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## Article

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Latin American Journal of Central Banking (LAJCB)

## Provided in Cooperation with:

Center for Latin American Monetary Studies, Mexico City

*Suggested Citation:* Torinelli, Viviane Helena; Silva Júnior, Antônio Francisco (2021) : Environmental risk analysis (ERA) in the strategic asset allocation (SAA) of the international reserves (IRs) managed by central banks (CBs), Latin American Journal of Central Banking (LAJCB), ISSN 2666-1438, Elsevier, Amsterdam, Vol. 2, Iss. 1, pp. 1-17,  
<https://doi.org/10.1016/j.latcb.2021.100021>

This Version is available at:

<https://hdl.handle.net/10419/336313>

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Contents lists available at ScienceDirect

## Latin American Journal of Central Banking

journal homepage: [www.elsevier.com/locate/lacbj](http://www.elsevier.com/locate/lacbj)

# Environmental risk analysis (ERA) in the strategic asset allocation (SAA) of the international reserves (IRs) managed by central banks (CBs)



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## ARTICLE INFO

### JEL classification:

G11  
G15

### Keywords:

Environmental risk analysis  
Strategic asset allocation  
Central banks  
International reserves

## ABSTRACT

This study addresses how to consider environmental risk analysis (ERA) in the strategic asset allocation (SAA) of international reserves (IRs) managed by central banks (CBs). For that, a multicriteria analytical framework is proposed for the evaluation of the environmental risk exposure of an investment portfolio, compatible with the investor profile of the CBs. Thus, the framework includes ERA in the traditional SAA approach of IRs. Environmental risks, as physical and transition climate ones, are resulting in a range of financial risks, but ERA is still incipient in the financial investment sphere, especially among CBs. Reports of the NGFS and NGFS members were reviewed, and we found no specific indication of ERA as an input on SAA of the IRs. Thus, the main argument of this study is that since ERA is included in the traditional approach to SAA, IRs investments will be more resilient to environmental and climate risk exposure. The framework discussed in this paper suggests that for each viable portfolio, a CB should use scenarios of environmental risks along with probabilities and potential impacts to choose the appropriate portfolio. The risk and return relationships of the portfolios in each scenario should be evaluated based on environmental factors.

## 1. Introduction

Effective risk management, including risk identification, measurement, and control, is essential for efficient operation in financial markets. In the worldwide discussion about financial risk management, analyses of environmental externalities, trends, and events are becoming recurrent and gradually more relevant (TCFD, 2017; Bank of England et al., 2017; CISL, 2016; Caldecott et al., 2014).

In December 2017, the Network for Greening the Financial System (NGFS) was established among central banks (CBs) to define and promote the implementation of best practices inside and outside NGFS members and to develop analytical work on green finance. In 2019, the NGFS encouraged CBs to lead by example and integrate sustainability factors into the management of some of the portfolios at hand (NGFS, 2019a), and it issued a sustainable and responsible investment guide for CBs' portfolio management (NGFS, 2019b).

Even though proper risk management is essential for efficient investment management, environmental risk analysis (ERA) is incipient in the financial investment sphere, especially among CBs (NGFS, 2020c,d). The theoretical and practical gaps in this subject have been highlighted since the first reports of the NGFS (NGFS, 2018, 2019a, b).

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<sup>1</sup> The 1st author is grateful for the financial support provided by the Central Bank of Brazil (BCB). The conclusions of the research are the responsibility of the authors, and therefore do not reflect the opinion of the BCB.

<https://doi.org/10.1016/j.lacbj.2021.100021>

Received 4 February 2020; Received in revised form 22 November 2020; Accepted 13 January 2021

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The management of environmental risks has not been a primary objective of international reserves (IRs) management (NGFS, 2018, 2019a, b). Possibly for that reason, CBs are not significantly addressing environmentally sustainable management and the green finance market from the perspective of IR managers (Sevillano and Romo, 2018). While most CBs are considering general climate-related measures in their monetary policy operations, the implementation of specific measures in their operational frameworks is still at a very early stage (NGFS, 2020f). Reports of the NGFS and NGFS members were reviewed, and we found no specific indication of ERA as an input on SAA of the IRs (NGFS, 2020e, 2019b; NGFS 2020c,d; BoE, 2020; BdF, 2020).

