissions and increase the resilience and capacity of societies to cope with climate change effects are essential for any development agenda, as established in the COP21 commitments (UNFCC, 2015). However, the transition to a low-carbon economy is a complex process that necessarily generates tensions and conflicts from micro to macro levels, while it imposes additional constrains on economic growth. In this regard, it can lead to important structural changes, in terms of productive specialization, innovation and technological development, consumption and investment patterns, and income distribution.

Macroeconomic policies should contribute to minimizing and solving such tensions and problems in such a way that the GHG mitigation and climate change adaptation is an intra and inter-generational *productive transformation with social justice*. Nevertheless, those climate-related risks that affect macro-financial conditions also influence the achievement of policy objectives and the degrees of freedom of policymakers. In this sense, macroeconomic policies must not only promote favourable conditions for an orderly adjustment to a low carbon path, but must also respond to the negative effects that some irreversible climate events and transition policies may have on the economy. This is important because the exposure of fiscal, monetary, financial, and external sector conditions to physical and transitions risks could diminish the capacities of the economy to mitigate and adapt to climate change.

Therefore, it is critical for an orderly and feasible low-carbon transition to assess how robust is the macroeconomic policy framework to climate-related risks. In this context, vulnerability assessments are a key tool to analyse not only the impact of climate-related stressors and some transition strategies on the economy, but also to understand how those impacts could be amplified or diminished by non-climatic factors that increase the exposure and coping capacity to a certain shock. These non-climatic factors could be related to the level of economic development, the structure of the economy and its pattern of international insertion, the orientation and role of the State within the economy, and the level of priority of environmental issues within the

hierarchy of objectives and management of economic policy.

This approach needs to emphasize on multifactorial analysis as vulnerability is not a univocal and directly observable characteristic, which cannot rely on an aggregate indicator or exclusively on quantitative considerations. Instead, there is a multiplicity of potential risks on macroeconomic and social conditions, which require deliberation about weighing and prioritizing objectives, evaluating possible intra and intertemporal trade-offs, and developing joint and coordinated policy responses between economic authorities. Consequently, those responses and hierarchies of objectives are not neutral regarding economic and transition outcomes.

This paper aims to propose a multidimensional approach in monitoring the vulnerability of the macro-financial system, emphasizing three major aspects of the economy: a) the fiscal conditions, b) the monetary and financial conditions and c) the vulnerability of the economy vis-à-vis the external sector. The proposed approach provides an explicit framework for understanding and evaluating the associated constraints and leeway in terms of policy making, aiming for a socially fair and smooth transformation.

Based on the above, the paper is organized according to the following structure. Section two provides a rigorous and analytic definition of macroeconomic vulnerabilities, while section three highlights the importance of multifactorial analysis in monitoring vulnerabilities, due to their highly complex nature. Section four proposes a set of factors that ought to be considered when examining potential risks in terms of fiscal policy. Likewise, sections five and six focus on similar factors that are related to monetary and financial conditions and the external sector, respectively. The ultimate section provides the concluding remarks.

# 1. Vulnerability and macroeconomic policies

The recent literature about macroeconomics and the low-carbon transition is mostly focused on the consequences of green policies such as taxes, subsidies, or public investments, the interaction between climate change and financial stability through the concept of physical and transitions risks, the feasibility of de-growth policies, the depletion of resources and State-led innovation, the investments and structural changes required in the energy sector, among others (Batten, 2018; Carnevali *et al.*, 2019; Feyen *et al.*, 2020).

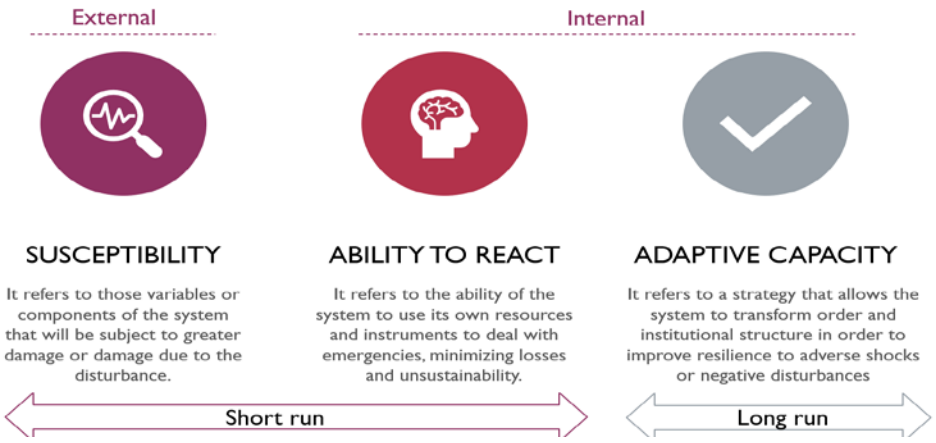
However, a consistent examination of the macroeconomic vulnerabilities to the actions aimed to move towards a low-carbon economy is missing. Transition strategies implemented both domestically and globally could affect macroeconomic conditions, inducing risks at the external, monetary, financial, and fiscal levels, as highlighted for some of these aspects by Espagne *et al.* (2021). The examination of these potential risks is critical, as they could affect the implementation and effectiveness of transition policies, amplify tensions between the public and the private sector, and impose further financing and political constraints. Therefore, it is important to define with rigor and analytical clarity the term vulnerability and its potential application in macroeconomics.

Important literature associated with the field of risk and disasters management has been reflecting on the subject for more than twenty years. Although there are different analytical approaches to the definition and measurement of vulnerability, depending on the priorities of the researchers, it seems that there is already a kind of semi-agreement on the determinants of vulnerability (Cardona Arboleda, 2001). Below follow two generic definitions presented in Marre (2013) that can be useful in this analysis:

> *Vulnerability is usually defined as the ability of a system to be affected by a disturbance or tension. It is a function of the probability of occurrence of the disturbance and its magnitude, as well as the ability of the system to absorb and recover from it (Suarez, 2002).*
>
> *Vulnerability is the degree to which a system, subsystem, or system components are likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor (Turner et al, 2003).*

Vulnerability can be associated with three conditions: susceptibility, ability to react and adaptive capacity. The first one has an external origin and is determined by the exposure to an external threat or danger (disturbance). The second and third ones have an internal nature and capture the capacity of the system to respond to the exposure, either in the short or in the long run. Figure 1 can help to understand more precisely the internal components or vulnerability drivers of a system.

