The new normal. Measuring balance-of-payments vulnerability vis-à-vis climate (transition) risks[1]

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Abstract

Climate change and its accompanying transitional effects exercise considerable risks for economies both nationally and globally. These risks are unequally distributed among countries, where low-income countries bear the brunt. Despite the growing number of indicators measuring the empirically observable impacts of climate change, there is no measure for both physical and *transitional* risk exposure for countries' *balance-of-payments* as proposed in this paper. This is a severe lacuna as the balance-of-payments constitutes an important mainstay of macroeconomic policy making. The paper's novel contribution consists of designing an indicator which enables a classification of susceptibility to climate (transition) risks for balance-of-payments. The indicator addresses the combined vulnerabilities arising from the exposure to climate (transition) risks and a subordinated integration in the international monetary system. It provides an important tool both for policy-makers to make informed decisions and researchers to draw a more complete picture of the physical and transitional impacts climate change has on macroeconomic variables.

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1 Introduction

There is a growing set of macro-finance literature on the physical risks of climate change and its transitional risks coming with climate policies, divestment from carbon-intensive assets, changing consumption patterns etc. – what we subsume as climate (transition) risks.[3] Here, due to data shortcomings and the complexity at hand, especially economic models – and less so empirical studies – have proven to provide interesting insights in the interaction between climate and economics. These studies, however, come to conflicting results in regard to questions of whether climate (transition) risks destabilise national and international financial systems, yield recessionary pressure and increase asymmetries. Dafermos *et al.*'s (2017, 2018) ecological stock-flow-fund models demonstrate that climate change is associated with a higher degree of financial instability: climate change induces instabilities both directly (e.g. via wealth losses and risen uncertainty) and indirectly (via reduced productivity and resulting recessionary pressure) into the global financial order. The risk of climatically-induced financial instability and recessions also stems from increased inequality levels: Carnevali *et al.*'s (2019) open-economy SFC-model focuses on international asymmetries and how they are reinforced through transitional risks of climate change by triggering capital outflows from technology-poor countries with a high carbon-intensity. Similarly, Dennig et al. (2015)'s model shows that the impact of climate change and transitions towards a low-carbon economy increases global inequality levels.

This set of literature hence supports the claim that climate (transition) risks impede the effectiveness of monetary policies (NGFS, 2019, 2020; Batten, Sowerbutts and Tanaka, 2020) by exacerbating risks of economic downturn, financial crises and global asymmetries. Other models, however, contest their conclusion. Pakko and Keen's (2007) closed-economy DSGE-model, for instance, asserts the well-functioning of monetary policies even against the backdrop of natural disasters and emphasise the unhampered validity of the Taylor rule in inflation targeting. What is more, and in contrast to claims that climate (transition) risks are associated with economic decline, Dellink *et al.*'s (2017) DSGE-models could not find a unequivocal effect of climate change on growth rates under different climate (transition) scenarios.

Empirical macroeconomic research provides additional insights where models produce contradicting conclusions. In regard to climate change and economic outlooks, Cuaresma *et al.* (2008) provide empirical evidences that low-income countries are more prone to recessions after being hit by a severe natural disaster – contradicting the *creative destruction hypothesis* which claims a positive correlation between natural disasters and growth (see Batten, 2018). A persistent water shortage was one causal factor of the severest recession since the 1930ies Brazil experienced starting from 2012 (Prates, Fritz and Paula, 2020). Against the backdrop of trade relations Porter *et al.* (2014) and Coulibaly *et al.* (2020) show how the physical effects of climate change such as droughts, temperatures shocks, floods as well as the accompanying destruction of harvests and disappearance of fertile soil harm the productivity of

[3] There is no universally agreed on definition and taxonomy of climate (transition) risks. Buhr et al. (2021) currently develop a taxonomy which provides a more granular distinction of a larger number of acute and chronic risks connected to climate change. According to them, climate risks are represented by Transitional, Physical and Adaptation Risks, where the latter is an umbrella term for Asset Valuation, Operational Impairment, Cost of Business Adjustments, Regulatory Changes and Loss of Subsidy Risks. Transitional Risks are compound of Regulatory, Technology, Going Concern, Water and Loss of Subsidy risks; and Physical Risk consist of Water Stress, Heat Stress, Sea Level Rise, Extreme Precipitation and Extreme Weather. These Climate Risks are complemented with Natural Capital Risks rooted in environmental degradation consisting of Subsidy Regime Change, Depletion, Boundary Condition and Geopolitical Event risks. Collins et al. (2021) distinguish nine categories of transitional risks: Social and Political Strain, International Impacts, Financial Stresses, Macroeconomic Challenges, Corporate Uncertainty, Environmental Damage, Energy System Strains, Technological and model risks.