IRs are investments held by CBs in a foreign currency with the economic objectives of intervention in the FX market within the monetary policy, execution of payment for goods and services, execution of payments for the government, granting of emergency liquidity assistance, underpinning of investor confidence in the country, and investment of excess reserves (Fender et al., 2019). They ultimately allow for the capacity to meet liquidity needs in crises and mitigate exchange rate volatility, among other purposes related to monetary and FX policy (Silva Jr. et al., 2004; Silva Jr., 2016; Hawkins and Rangarajan, 1970; Kohlscheen and O'Connell, 2004; Detragiache, 1996; Aizenman and Marion, 2002; Allen et al., 2002). In order to address such a broad and diverse array of objectives, the management of the IRs consists of the investment in asset classes available within the international financial market. IRs totaled US\$13.978 trillion in 2019 (The World Bank, 2020).

IRs provide two important and widely accepted functions for CBs in emerging markets. One is self-insurance (Calvo et al., 2013) and the other is warning signaling (Kaminsky et al., 1998). Avoiding environmental risks such as climatic ones (physical and transition) is compatible with these two rationales.

The environmental risks—climatic physical and transition—are beginning to be understood as sources of financial risks, which may affect the performance of investments (NGFS 2020c; Bank of England et al., 2017; CISL, 2016). As a result, the management of environmental risk exposure of the IRs is important for CBs.

ERA is prominently linked to strategic asset allocation (SAA) by means of a common time frame (i.e., the long-term horizon for the assessment). In this context, the question that this research seeks to address is how to consider environmental risk in the SAA of IRs.

For that, this study also discusses climatic physical and transition risks to which CBs are exposed as managers of IRs. A multicriteria analytical framework is proposed for the evaluation of the environmental risk exposure of an investment portfolio compatible with the investor profile of CBs. This work may support CBs' decision-making from a managerial perspective in addition to helping them with the construction of a related framework.

Other studies that addressed the environmentally sustainable performance of CBs had different objectives than those proposed in this study. They mostly focused on the environmental sustainability of CBs as financial market regulators and oversight agents but not as IR managers (e.g., Campiglioglio et al., 2018). The theoretical studies of ERA detailed in the following section were generally focused on other investors.

The scope of this study addresses climate and, more broadly, environmental factors (e.g., biodiversity) but does not include social and governance factors, which are typically also included in ESG (environmental, social, and governance) and SRI (socially responsible investing) analysis. SRI comprises a broad range of sustainable investment strategies (NGFS, 2019b). It incorporates ESG factors into investment decisions and active ownership. It considers both a) how ESG might influence the risk-adjusted return of an asset and the stability of an economy and b) how investment in and engagement with assets and investees can impact society and the environment (CFA UK, 2020a). According to the NGFS (2019b), CBs may choose to adopt SRI to a) mitigate environmental risks in their portfolio or b) create a positive impact on the environment and society alongside financial returns. These objectives can be translated into different investment strategies. This article is focused on a) a risk–return management and not on b) a positive impact investment perspective.

The scope of this study includes only item (a) above, a risk–return perspective on the management of the environmental risk exposure of IRs. As will be discussed in Section 3, environmental factors include climatic physical and transition financial risks with short-, medium-, and long-term impacts that are thus applicable to IR management. The outputs of the ERA, which contemplates environmental factors in different scenarios, are estimated changes in the value of assets and portfolios, with potential subsequent impacts on the SAA to mitigate risk exposure or explore opportunities. More details are found in Section 4.

This paper proceeds as follows: the first three following sections detail results of a literature review. Section 2 is about ERA and concludes with an ERA framework from theory to praxis. Section 3 covers the management of IRs. Section 4 connects ERA and the SAA of IRs. Section 5 presents the multicriteria analytical framework. The paper concludes in Section 6 with an outlook for future research.

## 2. The environmental risk analysis (ERA)

Environmental and climate challenges pose material risks for real economies and financial stability (Dafe and Volz, 2015; Volz, 2017). In addition to the usual risks already considered by financial market managers, environmental factors are associated with a range of material financial risks. According to *The Global Risks Report* (WEF, 2020), the five top risks in terms of likelihood, as well as three out of the top five in terms of impact, are environmentally related. The former risks include extreme weather events, climate action failure, natural disasters, biodiversity loss, and human-made environmental disasters.

Evidence indicates that environmental factors, including climatic physical and transition ones, result in business, market, and credit risks. All these risks have financial implications that can be nonlinear and disruptive (TCFD, 2017; Bank of England et al., 2017; G20 GFSG, 2016).