**Figure 1. Vulnerability components**



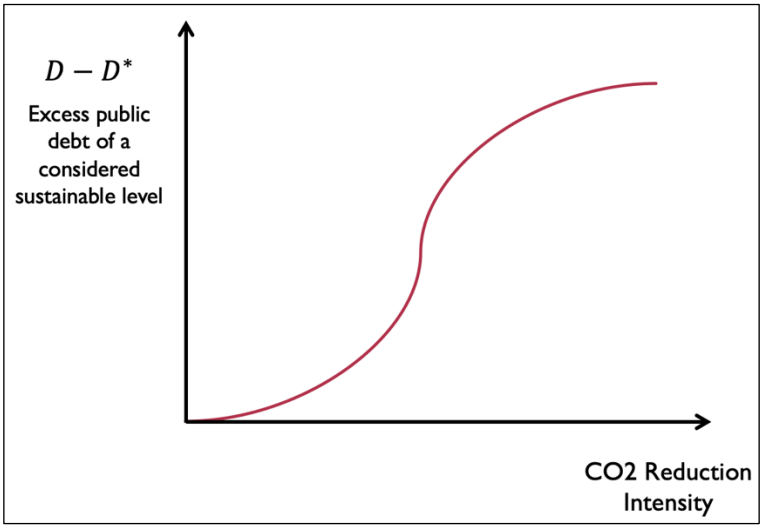

Source: Own elaboration based on Welle *et al.*, 2013.

Susceptibility and reaction abilities are short-run system properties. On the one hand, susceptibility refers to those variables or components of the system that will be subject to greater damage or disruption. On the other hand, reaction ability refers to the capability of the system to use its resources and instruments to face emergencies, minimizing losses and imbalances. Finally, adaptive capacity refers to a long-term strategy that allows the system to transform the order and institutional structure to improve resilience against adverse or negative shocks (Welle, *et al.*, 2013).

In this order of ideas, Carley *et al.* (2018, p. 1) define three interrelated dimensions associated with the previous vulnerability conceptualizations, which are applied to the case of the US energy policies. They define "vulnerability as a function of where and when these policies go into effect (exposure); the susceptibility of different communities to the impacts of these policies (sensitivity); and the capability of communities to attenuate, cope or mitigate the negative effects (adaptive capacity)".

As shown in IDEA (2005), it is possible to build vulnerability functions that allow the description of the system vulnerability depending on the intensity of the event or the disturbance that hits the system. As an example, Figure 2 shows that public debt levels (as a proxy for fiscal conditions) could be expressed in the form of a vulnerability function applied to the context of the low-carbon transition. The vertical axis indicates the excess of public debt from a level that is considered sustainable, and the horizontal axis represents the scale or intensity of GHG reduction that could be implemented by a certain country.

**Figure 2. Vulnerability function for fiscal conditions**

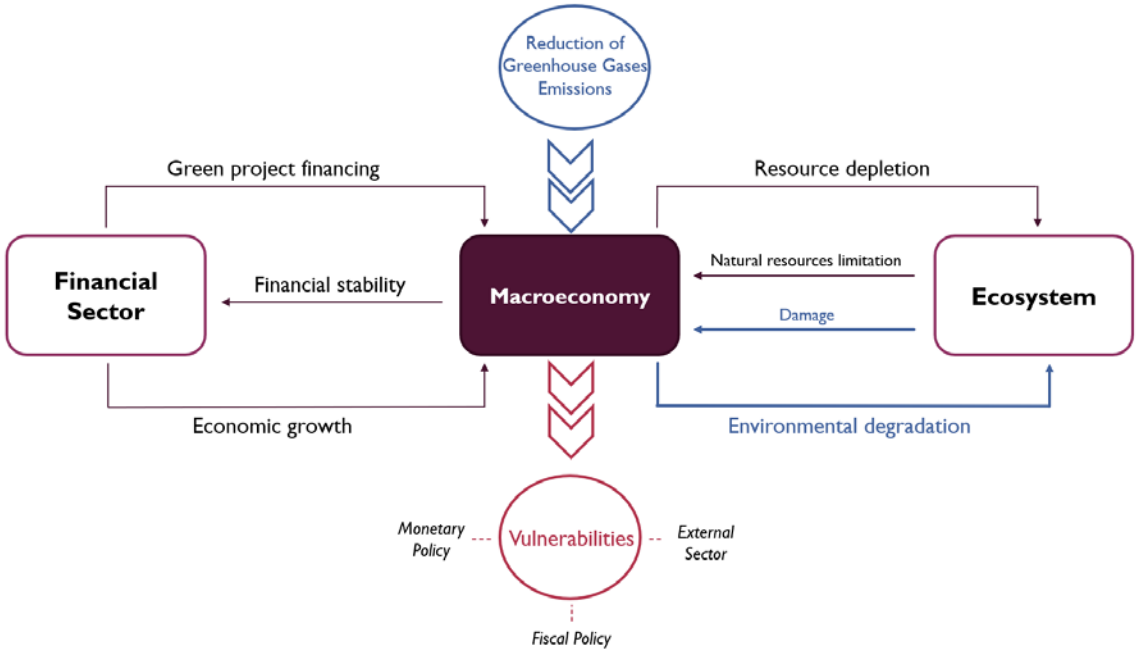



Source: own elaboration.