the agricultural sector implying deepened current account deficits – either because the country depends on agricultural exports or because it has to import foodstuff when the local production does not suffice due to the disaster. Transitional risks could have similar effects on the current account. Carbon-(import)-taxes such as the EU's Carbon Border Adjustment Mechanism deteriorates the competitiveness of exporters of carbon-intensive goods and hence their export revenues (European Commission, 2021; Gay, 2021). Same applies to other climate policies and decarbonisation efforts (IPCC, 2014, p. 475).

But climate change and transitional policies do not only deteriorate the current account balance, but also affect the capital account. One such channel is through exchange rate movements. Whilst an older study of exchange rates between 1960 and 1979 could not find a significant effect of natural disasters on exchange rates (Albala-Bertrand, 1993), a study conducted under the conditions of the current international financial system shows a significant effect of climate transition risks on exchange rates of fossil fuel exporters (Kapfhammer, Larsen and Thorsrud, 2020). Trade deficits might hence be worsened by a devaluation of currencies and further deteriorated terms-of-trade between primary commodities and manufactured goods. What is more, climate (transition) vulnerability also translates into higher capital costs for external finance both for the public and the private sector: Buhr et al. (2018): estimate that additional interest paid for climate vulnerability alone was around USD 62 billion for the V20 countries between 2008 and 2018.[4]

To focus explicitly on the impacts on monetary asymmetries and balance-of-payments constraints of climate change and policies is the first contribution this paper makes. Conclusive research on the interaction between a country's balance-of-payments and climate (transition) risks is still scarce. But this is a relevant research area as balance-of-payments management is a key policy challenge – especially for peripheral countries (McCombie and Thirlwall, 2004).[5] An exception is Svartzman and Althouse' (2020): they highlight that under the condition of high capital mobility and against the backdrop of a greater degree of affectedness by the physical effects of climate change, peripheral countries will see their balance-of-payments constraints tightened and global monetary asymmetries reinforced (Svartzman and Althouse, 2020, p. 2.5). But whilst their argument focuses on how global monetary asymmetries contribute to further ecological degradation, this paper considers how climate change and climate policies further exacerbate the balance-of-payment-constraints.

The paper's second contribution consists of supporting empirical research efforts in ecological macroeconomics by designing an indicator which both captures physical and transitional risks for balance-of-payments of peripheral countries. Though there are a number of indicators measuring the physical effects of climate change (e.g. Chen *et al.*, 2015; Germanwatch, 2021) and assessing the degree of how much a country managed to achieve sustainable transition (e.g. Singh *et al.*, 2012), up to date there is no indicator for transitional risks let alone one addressing the important aspect of macroeconomic vulnerability coming with the twofold susceptibility to both climate (transition) risks and the balance-of-payments constraint. But indicators are important to observe trends and serve as a compass for guide policy-makers to conduct informed decision-making and to design strategies to achieve improvements (Singh *et al.*, 2012, p. 282).

[4] The V20 refers to the Vulnerable Twenty (V20) Group of Ministers of Finance of the Climate Vulnerable Forum (V20, 2021).
[5] By peripheral countries we mean low-income countries whose trade structure is characterised by a strong commodity dependency.

The aim of the indicator is to provide guidance to research efforts to empirically capture balance-of-payments-implications of climate (transition) risks and to serve as basis for policymakers. Its primary aims are neither to enable inter-country-comparisons, nor to provide information to a wider public. The indicator therefore does not conduct a ranking among countries and trades easy communicability for accuracy.

To measure climate transition vulnerability is a hard endeavour because of the multi-facetted nature of climate transition risks. To reduce complexity and in line with the research question, we here focus on risks with macroeconomics implications for the balance-of-payments of a country including feedback loops into the domestic economy. Climate-induced changes in national and international inequality levels, international diplomacy, strains on the global energy system etc. have macroeconomic relevance, too, however, cannot be addressed in this research because of the paucity of data and the complexity of the issues at hand. Same applies for the vulnerability vis-à-vis the physical effects of climate change. The physical effects of climate change have a multitude of socio-economic consequences, e.g. risen inequality levels, displacement of populations and social conflict. Here, however, only factors potentially directly impacting the balance-of-payments are considered.