The dimensions of the environmental physical risks are climatic, geologic, and ecosystemic (Bank of England et al., 2017). Physical risks include shock events and changes in trends. Among the climatic physical risks, global warming is by far the most discussed one, strongly associated with anthropogenic carbon emissions. The devastating consequences of global warming are widely acknowledged, such as rising sea levels due to polar melting, drought-related fires destroying huge areas of forests on various continents, land degradation and landslides related to extreme weather events, and numerous other effects (IPCC, 2013). On the other hand, global warming benefits some nations and regions, such as Canada, Alaska, and Russia, by expanding arable land and increasing domestic production (Read, 2016).

The exact timing and severity of global warming's physical effects are difficult to estimate. The geographically varied, large-scale, and long-term nature of the problem, as well as the endogeneity and uncertainty of the effects and its transmission channels, makes it exceptionally challenging, especially in the context of economic decision-making (UNEP-FI, 2019).

A recent study from the McKinsey Global Institute (2020) characterizes the global climatic physical risks as increasing, spatial, nonstationary, nonlinear, systemic, regressive (the poorest communities and populations are the most vulnerable), and underprepared for (regarding worldwide adaptation). The report recommends that decision makers from financial institutions consider climate risk in their portfolios, pointing out that one of the biggest challenges could stem from using the wrong models to quantify risk.

The environmental physical risks and associated transition risks may increase market volatility and sector instability, driving potential financial losses. For instance, physical shock events, such as natural catastrophes, may impact corporate financials, especially in the insurance sector. In this way, changes in trends such as water scarcity, air pollution, and natural capital degradation represent risks to corporate sectors such as agriculture and power generation. A few examples include the devaluations (and even bankruptcies) that happened in the German electricity sector and in the United States (US) coal and automotive industries (Bank of England et al., 2017). In case of a fast transition process toward a low-carbon system, the possibility that this risk exposure may spread across the financial system should not be underestimated (Faiella et al., 2018).

It is already known that the effects of global warming are not just long-term. The worldwide policy effort to achieve a low-carbon economy affects virtually all industries and sectors significantly and even disruptively (TCFD, 2017). Carbon pricing systems are already stimulating the alignment of the energy market with green public policies. Change in the energy matrix that is incorporating clean technologies already exemplifies potential medium-term developments and impacts.

The transition to a low-carbon economy, including mitigation and adaptation measures to minimize global warming and its impacts, signals that the primary environmental risks go beyond physical effects. They include the economic effects of developing climate and environmental policies, of new technologies, and even of changes in investors' and consumers' sentiment. The financial implications of moving to a green economy with positive impacts on the environment are significant; such movement will require reallocations in the order of tens of trillion of dollars in investments (Scott et al., 2017).

The dimensions of environmental transition risks can be categorized as policy, technological, and sentimental (Bank of England et al., 2017). The first dimension includes policy actions to mitigate, or adapt to, climate change. In the regulatory field, it includes the establishment of carbon pricing systems, such as cap-and-trade regimes or a carbon tax, and government regulatory programs designed to reduce the total level of emissions of certain pollutants, particularly carbon dioxide, owing to industrial activity. By contrast, the second dimension of transition risks includes clean technologies, such as renewable energy sources and technology innovation in production, transport, and consumption. Finally, the third dimension is related to the sentiments of investors and public opinion, which influences asset price adjustments with direct impacts on financial markets.

Dietz et al. (2016) estimated the impact of twenty-first-century climate change on the present market value of global financial assets. The authors found that the expected "climate value at risk" (climate VaR) of global financial assets is 1.8% along a business-as-usual emissions path, which would total US\$2.5 trillion based on a representative estimate of global financial assets. However, as much of the risk is in the tail, the 99th percentile climate VaR is 16.9%, or US\$24.2 trillion. Cutting emissions to limit warming in this century to no more than 2 degrees Celsius (2C) above pre-industrial levels would reduce the climate VaR by an expected 0.6 percentage points, and the 99th percentile reduction is 7.7 percentage points. Including mitigation costs, the present value of global financial assets is an expected 0.2% higher when warming is limited to no more than 2C compared to during business as usual. The 99th percentile is 9.1% higher.

Benedetti et al. (2019) studied the climate change transition risk for investors and developed a model to capture the potential impact of carbon pricing on stocks sensitive to fossil fuel. The authors propose the creation of smart carbon portfolios to face the transition to a lower-carbon economy. They suggest this can be achieved by lowering the weightings of some high-risk fossil fuel stocks while raising the weightings in lower-risk fossil fuel stocks and/or the stocks of companies active in energy efficiency markets.