The graph above shows that the transition to a low-carbon economy can put pressure on public budgets and debt levels, as the more ambitious the emission reduction targets, the greater the public investments required in renewable energies and low-carbon and climate-resilient infrastructure. In a jointly published report by the Asian Development Bank, the University of London and other NGOs, Volz *et al.* (2020) argue that the sovereign risk may be increased not only by the effects of the gradual rise in temperature and the greater frequency of adverse climate events on the economy, but also by the commitments imposed by the transition. This is due to the emergence of contingent liabilities in the form of public guarantees on the various investment projects, the debt servicing burden in response to the increased green financing needs, lower revenues from highly carbon-intensive and fossil fuel extraction activities, and the surge in the expenditure required to minimize the social and economic stresses resulting from domestic and foreign transition policies.

Based on the above, Figure 3 presents a macroeconomic scheme that integrates the financial sector, the national macroeconomy and the ecosystem as proposed by (Dafermos, Nikolaidi, & Galanis, 2017). For this paper, two elements were added to the original diagram. The first corresponds to the shock or threat associated with the GHG emissions reduction agreement, which is supposed to affect both the economy as a whole and the ecosystem (through lower damage and environmental degradation). The second indicates that the fulfilment of those commitments affects and puts strain on monetary, fiscal, and external sector conditions. The blue arrows show the impact on the macroeconomy and the red arrows indicate the connection between vulnerability and the respective dimensions.

**Figure 3. Vulnerability analysis under macroecological interactions**




Source: Own elaboration based on Dafermos *et al.* (2017).

Even though for analytical purposes the decision to mitigate GHG emissions could be considered as exogenous or determined outside the system, its implementation and magnitude depend on specific dimensions and characteristics of each country, including the feedback and response to the macro-financial risks that could emerge as a response of the different transition drivers: policies and regulation, technological and structural change, shifts in consumers and investors' preferences. Thus, this approach is not just useful to analyse macroeconomic vulnerabilities linked to the low-carbon transition, but also for proposing mitigation policies environmentally effective with reduced risks and costs.

Ultimately, this type of approach would allow reducing the macro-financial risks that could arise during and after the transition, with risk, as exposed in eq. (1) understood as a function of threat and vulnerability (Cardona, 2001). Nevertheless, a proper risk assessment must recognize the complex nature of the economic relationships that may be exposed to the transition and adverse effects of climate change, as well as the difficulty of synthesizing vulnerability into a single aggregate indicator. Thus, the following section will discuss the relevance of the approach so far proposed to be holistic and multifactorial.

$$Risk = f(Threat, Vulnerability) \qquad (1)$$

# 2. The relevance of multifactorial analysis

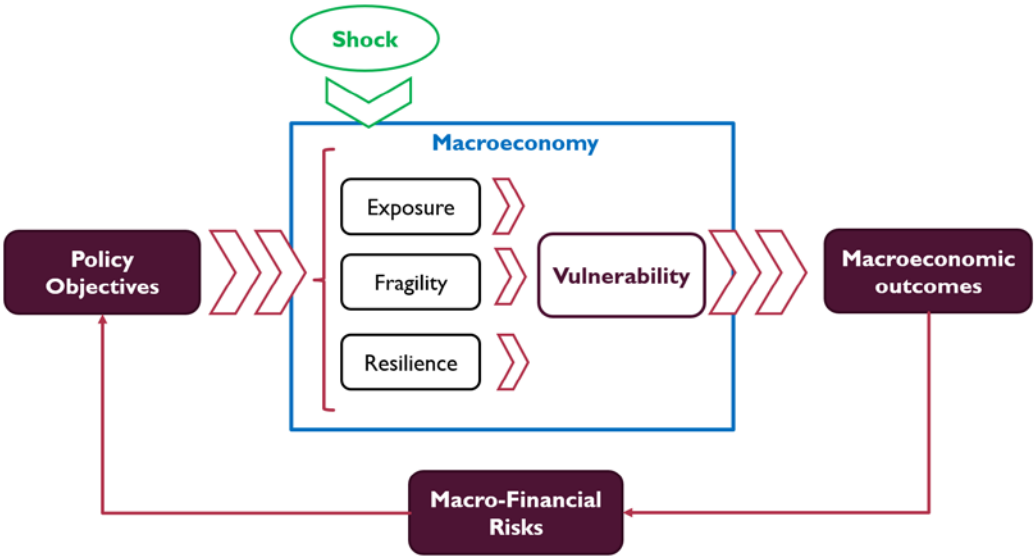
As already expressed above, the purpose of the paper is to establish a vulnerability framework to analyse how the transition to a low carbon economy and the adaptation to climate change could induce some macro-financial risks. To the extent that emphasis will be placed on fiscal, monetary, financial, and external conditions, the previous vulnerability conceptualizations will be complemented with a multifactorial analysis to adequately address the complex and uncertain interactions between the macroeconomy and the transitions strategies.

A multifactorial approach is important, as vulnerability is not a univocal and directly observable characteristic that can be summarized in a single aggregate indicator. On the one hand, the internal and external factors affecting the degree of vulnerability cannot be fully quantified, because certain latent elements have not yet been realized, others are more qualitative, and some are simply not comparable. On the other hand, focusing on an aggregate indicator would downplay the individual trends of each of the vulnerability drivers. It could be the case where the aggregate indicator does not change significantly, but there are opposite and offsetting movements in the exposure and the resilience of the unit of analysis that is not captured.

Instead, there is a multiplicity of potential risks on macroeconomic conditions that can arise from the transition to a low carbon economy. These perspectives require some sort of deliberation on the weighting and prioritization of objectives by policymakers, so that the hierarchy of objectives and the orientation of the policy framework end up conditioning the response of the economic authorities to the challenges of the transition. In this sense, policymakers need to evaluate possible intra and intertemporal trade-offs, develop joint and coordinated policy responses, and begin to address environmental issues and challenges in medium and long-term planning.