The paper is structured as follows: In the following section the paper presents existing indicators and identifies missing aspects. Section three introduces methodological concerns when constructing an indicator followed. Section four proposes a new indicator which addresses the combined vulnerabilities arising from the exposure to climate-related physical risks and the transitional risks coming with mitigation measures in a context an asymmetric international monetary system. The last section concludes.

2 Existing climate vulnerability indices and their shortcomings

Among the growing number of climate indicators we present the two most conclusive and intricate ones: the Notre Dame Global Adaption Index (ND-GAIN) conceptualised by the University of Notre Dame and the Climate Risk Index (CRI) as calculated by Germanwatch.

The NG-GAIN

The ND-GAIN is currently the most commonly used index to capture climate vulnerability (Buhr *et al.*, 2018, p. 8). It consists of 45 indicators based on 74 data sources for 184 countries from 1995 to present (Chen *et al.*, 2015, p. 5f.). The NG-GAIN Index is compound of two major sub-indices *Vulnerability* and *Readiness*.

Vulnerability refers to a country's vulnerability rooted in socio-economic and geographical conditions. This sub-index encompasses "exposure, sensitivity and adaptive capacity" with respect to "food, water, health, ecosystem services, human habitat and infrastructure" (Chen *et al.*, 2015, p. 3). The *Exposure*-indicator describes the stresses physical risks imply for a society. The *Sensitivity*-indicator is the extent to which societies are dependent on the sectors most exposed to the risks climate change imposes. The third *Vulnerability*-sub-indicator *Adaptive Capacity*, describes the capacities to adopt to climate risks (Chen *et al.*, 2015, p. 3).

The second main sub-index of the ND-GAIN *Readiness* calculates the ability to privately or publicly finance private or public investments into adaptation measures with regard to economic, governmental and social components. In other words, it measures the "Readiness to make effective use of investments for adaption action thanks to a safe and efficient business environment" (Chen *et al.*, 2015,

p. 4). The ND-GAIN *Readiness* index is composed of indicators approximating the economic (World Bank's *Ease of doing business index*)[6], governance (good governance, political stability and corruption) and social readiness (inequality, telecommunication infrastructure, education and innovation levels) to react to climate risks (Chen et al. 2015, 33ff.).

For each of the *Vulnerability*- and *Readiness*-sub-indicators, the NG-GAIN calculates a score each using the formula below (Chen *et al.*, 2015, p. 8; for a detailed description of the scaling of indicators and calculation of the ND-GAIN see: Chen 2015, p. 6ff.11ff.):

$$"score" = |"direction" - \frac{"\text{raw}" \; data - reference \; point}{baseline \; maximum - baseline \; minimum}|$$

The sub-indices *Vulnerability* and *Readiness* are then calculated by taking the arithmetic mean of their indicators' unweighted scores. The NG-GAIN of a country is finally calculated using the following formula:

$$ND - GAIN \; score = (Readiness \; score - Vulnerability \; score + 1) * 50$$

For the *Vulnerability* indicators, "direction" is 0 and for the *Readiness* indicators it is 1 to indicate that a higher value in vulnerability renders a country worse off, whilst higher values in *Readiness* are better for a country.

It is important to note that the ND-GAIN consists to a large extent of estimations of future developments of indicators and integrates empirical data to a much lesser degree. It does not consider a country's immediate affectedness by natural disasters, for instance. What is more, the ND-GAIN does not adjust for GDP to not doubly penalise low-income countries but its authors highlight that there is a strong correlation between a country's GDP and its score in the ND-GAIN (Chen *et al.*, 2015, p. 5).

The Climate Risk Index

In contrast to the NG-GAIN, the CRI only measures direct effects of natural disasters such as fatalities and economic losses originating in a climate event, but not indirect effects such as food shortage as result of a natural disaster (Eckstein, Künzel and Schäfer, 2021, p. 3). It captures climate-related natural disasters with immediate effects such as floods, storms and extreme temperatures, but leaves out processes with lasting effects such as the melting of pack ice and rising sea levels and those unrelated to climate such as earthquakes, tsunamis and volcano eruptions (Eckstein, Künzel and Schäfer, 2021, p. 28). The CRI is yearly published since 2006 (Germanwatch, 2021). It is based on data provided by MunichRE NatCatSERVICE and the IMF for the years 1995 to 2019 (Eckstein, Künzel and Schäfer, 2021, p. 2.29).