In this sense, Andersson et al. (2016) also presented an investment strategy to allow hedging climate risk for long-term passive investors without sacrificing financial returns. With low tracking errors in a decarbonized index, investors hold a "free option on carbon."

Cahen-Fourot et al. (2019) analyzed the impact of decarbonization on productive asset utilization and developed a novel methodological framework to investigate the exposure of economic systems to the risk of capital stranding. Combining input-output (IO) and network theory, the authors defined measures to identify sectors likely to trigger relevant capital stranding cascades and those most exposed to capital stranding risk. The authors show that in a sample of ten European countries, mining is among the sectors with the highest external asset-stranding multipliers. According to the study results, the sectors most affected by capital stranding triggered by decarbonization include electricity and gas, coke and refined petroleum products, basic metals, and transportation.

According to Caldecott et al. (2014), environment-related risks can cause "stranded assets," or ones impacted by unanticipated or premature write-downs, devaluations, or conversion to liabilities. Such occurs due to a range of environment-related risks that are poorly understood and regularly mispriced. The result is a significant financial, economic, and potentially systemic over exposure

to environmentally unsustainable assets. These authors identified nearly 80 published scenarios from respected public and private institutions that could be relevant to the stranded assets agenda, thus serving as an information source for investors and decision makers.

The [NGFS \(2020a\)](#) published climate scenarios that cover three of the following dimensions: orderly, disorderly, and hothouse world. The first two scenarios explore a transition consistent with limiting global warming to below 2 °C. The third scenario leads to severe physical risks. In the orderly scenario, a significant amount of investment is needed to transition to a carbon-neutral economy, but impacts of transition risk in the scenario are relatively small (4% GDP loss by 2100). In the disorderly scenario, the impact is a 9% GDP loss over the same period. In the hothouse world scenario, impacts of physical risk result in up to a 25% GDP loss by the end of the century. The transmission channels that connect climate risks to the economy and financial system are detailed as follows in [Fig. 1](#).

[Boissinot and Samama \(2018\)](#) understand that governments should seek to frame the climate change issue within a standard risk management approach, besides fostering financial innovation, supporting peer pressure/transfer of knowledge, and playing the role of catalysts. In this sense, the [NGFS \(2020a\)](#) provided a range of data on physical and transition risks and economic impacts, produced by a suite of models aligned and organized as Phase I. In Phase II, the NGFS will continue to work with academic partners to refine the scenarios and expand the set of macroeconomic indicators. A summary of scenarios, related models, databases, outputs, and the time horizon can be found in the [Fig. 2](#).

Also, in June 2020, the NGFS published a guide to climate scenario analysis for CBs and supervisors ([NGFS, 2020b](#)). The guide provides practical advice on using scenario analysis to assess climate risks to the economy and financial system. Basically, the document proposes a four-step analysis: 1) identify objectives, material risks, and stakeholders; 2) choose climate scenarios; 3) assess economic and financial impacts; and 4) communicate and use results. For example, step one may include assessing risks to a CB's own balance sheet, focusing on credit and market risk analysis and stress testing. This would support managing risks to the bank's own operations and communicating exposures according to the TCFD standard (the Financial Stability Board Task Force on Climate-related Financial Disclosures).

Still, from the systemic perspective, the Bank of International Settlements (BIS) and Banque de France's (the French CB) joint report classified the climate risk as a "green-swan" risk, which means it has the potential to cause extremely financially disruptive events that could start the next global financial crisis ([Bolton et al., 2020](#)). The authors go through methodological insights and challenges to identify and measure climate-related risks with scenario-based approaches.

[Mercer \(2011\)](#) published an important study on climate change scenarios and the implications of climate change for SAA, addressing investment impacts by asset classes and geographic regions. Examples of portfolio climate risk assessment tools are the Mercer TRIP model and Sustainable Energy Investment Metrics ([WWF, 2017](#)). A reference to carbon asset risk is the report issued by [WRI and UNEP-FI \(2015\)](#) to address all this environmental data and incorporate it in the investment process.

The concept of ERA includes tools and methodologies to integrate environmental data into the risk management and asset allocation processes. According to [G20 GFSG \(2017\)](#), ERA contemplates risk identification (financial analysis of environmental factors), analysis (pricing and implications for investment portfolios), and management (actions to mitigate or transfer risks).