In line with the previous section, a holistic interpretative scheme is also presented in this section, which is an adaptation of the natural disaster risk models (Suárez, 2009; IDEA, 2005; Cardona *et al*., 2005) and will serve as a conceptual guide for the analysis. Figure 4 shows the interaction between the transition to a less carbon-intensive economy (shock) and the different elements that comprise the concept of vulnerability, which lead to macroeconomic outcomes that may differ from policy objectives. Consequently, risks in macro-financial conditions are defined in terms of imbalances in key macroeconomic variables and non-compliance with policy objectives.

**Figure 4. Vulnerability drivers and macro-financial risks**




Source: own elaboration based on Suárez (2009).

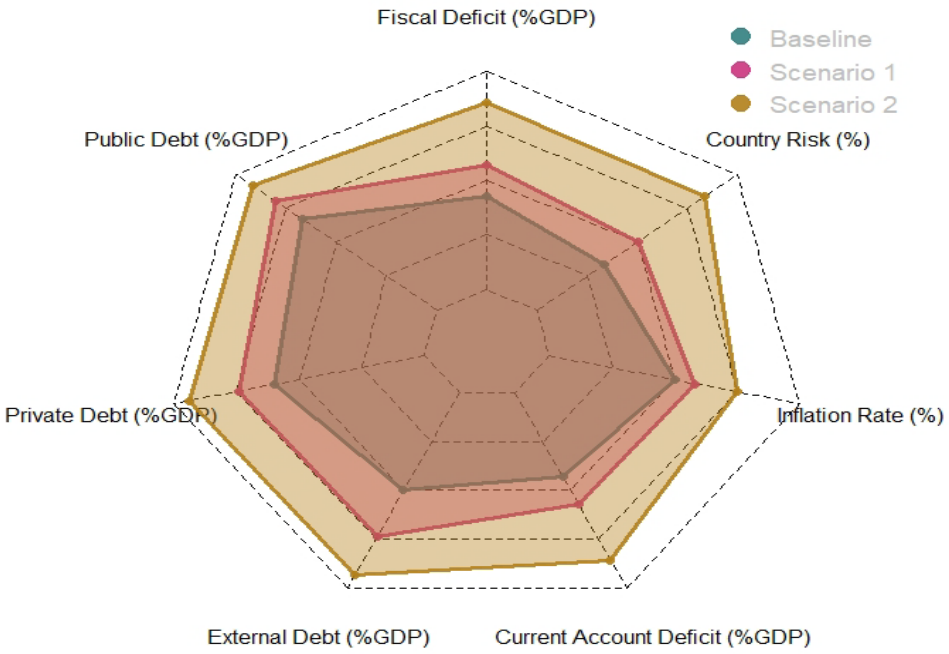
The implementation of certain policies and strategies to reduce GHG emissions and to adapt to climate change is an event that can be understood as a shock to the system. Hence, the exposure or susceptibility is related to the main macroeconomic and financial variables that will be subject to the greatest impact from the low-carbon transition, affecting the goals of the economic authorities. However, the economic impacts derived from domestic and foreign transition policies could be amplified or diminished depending on the fragility of macroeconomic conditions and the economic policy resilience.

The first refers to the macroeconomic and financial predisposition to be affected by external disturbances, and the limitations they have to act efficiently in the short term, and therefore, mitigate or reduce the impacts on the economic performance. The second refers to the capacity of macroeconomic policy to face, adverse situations or economic emergencies resulting from the external event, using its resources and instruments. At the same time costs and imbalances are minimized, while the system recovers and strengthens.

Thus, the response of some key variables and indicators to a certain low-carbon transition strategy will make it possible to assess the vulnerability of macroeconomic conditions. These outcomes could compromise the achievement of policy objectives and the degrees of freedom of policymakers, while limiting the capacities and predisposition of the economy to mitigate and adapt to climate change. The preliminary outcomes variables that will be used in the multifactorial vulnerability assessment are *current account deficit (%GDP), external debt (%GDP), exchange rate depreciation (%), fiscal deficit (%GDP), public debt (%GDP), private debt (%GDP), inflation rate (%),* and *country risk (%).*

Figure 5 presents a radar chart that shows how these variables behave under different transition strategies with varying intensity. The scheme aims to compare the results of each transition scenario and to analyse the discrepancy between macroeconomic outcomes and policy objectives, even though there are no specific target values for most of them. In other words, depending on the effect that the transition may have on the outcome variables, the macroeconomy reflects greater or lower vulnerability. Therefore, the purpose is to analyse how each axis evolves, incorporating projections of different models (such as an Integrated Assessment Model or an ecological Stock-Flow Consistent model).

**Figure 5. A radar plot for vulnerability assessments**




Source: own elaboration. Ad hoc values.

Based on the above, it is possible to carry out a sensitivity analysis for each scenario since the impact of the same transition strategies and policies on each axis reported in Figure 3.2 could differ according to the current fragility and resilience conditions. The exposure of the outcome variables to the effects of the transition could be amplified by factors that increase macroeconomic fragility in the face of a certain adverse shock, as they amplify the intensity of the shock and reinforce its transmission channels. Among them stands out the initial stock of international reserves, the short-term external debt, the specialization pattern in international trade, the tax structure, the effectiveness of monetary transmission mechanisms, the exchange rate pass-through, among others.

Similarly, the response of the outcome variables to mitigation and adaptation measures may be affected by certain factors that influence how the economy and policymakers

respond to the shock. Among the factors that alter the resilience, and the coping capacity of the economy stands out the leeway to manage interest rates, capital account regulations, the exchange rate regime, access to external financing, institutional strength and credibility, countercyclical fiscal rules and automatic stabilizers, the degree and effectiveness of the interventions in foreign exchange markets, the economic complexity of the productive system among others. Ultimately, these factors reflect the degrees of freedom of policymakers and the available instruments to respond to physical and transitional risks to mitigate their impact and increase the resilience of the economy.