The CRI is calculated using the country ranking as normalization. A country's ranking in each sub-category is then multiplied by a weight (Eckstein, Künzel and Schäfer, 2021, p. 29) as represented in the equation below:

[6] The *Ease of Doing Business* measures the attractiveness for business to invest. It consists of 40 indicators capturing ten themes: starting a business, dealing with construction permits, getting electricity, registering property, getting credit, protecting investors, paying taxes, trading across borders, enforcing contracts, and resolving insolvency (Chen *et al.*, 2015, p. 33).

$$CRI\ Score = \frac{rank_{death\ toll}}{6} + \frac{rank_{deaths\ per\ 100.000\ inhabitants}}{3} + \frac{rank_{absolute\ losses\ in\ PPP}}{6} + \frac{rank_{losses\ per\ GDP\ unit}}{3}$$

By putting the number of deaths in relation to the size of the overall population and by providing the economic losses in purchasing power and units of GDP, the sub-indicators account for differences in population size and income levels of a country improving comparability (Eckstein, Künzel and Schäfer, 2021, p. 29f.). The CRI both calculates absolute as well as relative vulnerability both for a particular year as well as in the long-run (Eckstein, Künzel and Schäfer, 2021, p. 5ff.) – though from 2019 onwards only relative values are published.

Limitations of the NG-GAIN and CRI

In regard to the ND-GAIN and CRI a number of caveats have to be made. These are summarised in the four points below and ordered according to increasing severity of shortcomings.

1.) Ranking countries is of limited use: The CRI is based on a country ranking. Though there is a certain elegancy in being able to compare countries, such a relative positioning is of limited use when the absolute vulnerability of climate affectedness on macroeconomic variables of a country constitute the research interest.

2.) The indices either measure direct effects *or* potential hazards, not both: The CRI only captures direct empirically observable hazards but no subsequent effects. In contrast, ND-GAIN-indicators does not account for the hazards that already took place, but focuses more on the potential future ones e.g. in its sub-indicators on projected affectedness by sea level rise, changes of flood hazards and annual groundwater recharge (Eckstein, Künzel and Schäfer, 2021, p. 3). But none of them captures both.

3.) No transitional risks considered: Both the CRI and the NG-GAIN focus on physical effects of climate change. However, transitional climate risks are likely to be even more severe for affected countries (Buhr *et al.*, 2018, p. 2; Althouse, Guarini and Porcile, 2020). Not addressing transitional risks of climate change and policies is therefore a big lacuna in both indicators – and to this date (and to our knowledge) there is no indicator for transitional risks, yet.

4.) No consideration of vulnerabilities stemming from a subordinated integration in the monetary system: Critical literature on macro-finance shows that a subordinated integration in the international monetary system comes with macroeconomic risks like susceptibility to capital flight, higher interest rate levels and volatile exchange rates implying the risk of balance-of-payments difficulties. A subordinated monetary integration inhibits policy space of recipient countries because investors' readiness is largely influenced by financial regulatory arbitrage (with deregulation enabling high capital mobility) and a high interest level vis-à-vis core interest rate levels making a country more profitable as investment destiny (Grabel, 1996; Paula, Fritz and Prates, 2017; Bortz and Kaltenbrunner, 2018; Rey, 2018). A limitation of policy space reduces countries' potential to conduct much needed climate mitigation and adaption measures, however (Mottley, 2021). Considering a country's position in international monetary hierarchies (with close connection to its position in global value chains) is therefore essential when measuring a country's exposure and readiness to cope with climate (transition) risks.

These findings are not reflected in the existing indicators. Whilst the CRI does not consider financial aspects at all, ND-GAIN's *Economic Readiness*' uses the World Bank Ease of doing Business indicator which measures a country's attractiveness for international investors in regard to taxation, Moody's ranking of financial risk and the form of collaterals accepted, regulations, perceived efficiency of credit markets as well as a financial system's soundness and its sophistication (World Bank, 2021b). But instead of viewing a country's degree of financial deregulation as potential macroeconomic risk which curbs policy space and with it the potential to act on natural disasters, the ND-GAIN views investors' readiness to invest rooted in deregulation as an important mainstay of climate resilience: "ND-GAIN measures readiness by considering a country's ability to leverage investments to adaptation actions." (Chen *et al.*, 2015, p. 4) But neither does it address the problem of limits to policy space as result of a country's grown liability stock, nor the ex-ante reduction of policy space coming with the policies aiming to make a country more attractive to international investments.