The inputs of an ERA are physical and transition environmental risks, analyzed in various forward-looking scenarios connected to specific metrics (sudden stops, decrease in revenues, increase in costs, reduction in the present value of cash flows or dividends, etc.) that are deployed in investment analysis. Thus, the outputs of ERA are estimated changes in the valuation of assets and portfolios under different scenarios ([NGFS, 2020c](#)).

Currently, performing ERA is still a big challenge. The analysis involves the identification of environmental factors and the evaluation of related direct or indirect risk exposure of the financial assets over time. These environmental risk factors must then be translated into quantitative measures of financial risk to support investment decisions on capital allocation. ERA peculiarities across different asset classes that are usually invested within IR management are further detailed in [Section 4](#), dedicated to the integration of the ERA with the SAA of IRs. As an example, transition scenarios may consider complex climate-economy models, such as by [IPCC \(2014\)](#) or [IEA \(2016\)](#). Some ERA tools already in use to manage the financial risks associated with environmental risk factors are detailed in [Fig. 3](#).

[Robins and McDaniels \(2016\)](#) found that the spread of ERA practice varies considerably across asset classes and may be very difficult to measure in certain sectors. In fact, the appropriateness of risk analysis tools and associated metrics primarily depends upon asset classes and risk type exposure. For instance, fixed-income investors may be the most concerned with credit risk. In addition, especially for longer-dated securities, the impacts of environmental factors on future cash flow analysis require more attention, including in rating decisions. Examples of ERA at individual asset, portfolio, and systemic levels are summarized in [Fig. 4](#):

To sum up the information provided so far, [Fig. 1](#) highlights the link between climate and financial risks; [Fig. 2](#) summarizes reference models, databases, outputs, and time horizon related to climate scenarios; and [Figs. 3 and 4](#) build a valuable framework with tools for assessing exposure and measuring risks stemming from environmental risks.

The integration of the above data into the SAA may lead to a reallocation of investments among asset classes or the inclusion of new ones to reduce negative impacts of the analyzed environmental factors or increase opportunities in a risk–return analysis in the asset or portfolio level. Collinearity and diversification issues should be considered at the portfolio level and across risk profiles (credit, market, etc.). Further details are explored in [Section 4](#).

The sovereign credit risk is particularly relevant for the management of IRs due to the large share of sovereign bonds in CBs' investment portfolios, as detailed in the next section. [Moody's \(2016\)](#) uses a methodology to capture the effects of physical climate change in a broad set of rating factors that influence a sovereign's ability and willingness to repay its obligations (principal and interest) linked to sovereign bonds. They monitor a series of climate trends and climate shock indicators, which led to four primary

transmission channels from physical climate change to sovereigns' credit profiles. These four channels are 1) impact on economic activity, 2) damage to infrastructure, 3) social costs, and 4) population migration due to severe climate impacts in their homelands.

Battiston and Monasterolo (2019) developed a climate risk assessment methodology under uncertainty to price climate risks of sovereign bonds' portfolios. First, the authors estimated the change in green/brown energy sectors' market shares under forward-looking climate transition risk scenarios using integrated assessment models. Second, the authors modeled the shocks' transmission to specific sectors and integrated them in a climate-enhanced financial pricing model for sovereign bonds. Third, the authors introduced climate to the calculation of the bonds' spread, considering specific countries' debt conditions and the carbon intensity of revenues. Finally, the authors assessed the largest losses (gains) in the Austrian National Bank's portfolio. The conclusion was that investments' alignment with a credible 2C trajectory can strengthen the sovereign's fiscal and financial position by decreasing the climate spread, while misalignment with a 2C trajectory can increase it, with financial risk implications for its investors.

Institutional investors analyzed, evaluated, and tested state-of-the-art methodologies to enable climate scenario-based analyses of their portfolios in line with the recommendations of the Task Force on Climate-related Financial Disclosure (TCFD) (UNEP-FI, 2019). The investors explored, enhanced, and applied the Carbon Delta/MSCI methodology to road-test Climate Value at Risk (CVaR) for listed equities, corporate debt, and real estate under several future scenarios. Inputs on SAA decisions are further detailed in Section 4. Other relevant tools are also available, such as PACTA and the Transition Pathways Initiative (TPI) (Portfolio Alignment Team, 2020).

Based on the concepts presented so far, the ERA synthesis is comprised of the stages presented in Fig. 5.