It is important to mention that although multiple indicators are describing macroeconomic conditions, they are all interconnected and subject to common stressors. For example, current account deterioration has negative effects on the exchange rate, which imply that the central bank would likely have to intervene due to the "pass-through effect" on inflation. Regarding fiscal conditions, a depreciated exchange rate puts pressure on the government debt service. At the same time, an unsustainable current account deficit creates more difficulties for the government and private sector to get access to external financing as the risk perception increases. In this context, the analysis will be laid upon each condition separately, but the conclusions will take to account findings in conjunction, *i.e.*, the final assessment needs to be holistic.

Having specified the framework for analysing vulnerabilities at the monetary, financial, fiscal, and external sector levels in the context of the transition to a low-carbon economy, the following sections will briefly delve into each of these dimensions. To do so, we will briefly present how conventional economic analysis approaches each of these dimensions, and then establish the respective links with the transition risks and possible adverse effects of climate change. Finally, the main variables that influence the exposure, fragility and resilience of each dimension are summarized for further studies.

# 3. Fiscal conditions

In most macroeconomic models, fiscal policy is included in a relatively simple way. Generally, there are three dimensions: tax revenue flows (direct and indirect taxes, social contributions), expenditure flows (social benefits, infrastructure, defence, and operating expenses) and public debt stock (external and internal). Thus, the government's budget constraint allows to link the two categories of fiscal variables: the debt dynamics and the balance (or imbalance) of the public budget, added to the feedback between higher debt levels and interest payments. This is particularly important in developing economies where the public deficit is financed through public debt in financial markets, where the so-called investors and credit rating agencies, can restrict access to financing resources.

In this sense, fiscal authorities define policy objectives by which they determine the short and long run actions to be followed to be consistent with economic stabilization and long-term growth. Consequently, they use several instruments to fulfil different objectives such as a target level of debt or fiscal deficit. However, fiscal outcomes are not independent of the behaviour of the economy and could not be fixed ex-ante, since under this approach neither tax revenue, expenses, debt balances nor sources of financing are given. On the contrary, income and expenses have an endogenous component that imposes limits on the fiscal policy makers.

Likewise, in many countries, some institutional arrangements and rules influence both policy objectives and fiscal outcomes. For example, self-imposed fiscal rules (balanced budget rules) are an explicit mechanism by which restrictions are placed on discretionary fiscal policy and macroeconomic management. In other words, the constitutional constraints associated with ceilings to the public deficit or the debt dynamics may eventually trigger the financial fragility of the public sector.

Based on the above, some authors recognize that fiscal conditions must be understood in a vulnerability context (Baldacci *et al*., 2011; Hayes, 2011). Stoian *et al.* (2018) who summarize the literature regarding fiscal policy vulnerability indicators, define fiscal vulnerability as "any kind of intrinsic weakness in the existing fiscal policy or exogenous shocks that lead to a significant deterioration in the level of a public budget balance and/or public debt that will limit the government's ability to achieve its goals" (Stoian *et al*., 2018, p. 6). This definition incorporates several elements that can be better identified with the risk analysis proposed in previous sections.

For instance, the implementation of a policy to reduce GHG emissions is an event that could lead to important changes in public budgets because of the green investments and environmental tax policies required. Hence, *intrinsic weakness* can be interpreted as the conditions of exposure and susceptibility of fiscal policy to the transition risks and the intensity of the event is related to the magnitude and timing of the transition. Likewise, the *ability limitation* may be associated with fiscal fragility, the resilience of fiscal policy in facing

the stress events efficiently, and its capability for a quick recovery. Finally, *risk* can be defined as a failure to meet the desired fiscal conditions and targets.

One of the possible vulnerabilities that could emerge during and after GHG reduction strategies could be related to public debt sustainability. Although there are no scientifically rigorous criteria to determine the optimal level of public debt -*sustainable debt to GDP ratio*- ***D****, empirical researchers assume arbitrary values defined by market conventions or by the credit rating agencies. Hence, these "standards" can become a potential vulnerability factor because the recent history of financial crises indicates the existence of a pro-cyclical behaviour of valuation risk. In those scenarios when more resources are required to sustain counter-cyclical policies, credit rating agencies can worsen the credit conditions access for the countries at hand. This can be seen through increases in the risk premiums or rationing liquidity to the countries in the financial markets, amplifying other fiscal and macroeconomic vulnerabilities especially in developing economies.

Under this scenario, a relationship between financial risks and fiscal variables emerges. This connection limits the actions of discretionary fiscal policy for addressing exogenous shocks to the system and actions aimed to decrease public finances vulnerability. For example, a fiscal sustainability risk emerges due to the implementation of climate change mitigation and adaptation policies. This reduction in the degrees of freedom because of the discrepancy between fiscal outcomes and policy objectives, would force the fiscal authorities to decrease the intensity of GHG reduction and other complementary policies, to improve fiscal indicators.

# 4. Monetary and financial conditions

Within the so-called *New Consensus* school of thought, whose formal representation is found in Dynamic Stochastic General Equilibrium models (DSGE), it is established that the most effective tool for stabilizing the economy in the short term is the *monetary policy*. Several authors do not hesitate to recognize the new institutional framework of macroeconomic policy as *monetary dominance* (Rochon & Setterfield, 2007).

One of the pillars of the new institutional arrangement is the central bank independence, which isolates monetary policy from interference or ad-hoc interventions of other institutional agents. Indeed, central bank independence is defined in two ways: (i) independence to define monetary policy objectives and (ii) autonomy to determine the monetary tools to be used and how they are implemented.