5.) No consideration of vulnerabilities stemming from a low position in global value chains, a high degree of commodity dependence, respectively: What applies to a subordinate position in the international monetary system also applies to a high dependence on the exports of low-value goods. Countries whose main exports consist of primary commodities enjoy a much lower degree of policy space and experience higher macroeconomic instability. Both factors reduce resilience vis-à-vis climate (transition) risks, however this is not reflected neither in the CRI nor the ND-GAIN.

The novel indicator proposed here solves the identified caveats to a large extent. It refrains from country ranking, addresses short-, long-term risks as well as transitional risks and those arising from the combined susceptibility to climate (transition) risks and a subordinated integration in the international financial system and global value chains.

3 Proposal for a climate (transition) vulnerability index

Climate (transition) vulnerability is a complex issue which has no single empirical expression. We therefore identify dimensions which can – at least in part – capture how climate change and its accompanying effects impact countries' balance-of-payments. In the context of this paper, the nature of the risk is less relevant than its effect on a country's balance-of-payments. As a consequence, we adopt a reduced understanding of risks coming with climate change where we define climate (transition) vulnerability as the combination of vulnerabilities arising from the physical and transitional risks of climate change. Physical and transitional risks have a high degree of interdependence and affect the balance-of-payments in a similar way. In the construction of the climate (transition) vulnerability index, we therefore do not explicitly distinguish between them. Instead, we distinguish between two channels of how climate (transition) risks impact the balance-of-payments: the current-account- and the capital-account-channel with a high degree of interdependence between the two channels. These two channels constitute in combination the climate (transition) vulnerability index.

$$CVuln = CVuln_{CUA} + CVuln_{CAA}$$

CVuln … Climate (transition) vulnerability index
$CVuln_{CUA}$ … Climate (transition) vulnerability transmitted through the current account
$CVuln_{CAA}$ … Climate (transition) vulnerability transmitted through the capital account

Climate (transition) vulnerability via the current account

The current account balance is affected when climate (transition) risks lower the productivity of the export sector, the demand of export goods which are important sources of foreign exchange and impact their prices, their terms-of-trade, respectively, the need to import becomes greater as well as the prices for imported goods especially food stuff. We first elaborate how exports of peripheral countries are affected, followed by the import-side of the trade balance.

Exports

There are four important sources of foreign exchange (especially for low-income countries) which are *climate policy relevant sectors* (CPRS) and are therefore likely to be affected by climate transition: the export-oriented sector for (i) fossil fuels, (ii) agricultural products, (iii) rare earths and (iv) external tourism.

(i) Current developments hint that hydrocarbons lose their relevance as ultimate energy source. Causes are changes in consumption patterns and technological advances, both supported by climate protection efforts (Blanco *et al.*, 2014). The International Energy Agency (IEA) estimates that by 2040, electricity in final consumption will trespass that of oil – despite oil being currently twice as important as electricity (IEA, 2019, p. 4). This development is connected to the steady replacement of fossil fuels (especially oil) by renewables (solar and wind energy as well as biofuels) in the energy generation since the 1990ies (IEA, 2021). Though the revival of the US-American shell gas production probably played the greatest role in the drastic oil price fall in 2014, the infant production of electric vehicles and other fossil-fuel-substitution technologies foremost in China were factors influencing (performative) expectations of future developments of oil prices (Akinkugbe-Filani, 2019; Center for Sustainable Systems, 2019; IEA, 2019, p. 2; on the role of speculation in the determination of oil prices, see: Kaufmann and Ullman, 2009). Those processes are likely to imperil international trade in energy,[7] oil prices and demand security for oil exporters (IPCC, 2014, p. 475).

(ii) The second component of the current-account-channel is related to the agricultural sector. Changing consumption patterns rooted in grown environmental awareness could also imply a regionalisation of the production and consumption of agricultural products (IPCC, 2014). Additionally, the policy instruments of CO_2-taxes gain relevance. The recently introduced Carbon Adjustment Mechanism by the EU is an example for how CO_2-(import-)taxes could increasingly diminish competiveness of low-income exporters severely impacting their export revenues generated from carbon-intensive goods. Though the current policy setting is constrained to goods falling under the EU's carbon-trading regulations, fears are sparked that future extensions might also affect agricultural goods (Gay, 2021).