### 3. IR management

The objectives of IR management vary among CBs and portfolios under the same investment manager. For some of them, the main objective is to hold liquid and safe foreign exchange (FX) assets for interventions within monetary policy tasks. For others, it is capital preservation as fiduciary duty. It can also be financial stability through the management of a financial buffer for interventions in financial crises, among other strategies, as inflation management. According to the UBS Annual Reserve Manager Survey (2019), which collected responses from over 30 IR managers, the primary investment objectives of IR management are capital preservation (74% of the answers), liquidity (52%), return maximization (42%), and supporting monetary policy (6%). According to the survey, "several participants stressed that they consider return objectives to be important, but only as long as liquidity and capital preservation targets are fulfilled" (UBS, 2019). On the liquidity side, 71% of the answers to the UBS survey indicated that CBs should not invest in illiquid asset classes such as real estate and infrastructure (UBS, 2018).

When asked about the investment instruments approved for IR management, 94% of respondents included supranationals on their lists, followed by sovereign Eurobonds (85%), US agencies (85%), inflation-protected bonds (73%), corporates (61%), asset-backed securities (ABSs)/mortgage-backed securities (MBSs) (58%), covered bonds (45%), bank debt (45%), emerging markets (36%), equities (39%), private equity (18%), and hedge funds (15%) (UBS, 2019). What is common among IR managers is that reserves investments are oriented toward safe and liquid securities or other assets with low storage costs (e.g., precious metals). Most IRs are invested in long-term fixed-income securities from supranational issuers or highly rated/investment-grade governmental or government-related ones (Vecchio, 2009; McCauley and Rigaudy, 2011; UBS, 2018; Jones, 2018).

Indeed, most IRs are primarily composed by US government debt, i.e., US Treasury bills (McCauley, 2019; Jeanne, 2012). The RMB is expected to become a leading reserve currency on the level of the US dollar (USD) and EUR today, according to 38% of more than 30 CBs interviewed by UBS (2019).

The euro is currently the second most commonly held reserve currency, comprising about 20% of the global total (IMF, 2018). Besides the USD and euro, baskets of currencies called special drawing rights (SDRs) are also present in IR portfolios. SDRs are foreign-exchange reserve assets created by the International Monetary Fund. Since 2015, the SDR currency basket consists of five currencies: the USD (41.73%), the euro (30.93%), the Renminbi/Chinese yuan (10.92%), the Japanese yen (8.33%), and the British pound (8.09%) (IMF, 2019).

Other advanced country currencies usually considered by IRs managers are the Swiss franc (CHF), the Australian dollar (AUD), the Canadian dollar (CAD), the New Zealand dollar (NZD), the Danish krone (DKK), the Norwegian krone (NOK), and the Swedish krona (SEK) (Morahan and Mulder, 2013).

The NGFS report on CBs' portfolio management (2019) divides CB investments into four typical portfolios, as detailed in Fig. 6. The IRs would be mainly found in the policy portfolio, but depending on CBs' legal mandates, a third-party portfolio is also possible (i.e., when the CB manages IRs on behalf of the government). The representativeness of each portfolio for the whole CB community may be expressed by the status of the 40 respondents of the NGFS SRI portfolio management survey 2020 (NGFS, 2020e). In total, the surveyed CBs manage 82 portfolios: 29 policy portfolios, 11 pension portfolios, 18 third-party portfolios, and 24 individual portfolios. The survey only included pension portfolios that are part of CBs' balance sheets. This means CBs' pension portfolios managed by independent entities are not represented.

In crises, IRs are fundamental to quickly mobilize funds in liquid portfolios (or even investment ones) to meet domestic banks or firms' foreign currency needs and support the FX value of the domestic currency (McCauley and Rigaudy, 2011). The financial stability objectives are an important constraint to IR management, short-term liquidity needs, and reputational concerns. Jones (2018) documented evidence indicating procyclical behavior of IR portfolios during crises. For the author, the evolution of related vulnerabilities justifies "cautious optimism and lingering concern" (p. 2). Special caution is necessary to synchronize investment practices among reserve managers and other private-sector investors.

Environmental factors may be behind the next big crisis, possibly related to global warming, water, or biodiversity stress (details in Section 2). For this reason and for risk-return investment management purposes, ERA should inform the IRs management process.