Setterfield and Rochon (2007) summarize the foundations of the inflation targeting scheme and the Taylor rule in the following terms:

- The production function determines the natural output, which behaves as the gravity centre. The model supply conditions determine the economy capacity on the one hand. On the other hand, following Solow, the growth of the labour force and technical change determine the long-term growth rate.
- A long-run vertical Phillips curve matches the potential output (Non-Accelerating Inflation Rate of Unemployment - NAIRU), which implies that there is no trade-off between inflation and unemployment at this level of output. Consequently, monetary policy is neutral in the long run as it does not affect real variables but only inflation.
- The changes in aggregate demand determine the short-term deviations of potential output. This can occur due to the difference between r (interest rate) and r* (natural interest rate) or due to fiscal policies. After a certain adjustment lag, the economy returns to its equilibrium full employment position. Similarly, the short-term price rigidity explains the Keynesian results of the model in the short and medium run, during which money is not neutral.
- Inflationary expectations play a fundamental role. Therefore, the Central Bank must act with transparency and gains credibility and consistency through its policies.
- Guided by the Taylor rule, the Central Bank sets the interest rate. Money supply is endogenous as it ensures equilibrium in the money market.
- The natural interest rate (r*) is determined by the balance between savings and investment at the level of full employment and cannot be altered by the Central Bank. In other words, the forces that interact are real and not monetary.

Certainly, the institutional and technical arrangement of the monetary policy eliminates any possibility that the Central Bank actions have real lasting effects on the economy. Central Bank actions can affect GDP and real variables just in the short run if there is some kind of real or nominal rigidity that prevents prices from adjusting efficiently. But once they gradually adjust, the economy will return to its natural equilibrium, thus erasing the history of small recessions on the path to steady-state equilibrium.

Regarding climate change, monetary policy could modify the environmental balance in the short run. However, the monetary authorities' actions on the environment fade out in the long run (Heyes, 2000; Lawn, 2003). In this scenario, the money neutrality axiom is maintained, and in turn, is directly extended to the problems of climate change and environmental deterioration, which can be defined as the *ecological neutrality of monetary policy* (see Faria *et al.*, 2021). Thus, Central Bank independence excludes any concern regarding the impact of climate change and environmental deterioration on the operating logic of the monetary policy.

In line with the above, Bolton *et al.* (2020) who researched on behalf of the Bank for International Settlements and the Banque de France recognized explicitly that *The Green Swan*[1] could compromise the implementation of monetary policy, limiting its ability to respond to the challenges of a permanent shock, such as the climate change. This could lead to persistent imbalances on the supply and demand sides. The current central banks' instruments and operational protocols are not properly designed to address the state of climate emergency and its socioeconomic implications. These concerns are consistent with the need for an epistemological break in the monetary policy, financial regulation, and supervision approach.

In a scenario of intense climate change, central banks should not limit themselves to just measuring the possible risks that may arise on price stability, while delegating other government actors to take actions to mitigate and adapt to these climate-related risks. There is a need for more active central banks policies to cope with climate change effects and to encourage the low-carbon transition, such as implementing green monetary policies (Campiglio, 2016; Dafermos *et al.*, 2017). Even, in the worst scenario, central banks ought to take the role of climate rescuers of last resort. This becomes particularly important considering the adaptive capacity of the economy, which by definition is examined in the long-term, and in which period the central bank policies are considered in an ad-hoc manner as ineffective or inflationary.

[1] The idea of "green swan" came from the now widely known concept of "black swan". The black swan concept was developed by Taleb (2007) and it refers to unexpected and rare events which are out of the standard expectations, but at the same their impacts have a wide range and they just can be understood and explained after the fact (Bolton *et al.*, 2020). Thus, green swans (*i.e.*, climate black swans) are events of this type but related to climate-change risks. These events are "characterised by deep uncertainty and nonlinearity, their chances of occurrence are not reflected in past data, and the possibility of extreme values cannot be ruled out" (Weitzman (2009, 2011)) in Bolton *et al.* (2020.)

However, appropriate interventions and policies require an understanding of the types of risks that central banks and the financial system may face because of climate change and the low-carbon transition. On the one hand, physical risks correspond to the adverse effects and damages that the increase in global temperature and the intensification of extreme weather events could have on the economies from micro to macro levels, human beings, and natural systems (NGFS, 2020; Batten, Sowerbutts & Tanaka, 2020). On the other hand, continuing with the statements of Bolton *et al.* (2020, p. 18), "*Transition risks* are associated with the uncertain financial impacts that could result from a rapid low-carbon transition, including policy changes, reputational impacts, technological breakthroughs or limitations, and shifts in market preferences and social norms".

Both physical and transition risks are one of the challenges that can face monetary policy in a scenario of climate change and environmental deterioration, as they influence each other. This fact makes it necessary to recognize the relationship between both types of risks. According to Bolton *et al.* (2020, pp. 18-19):

> *A strong and immediate action to mitigate climate change would increase transition risks and limit physical risks, but those would remain existent (we are already experiencing some of the first physical risks of climate change). In contrast, delayed and weak action to mitigate climate change would lead to higher and potentially catastrophic physical risks, without necessarily eliminating transition risks (e.g., some climate policies are already in place and more could come). Delayed actions followed by strong actions to catch up would probably lead to high both physical and transition risks.*

Therefore, physical and transition risks related to climate change could induce financial losses and deterioration in the balance sheets of the different institutional sectors. This is expressed through the damage and loss of value in collaterals, the devaluation of some financial and real assets, as well as the emergence of stranded assets in activities more exposed to climate change impacts and transition policies. According to the Network of Central Banks and Supervisors for Greening the Financial System (NFGS, 2020), financial imbalances related to climate change have potential systemic consequences, to the extent that liquidity and credit access conditions tighten, insurance risk premiums increase, debtors 'ability to pay decreases, and asset holders' expectations abruptly change.

One of the drivers of these potential financial imbalances corresponds to the emergence of stranded assets in highly carbon-intensive activities and those that have financial and real intersectoral linkages with them. These stranded assets arise because of a misalignment between current conventional investment patterns and future (also current) transition policies which, if carried out in an unplanned and disorderly manner, may induce sharp devaluations in certain assets and reduce their cash flows considerably (Semienuk *et al.*, 2021). The sectors where this phenomenon could have the greatest repercussions would end up being those that fail to adapt to a low-carbon infrastructure and productive structure.