(iii) But commodity dependent countries are not only losing out because of climate transition processes. Because of the grown relevance of electrification, climate policies and changing consumption patterns are said to contribute to the grown importance of rare earths and metals needed as input factors for rechargeable batteries like lithium and cobalt. We therefore include the share of ores and metals in overall exports as published in the World Bank's Development Indicator database (World Bank, 2021) in the index – however with a negative sign as a higher share positively influences a country's balance-of-payments resilience vis-à-vis climate (transition) risks, hence reduced climate (transition) vulnerability.

[7] As long as storage capacities of electricity are limited and expensive, electricity is locally produced and only traded – if at all – between neighbouring countries as it preconditions a transnational grid. Therefore, climate mitigation measures are likely to diminish global trade in energy by 10–70% by 2050, 40–74% by 2100, respectively (IPCC, 2014, p. 475).

(iv) The fourth component is the importance of external tourism as source of foreign exchange. With transportation contributing a discernable share in carbon emissions (Ritchie and Roser, 2020), international tourism is likely to be negatively affected by changing consumption patterns rooted in environmental concerns (Blanco *et al.*, 2014, p. 388). What is more, climate change is said to contribute to the emergence of pathogens which might contribute to global pandemics and their adverse effects on international tourism, as was well demonstrated by the COVID-19 pandemic. But some peripheral countries are highly tourism dependent. As examples, in 2019 the share of external tourism in total exports was 85% on the Maldives, 81% on Aruba, 51% on the Fijis, 51% in Albania, 48% in Lebanon and 42% in Jordan (World Bank, 2021a).

It becomes clear that the share of CPRS in the export structure of a country is an important component of climate (transition) vulnerability vis-à-vis balance-of-payments, that is the higher the sum of share of CPRS in exports (with the share of ores and metals in overall exports bearing a negative sign), the higher the value of the index indicating a higher vulnerability vis-à-vis climate (transition) risks for balance-of-payments. We therefore include the exposure to changes in prices and export potentials of fossil fuels, agricultural products, ores and metals an external tourism in the current account channel of the climate transition indicator by calculating their share in the total revenues of foreign exchange.

Imports

Climate (transition) vulnerability also impacts the import-side of the current account balance. Here the physical risks of climate change are particularly important. We consider two important aspects: (i) food price inflation as consequence of impeded agricultural production due to the physical effects of climate change; and (ii) the risen need to import capital goods and reconstruction material when natural disasters destroy productive capital, housing and infrastructure and necessitate the import of goods needed for climate mitigation measures such as cooling devices, water storage and irrigation systems.

(i) Climate change is projected to increase food price inflation for staples because it impedes agricultural productivity (Chen *et al.*, 2015, p. 12; Batten, Sowerbutts and Tanaka, 2020). The effect of natural disasters on food inflation is especially severe in low-income countries, where food price inflation is the most important determinant of overall inflation levels (Heinen, Khadan and Strobl, 2018; Parker, 2018). What is more relevant to the index, however: food price inflation deepens current account deficits for countries highly dependent on the import of foodstuff. We therefore include the food import dependency as provided by the FAO, which provides the three-year average percentage share of imported cereals in overall cereal consumption (FAOSTAT, 2021). As only three-averages are available we use the food import dependency assign the last year of the three-year period to the data point under consideration to account for the fact that previous periods of high import prices impact the current account balance of one year and not future ones.

(ii) Different to the NG-GAIN, we include the empirically observable exposure to immediate physical climate risks by accounting for the actual occurrence and severity of natural disasters. The assumption here is that an exposure to natural disasters impacts the current account by increasing the need to import for reconstruction and adaptation measures, where necessary goods cannot be sourced locally. Despite shortcomings its shortcomings, we here use the CRI as provided by Germanwatch (2021) as proxy for the affectedness by physical disasters.

The physical exposure to climate risks is included as factor to account for the fact that the mechanics adversely affecting the current account described above will be graver the more a country is affected by

natural disasters. Heat waves, salinisation of fertile land, desertification, droughts and floods also disproportionately affect the productivity of the agricultural sector. Physical exposure to climate change therefore increases the chance that food price inflation negatively impacts the trade balance of food net importers. The export potentials of the other CPRS are also impacted by the physical effects of climate change: Production sites like oil platforms are threatened by storms, heat waves might ensue ignition of drilling stations and damage pipelines. International tourism is harmed by the physical effects of natural disasters when the potential of international transportation is hampered where storms make shipping and flying impossible. Additionally, the international tourism sector is hurt when customers insist on the compensation of their cancelled holidays. With catastrophe tourism being only a small share of the touristic sector, package tourism will be detrimentally affected by a reduced willingness to go to areas higher at risk of natural disasters and tropical diseases which are projected to become more prevalent due to climate change.