Risk response management decisions will lead to aligning IRs' risk exposure with CB's risk tolerance and/or exploring opportunities according to the CB's risk appetite. Among possible risk responses, reweighting SAA is an option, without necessarily implying any green investment strategy. The next section explores possible ERA impacts on the SAA of IRs.

#### 4. ERA as input on the SAA of the IRs

##### 4.1. ERA in the SAA

SAA is an investment decision made by asset owners to manage portfolio performance and risk over the long term. Each of the asset classes presents different risks and opportunities, demanding a multifaceted strategy across the total portfolio. In turn, the ERA comprises a financial analysis of environmental factors, including pricing and implications for an investment portfolio. Thus, ERA allows the integration of environmental data into risk management and asset allocation processes.

Traditional approaches to modeling SAA fail to consider environmental risk (e.g., climate change) while relying mainly on quantitative historical data, which do not address the key financial impacts associated with environmental factors required for the addition of qualitative data and scenario analysis. This issue must be overcome, as more than 90% of the variation in portfolio returns over time is attributable to SAA decisions (Campbell and Viceira, 2002). Also, as suggested by the TIP<sup>TM</sup> framework, climate policy could contribute up to 10% to overall portfolio risk, in addition to other environmental factors (Mercer, 2011).

It is possible to incorporate environmental investment opportunities and mitigate risks through asset, region, sector and sub-asset class allocation (PRI, 2019). Before that, asset owners undertake scenario analysis and consider the impact of environmental risks and opportunities regarding expected risk, return, and correlation assumptions. The result of this analysis may lead to the review of SAA targets and ranges, including the opportunity set, widening the potential investment alternative universe.

Top-down integration is highly recommended to incorporate ERA analysis into SAA, instead of employing a case-by-case bottom-up approach to climate change and other environmental issues (Ortec, 2020; WWF, 2017; WRI and UNEP-FI, 2015). In a climate guide for asset owners, WWF (2017) encourages the integration of investment beliefs and policies into SAA, including a) the review of assumptions considering, for example, the risk of lower returns and higher volatility on high-carbon assets; b) the measurement of estimated impacts and probabilities (e.g., portfolio carbon footprint), with subsequent reduction in the risk exposure or increase in opportunities within existing SAA targets (e.g., review passive investments in low-carbon/environmental benchmarks, review investment priorities, engage with fund managers/companies and consider eventual change of asset managers, or even replace existing fund managers); and c) the evolution of SAA targets over time, following ERA outputs without undermining IRs' economic and investment objectives.

A practical example of top-down integration between ERA and SAA is a case study by Ortec (2020). They performed a climate scenario analysis from a top-down, systemic risk perspective, estimating the macroeconomic consequences of physical and transition risks. These macroeconomic risk drivers affected risk-return expectations across all asset classes, regions, and sectors. This, in turn, provided relevant information to SAA.

Also, according to Mercer (2011), investors' management of climate risks includes the following pragmatic initial actions, including clear indication of changes in SAA:

introduce a climate risk assessment into ongoing strategic reviews; increase asset allocation to climate-sensitive assets as a climate "hedge"; use sustainability themed indices in passive portfolios; encourage fund managers to proactively consider and manage climate risks; and engage with companies to request improved disclosure on climate risks. It also highlights the need for investors to communicate with policymakers the need for a clear, credible and internationally coordinated policy response and for dialogue to emphasize the potential economic and financial cost of delay. While many institutional investors might view engagement with policymakers as a separate function from strategic decision-making processes, the findings of this study suggest that it can play a vital role in overall portfolio risk management (p. 2).

On top of the SAA's practical indications, the above guidance underscores that SRI strategies, such as engagement, are crucial for portfolio risk management and thus relevant from a risk–return investment perspective, not only a positive impact one.

Also, Mercer's updated approach to SAA (2015), based on ERA, provided investors with an insight into potential impacts on return distribution expectations for the SAA, enabling them to examine the implications of different climate scenarios in the context of their current asset allocation and consider resulting actions and opportunities. The report indicates that climate change "will inevitably have an impact on investment returns, so investors need to view it as a new return variable". Industry-sector impacts will be the most significant (e.g., energy—with expressive losses in coal and gains in renewables), so climate-sensitive industry sectors should be investors' primary focus. Asset class return impacts could also be material:

For example, a 2 °C scenario could see return benefits for emerging market equities, infrastructure, real estate, timber and agriculture. A 4 °C scenario could negatively impact emerging market equities, real estate, timber and agriculture. Growth assets are more sensitive to climate risks than defensive assets (p. 7).