For instance, it may be the case where proven reserves of fossil fuels could not be extracted, thus becoming *stranded assets*, which could have significant consequences on the financial system and, therefore, prompt a possible financial crisis (a climate-related Minsky moment). Transition risks would also indirectly impact sectors dependent on fossil fuels such as the automobile industry or mining companies, as well as the confidence in macroeconomic prospects for commodities exporting countries (Bernal & Ocampo, 2020). Consequently, the transition to a low-carbon and climate-resilient economy can induce financial imbalances, which can be amplified if they are carried out in a disruptive manner and without the involvement of central banks.

Ultimately, the timing and type of climate change adaptation and mitigation strategies would not only affect the real side of the economy, but also the operation and fulfilment of objectives of the monetary and financial authorities. In consequence, the low-carbon transition must assess how robust is the monetary policy framework to climate-related and transition risks. In this sense, Stoian *et al.* (2018, p. 6) define monetary vulnerability as any kind of intrinsic weakness in the central bank policy or as an exogenous shock that leads to a significant deterioration in the financial sector dynamics or inflation targeting. Thereby, it limits the monetary authorities' ability to achieve their goals.

Following Bolton *et al.* (2020, pp. 19-20), the concept of financial risk comprises five categories:

i. *Credit risk* could increase mainly by two causes: higher default probabilities (PD) and a higher loss-given default (LGD) prompted by the deterioration in borrowers' ability to repay their debts due to climate-related risks, as well as the potential depreciation of assets used for collateral.

ii. *Market risk*: under an abrupt transition scenario, financial assets could be subject to devaluation and a change in investors' perception of profitability, which could trigger a financial crisis.

iii. *Liquidity risk*: It can occur when banks whose balance sheet was hit by credit and market risks are unable to refinance themselves in the short term. At the same time, it would produce tensions in the interbank lending market, affecting both banks and non-bank financial institutions.

iv. *Operational risk*: financial institutions can be affected through their direct exposure to climate-related risks. For instance, damages in their offices due to physical risks could affect their operational procedures, together with other institutions across its value chain.

v. *Insurance risk*: insurance and reinsurance sectors could be affected by higher expected insurance claim pay-outs resulting from physical risks, as well as, by potential under-pricing of new insurance products covering green technologies due to transition risks.

# 5. External Sector

In developing economies, the vulnerability of the external sector is assessed through the balance of payments dominance (Ocampo, 2016). This approach points out that the main determinants of domestic economic cycles (booms and recessions), as well as the pro-cyclicality of macroeconomic policies, are the real and financial shocks transmitted from the current and capital account of the balance of payments to the domestic side of the economy. In other words, "[balance-of-payments dominance is] the regime in which the external shocks, both positive and negative, are the essential determinants of short-term macroeconomic dynamics. Under this regime, the balance of payments exercises strong cyclical shocks through trade and the availability and cost of external financing" (Ocampo, 2016, p. 212).

Developing countries have two main characteristics that amplify the impact of external shocks on the internal performance of the economy. The first one is related to the fact that developing economies do not issue a key currency, which cannot be used for international transactions. This implies that these countries are dependent on external financial flows to meet their obligations and payments to the rest of the world if they are not able to generate sufficient foreign exchange by exporting goods and services. In this case, real and financial cycles in advanced economies are transmitted to peripheral economies, inducing volatilities and recurrent shocks that affect their performance in the short and medium-term.

The second one is the structural heterogeneity and the specialization pattern in international trade. Peripheral economies have a productive structure that generates large inter and intra-sectoral productivity differentials. This in turn segments the productive system into two distinct sets of loosely integrated activities, creating a dual economy. On the one hand, there are modern tradable activities, which use cutting-edge technology, are highly capitalized and have a high level of wages and productivity. On the other hand, there is a great variety of traditional or informal activities that use artisan technologies and have a low level of capitalization, productivity, and precarious remuneration. This last type of activity absorbs most of the workforce, while foreign trade is concentrated in a few primary goods or commodities (Cimoli and Porcile, 2014).

Although there has been an extensive discussion concerning the problems derived from Dutch disease in the economic development of peripheral economies, (whether its origin comes from a real or financial balance of payments shocks; see Corden and Neary, 1982; Botta *et al*., 2014; Wunder, 1992), the literature on the external sector vulnerability is oriented towards other types of problems. It focuses primarily on the economy's short-term performance, especially on the *balance of payments* crises and the unsustainability of the external debt (Supriyadi, 2014; Radziunas and Montoya, 2004).

Recently, Ramírez and Díaz (2019) define external vulnerability as the degree of the economy's exposure to withstand a sudden stop. This definition is inconsistent with the

international literature, as well as experience. In the first place, the concept of vulnerability contains additional aspects to the exposure of the systems, therefore, features related to fragility and resilience should be included. On the other hand, a sudden stop is just a stage of a more complex process as is the currency or balance of payments crisis. Indeed, the third-generation models refer to the twin, financial and balance of payments crises.

Therefore, following Esser (2015), the vulnerability of the external sector will be defined as the possibility that the balance of payments could be negatively affected by an external shock. This in turn would affect the sustainability of the external debt or trigger a balance of payments and financial crisis in the national economy. Even though there are no scientifically rigorous criteria to determine the optimal level of the country's current account deficit or external debt ($D^*$), it is possible to find some arbitrary values, which are defined by the market conventions or the credit rating agencies.

Bhering (2021) proposes an approach to assess the sustainability of development finance, where the external sector vulnerability is associated with creditworthiness or the ability to pay foreign liabilities. In this sense, the ratio of foreign liabilities to the sum of exports plus remittances should not grow indefinitely, as the latter variables are the most sustainable sources of foreign exchange supply and determine an economy's long-term capacity to pay its trade and financial commitments with the rest of the world. Therefore, an unsustainable path of this ratio would be a manifestation of increasing risk in the external sector, which would be a result of continuously unfavourable export growth relative to the cost of net external liabilities and import growth leading to higher external debt burden and servicing.