In sum, the climate (transition) vulnerability impacting the balance-of-payments through the current account consists of relevance of 1.) CPRS (here: fossil fuels, agricultural production and the external tourism sector) for foreign exchange revenues; 2.) the reliance on imports of food stuff and exposure to their international prices; and 3.) the direct immediate exposure to natural disasters. Equation 1 represents how the current account climate vulnerability is calculated:

(1) $$CVuln_{CUA} = (ShareCPRSinEX + CerealIMDependency \times CommodityPIndexFood) \times CRI$$

Climate (transition) vulnerability via the capital account

Climate (transition) risks also impact the capital account via (i) a grown liability stock to finance current account deficits deepened by climate (transition) risks (captured in $CVuln_{CUA}$); (ii) a grown susceptibility to capital markets when climate risks and mitigation measures increase the need to attract additional external finance, hence strengthening the need to adhere to investors' preferences; or when climate (transition) induced instabilities aggravate the susceptibility to capital markets via already existing portfolio finance stocks; (iii) and an increased burden to the capital account via additional yields demanded for climate (transition) vulnerability against the backdrop of existing liability stocks.

(i) When climate (transition) vulnerability leads to grown current account deficits, these deficits are financed by issuing additional external liabilities. This stratum of climate (transition) vulnerability is already captured in $CVuln_{CUA}$ which accounts for the additional external financing needs transmitted through the trade balance and will therefore not be additionally included in the $CVuln_{CAA}$.

(ii) A grown liability stock rooted in climate (transition) vulnerability contributes to a grown susceptibility to international capital markets: in times of international financialisation, these deficits are predominantly financed out of portfolio finance. A reliance on international capital markets strengthens the susceptibility to capital flight, because portfolio finance is more mobile, i.e. it implies a grown susceptibility to investors' sentiments which react to changing international macroeconomic conditions (Grabel, 1996; Bortz and Kaltenbrunner, 2018; Rey, 2018). A high reliance on portfolio flows hence implies an increased susceptibility to financial instability, which is projected to become more severe as

spill-over effects of physical risks of climate change and climate transition[8] into the liability structure of financial agents become more frequent (Carney, 2015; NGFS, 2019; Buhr *et al.*, 2021). This also applies to already existing portfolio stocks independent of whether they are rooted in climate (transition) vulnerability. We therefore include the dependence on external portfolio finance controlled for by foreign exchange stocks which are likely to be considered by investors as a country's potential to buffer capital outflows vis-à-vis fire sales).

As indicator to approximate the external portfolio dependence we use the indicator "Debt securities held by nonresidents" as provided by the IMF's Coordinated Portfolio Investment Survey (CPIS) and published in the JEDH database (BIS *et al.*, 2021). It encompasses stocks of portfolio investment liabilities at all maturities held by non-residents as defined by their legal registration. We here only include non-residents which are assumed to be more prone to capital flight.

(iii) The mere size of the liability stock and the increased risk perception of countries particularly exposed to climate (transition) risks leads to higher interest demanded by the investors holding a country's assets as compensation for risen uncertainty levels concerning a country's ability to service its liabilities. This poses an additional burden to the capital account. These costs are exorbitant in relation to the affected countries' economic size. Buhr et al. (2018) estimate the additional costs for public and private external debt due to climate vulnerability for 2008-18 to be around USD 62 billion for the V20 countries. These interest payments are projected to increase in the course of time as climate changes adverse effects are accelerated. The authors estimate for 2018-2028, that the risk-premium additionally demanded for climate vulnerability will rise to USD 146-68 billion (Buhr *et al.*, 2018). Here, physical risks alone are considered. But the additional interest burden demanded for climate transition vulnerability is said to be just as high or even trespass that demanded for vulnerability stemming from physical risks (Buhr *et al.*, 2018, p. 2).