However, another way to view the structural competitiveness of the economy and the connection between the capacity of its productive structure and the balance of payments is the economic complexity. Both the resilience of the economy and its adaptive capacity vis-à-vis external shocks and the evolving external conditions are closely related to the depth of production (vertical and horizontal interlinkages), the product differentiation, its level of technology and the use of high-skilled labour inputs (Haussman *et al.*, 2014, p. 18).

For instance, during the low-carbon transition process, the necessity of high-tech imported products for green investments would generate negative pressures on the trade balance and the balance of payments. The magnitude of this pressure depends on the economic complexity of the economy since an economy with a more complex productive system: a) produces domestically or holds an important part in the global value chain of the required intermediate or capital goods and b) green investment in one sector boosts the economic activity in other sectors due to horizontal interlinkages (Lopes *et al.*, 2012).

Consequently, the external vulnerability of the economy ought to consider the dependence of the domestic economy on imported intermediate and capital goods, the technological gap that could affect, implicitly, the exchange rate in the long term (Gabriel *et al.*, 2016). And, in general, the overall complexity and diversification of the economy that measures the intra and intersectoral connections, in terms of high technology and high skilled inputs.

Indexes that take into account the share of imported capital goods over the exported ones or an economic complexity index as proposed by Haussman *et al.* (2014) could be employed at the service of this goal.

Finally, the fragility of the economy to the external conditions is also critically dependent on the financial fragility of the corporate sector, as the relationship between the exchange rate, the firm size and the leverage structures are highly sensitive to the international financial conditions and the external shocks (Alfaro *et al.*, 2019). For instance, the developing economies were hit by the financial repercussions of the COVID-19 crisis, before the pandemic started to spread in the population. This also explains why a more dynamic analysis is important in understanding the external vulnerabilities of the economy.

All the above is consistent with two dimensions of external sector vulnerability. On the one hand, given that the transition to low carbon emissions is a process that requires significant structural changes in investment patterns and the production matrix, it is necessary to consider structural competitiveness and productivity differences between economies as a risk factor, since they can generate significant negative pressures on the trade balance and greater susceptibility to the availability of external financing. In this sense, economies that are highly dependent on imports with high technological content and incapable of developing their productive capacities would face difficulties in carrying out a transition process without strong imbalances in the external sector.

On the other hand, external sector vulnerability is also compatible with the approach proposed by Bhering (2021) and Ocampo (2016). For the former, good export performance is essential to ensure the long-term ability to pay external liabilities. For the latter, a low level of vulnerability in the external sector depends on:

> [...] (1) lower current account deficit, (2) competitive exchange rates, (3) a high level of foreign exchange reserves, (4) reduced short-term external liabilities, and (5) capital account regulations being in place (p. 224).

# 6. Conclusions

For several years, diverse academic studies have documented the potential effects that climate change may have on society and the economy through gradual increases in global temperature and the intensification of extreme weather events. However, a much more recent focus within the literature has attempted to address the challenges and implications of the process of adjustment to a low-carbon economy. In this regard, it is considered that changes in climate mitigation and adaptation policies, green technological progress, and disruptions in consumption and investment patterns on a global scale may induce non-trivial macroeconomic impacts, especially in developing economies, as highlighted by Espagne *et al.* (2021). These impacts may exacerbate certain financial and political constraints facing the countries, which have the potential to delay and discourage transition commitments.

Consequently, assessments of the different low-carbon transition alternatives and scenarios need to incorporate the concept of vulnerability of the macro-financial system in their analysis. This paper proposes an analytical framework that allows for flexible integration of this facet in fiscal, monetary, financial, and external levels, for monitoring and understanding transitions risks that are likely to affect those dimensions jointly. In this way, the restrictions and conditions that any decarbonisation and greenhouse gas reduction path must meet to be viable and sustainable in the medium term are made explicit. Ultimately, this approach is useful for understanding the robustness of the macroeconomic policy scheme to climate-related risks and transition stressors.

On the fiscal dimension, it is emphasized that the implementation of any policy which focuses on reducing GHG emissions and adapting to climate change is a stressor that can directly affect public finances. For instance, the large number of investments and resources needed to achieve decarbonisation commitments, which may be undertaken directly or supported by the Government, pose a scenario of deteriorated public budgets and increased public indebtedness. This can be a vulnerability driver as long as it increases exposure to shocks on economic growth and changes in the international risk perceptions, the exchange rate and domestic and external interest rates.

Similarly, it is key to emphasise that the low-carbon transitions not only affects the real side of the economy, but also the financial side. It is thus important to involve central banks in the process to minimise tensions with other policy objectives and risks to financial stability. Physical and transition risks related to climate change have the potential to induce financial losses, balance sheets deterioration, credit and liquidity constraints, and sharp and accelerated devaluations in assets. These financial imbalances and vulnerabilities could have systemic consequences if transition policies are not implemented in an orderly and sustainable manner, which would result in higher interest rates and tighter credit rationing

schemes that would affect the availability of financing for climate change adaptation and mitigation.

The external sector vulnerability appears as the low-carbon transition requires a significant amount of technology and capital-intensive goods to transform the productive matrix, which will be mostly covered by imports. This, together with the high-carbon content of its export basket and the gaps in competitiveness and productivity between economies, can lead to significant current account pressures, reduced long-term capacity to pay external liabilities, and increased dependence on external financing. In the coming decades, this external constraint for developing economies may become more binding, as the effects of climate change and disorderly transition policies on the financial system and the global economy have the potential to decrease the availability of external financing through capital inflows shortfalls and tightened risk perceptions.

Therefore, for the transition to a low-carbon economy to be achieved in a relevant, orderly and feasible manner, it is crucial to assess how much the economy may be affected by climate and transition-related risks. Answering this question is relevant, as exhibiting greater vulnerability may amplify certain political, financial and socio-economic constraints that are generally stronger in developing economies, as well as indefinitely delay decarbonisation and adaptation agreements. Consequently, when thinking about transition policies, it is also necessary to identify which macroeconomic policy framework features may amplify these vulnerabilities, either by increasing the fragility and/or decreasing the resilience of the economic system.

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