We use a country's external liability stock as proxy for the potential deterioration of confidence in the solvency of a country and the stability of its currency. As indicator for the external liability stock we use the "Liabilities to BIS banks, locational total" as provided by the Bank of International Settlements and published in the JEDH database. "Liabilities to BIS banks, locational total" comprise all cross-border liabilities independent of the instrument to banks that report to the BIS Locational Banking Statistics. By additionally including the exposure to external portfolio investment, we doublecount this sort of external finance taking into account the particular dangers implied in this sort of finance for countries balance-of-payments.

The ratio between exposure to external portfolio finance and foreign exchange funds weighs heavier the more volatile international financial markets are. We therefore multiply it with the Cboe Volatility Index (VIX; Cboe Exchange, 2021) as factor. What is more, the burdens on the capital account will weigh heavier the more a country is exposed to the physical effects of climate change as this impacts investors' perception of the security of a country as investment destination. We therefore also include the CRI as multiplier in the climate (transition) risks transmitted through the capital account.

[8] As our current economic system is deeply invested in carbon-based industries, divestment away from fossil-fuels is said to substantially contribute to the financial instability stemming from stranded assets and their sudden fire-sales, write-downs etc. This will be particularly severe in peripheral countries, where more carbon-intense industries are located (Malm, 2015; Svartzman and Althouse, 2020).

In sum, climate transition vulnerability transmitted through the capital account depends on the reliance of external finance, especially portfolio finance, global investors' uncertainty levels and physical risks exposure. Equation 2 sums the capital account transmission channel up:

$$(2) \qquad CVuln_{CAA} = \frac{ExternalLiabilityStock + PortfolioFinanceStock}{FXStock} \times VIX \times CRI$$

The total impact on a country's climate (transition) vulnerability on the balance of payments is represented in Equation 3:

$$(3) \qquad CVuln = \Big[(ShareCPRSinEX + CerealIMDependency \times CommodityPIndexFood) \times \Big(\frac{ExternalLiabilityStock + PortfolioFinanceStock}{FXStock} \times VIX\Big)\Big] \times CRI$$

Overview over indicators included in the index

Table 2 provides an overview over the indicators included in the index and the dimension of climate (transition) vulnerability measured.

Table 1: Overview over indicators included in the Climate (Transition) Vulnerability Index and what aspect of balance-of-payment vulnerability they measure.

	Aspect of research question addressed	**Indicators**	**Data Source**
current account	In how far will a country's external balance be affected by a decline in demand, productivity and prices of fossil fuels, agricultural exports and external tourism, and in how far profit from an increased demand for ores and metals?	Share of CPRS exports in overall exports	World Bank's Development Indicator data base (World Bank, 2021)
	In how far will the external balance be affected by climatically induced food price inflation?	Cereal Import Dependency Ratio	Food and Agricultural Organization (FAOSTAT, 2021)
	In how far is a country affected by physical risks of climate change potentially necessitating increased imports and deteriorating export potentials?	Climate Risk Index	Germanwatch (2021)
capital account	In how far is a country's capital account susceptible to sudden capital flight in the face of surged global uncertainty levels?	External portfolio in relation to the stock of foreign exchange	Joint External Debt Hub (BIS *et al.*, 2021)
	In how far will country be subject to higher risk assessment by international investors judged by the existing liability stocks?	External liability stock in relation to the stock of foreign exchange	Joint External Debt Hub (BIS *et al.*, 2021)
	How high are global uncertainty levels?	VIX	Cboe Exchange (2021)

	In how far is a country likely to receive deteriorated confidence by international investors due to the direct affectedness by climate change?	Climate Risk Index	Germanwatch (2021)

4 Conclusion and desiderata

The paper sketches a first proposal for an indicator measuring the physical and transitional risks exposure to a country's balance-of-payments. This is an important exercise as the balance-of-payments is a key determinant of macroeconomic policy space. It is the realm where vulnerabilities of foreign capital exposure as well as risks stemming from climate change and its transitional effects become apparent. To identify the susceptibility to these combined risks is the indexes main contribution. The second contribution is to explicitly focus on transitional risks next to climate change's physical risks. Transitional risks, which encompass risks of climate policies, changing investment strategies and changing consumption patterns, receive much less attention in the current literature than physical risks despite being potentially more severe – especially for low-income countries. Despite the improvements the index makes against the backdrop of efforts of measuring (and acting on) climate change related macroeconomic vulnerabilities, the development of the index is still in its infancy and the index remains to be validated against the backdrop of statistical assessments such as Principle Component Analysis and can therefore only provide preliminary insights.

5 Literature

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