The above information is also relevant considering other economic objectives of IR management, especially for some CBs with significant IR volumes under management that would be impacted significantly in the analyzed scenarios.

In a risk–return analysis at the asset or portfolio level, collinearity and diversification issues should be taken into consideration at the portfolio level and across various risk profiles to reduce negative impacts of the analyzed environmental factors or increase opportunities. The integration of ERA into the SAA process may lead to a rebalance of investments among asset classes.

According to the [PRI \(2019\)](#), environmental factors can be embedded within the traditional SAA approaches, which are mean-variance optimization (MVO), factor risk allocation, total portfolio analysis, dynamic asset allocation, liability-driven asset allocation, and regime-switching models. The PRI report, after analyzing the outputs to reflect environmental issues for each SAA approach, suggests a framework largely based on a traditional MVO. Notwithstanding, the extreme limitations of MVO and factor risk allocation in the context of a systemic risk must be considered. For [Lydenberg \(2016\)](#), one clear limitation is that by focusing on risks and rewards at the portfolio level only, the traditional SAA approaches within the modern portfolio theory (MPT) fail to consider risks, rewards, and ERA at a systemic level.

As [Bose et al. \(2019\)](#) stated, despite MPT facilitating essential aspects of an asset owner's work, there are relevant limitations to be considered, "particularly its very limited portrayal of the nature of risk and the tendency to forget the interdependence of portfolio choice and systemic outcomes." For Bose, it is significant that ESG (including environmental factors) investing could involve selecting positive impact securities and selling negative impact securities, generating ESG (including green) alpha from such security selection. Notwithstanding, it is challenging to implement for the largest asset owners, such as CBs, given their scale.

UNEP-FI investor pilot-group members had a different understanding about scenario analysis methodologies informing SAA decisions. For them, scenarios should not inform SAA in the present, but maybe in the future, with more reliable information ([UNEP-FI, 2019](#), p. 117).

It is critical for each CB to assess the level of reliability required for ERA outputs as SAA input, considering the economic objective of the reserves. One can then decide to calibrate which asset class is best suited to the investment pillars (safety, liquidity, return, or even sustainability), given the objective of each portfolio and CB in managing IRs ([Fender et al., 2019](#)).

#### 4.2. ERA and SRI in the SAA of IRs

After reviewing reports from the NGFS and its members, we found no specific indication of ERA as input for the SAA of IRs ([NGFS, 2020e, 2019b, 2020c, 2020d; BoE, 2020; BdF, 2020](#)). These reports provide information about SAA impacts on investment portfolios in different scopes, with shadow areas as the focus of this study, as detailed follow.

Some SAA impacts are related to SRI strategies in policy/IR portfolios, which include ESG financial (risk–return) and nonfinancial (positive impact) objectives ([NGFS, 2020e](#)). ERA may be part of this as financial input in the environmental risk management process, which in turn produces input on the SAA process. "Protecting portfolios against sustainability risks" and "enhancing risk–return profile" are among the four main reasons CBs adopt SRI investment strategies, along with "mitigate reputational risk" and "set a good example" ([NGFS, 2020e](#), p.9).

The reports also provided information about the carbon footprint of investment portfolios related to policy purposes. This is related to the climate risk analysis, which is part of the ERA scope in addition to other environmental factors ([BoE, 2020](#)). However, IR management and policy portfolios are not representative of the total investments of the most prominent CBs in the worldwide environmental discussion so far (e.g., BoE—British CB, Banque de France, and DNB—Dutch CB).

SAA is one of the possible elements of an ESG integration investment strategy ([CFA UK, 2020b](#)). In policy portfolios, there is an indication that ESG integration (including financially material ESG criteria in the investment analysis to improve the risk–return profile of the portfolio) has been considered for sovereign, supranational, and agency (SSA) bonds by four CBs, for corporate bonds by two CBs, and for equities by one CB ([NGFS, 2020e](#)).

The most prominent sustainable investment strategies adopted by CBs are green bond investments, negative screening, and ESG integration ([NGFS, 2020e](#)), which give us some information about SAA, but are not necessarily a consequence of an ERA. The NGFS survey also indicates that many CBs hold green SSA as well as corporate and covered bonds in their policy portfolios. Thus, it is not clear if the investment strategy of holding these green bonds is a result of a risk–return analysis, including ERA. Impact investment could be a reason, but it does not appear in the survey as a relevant investment strategy.

Negative screening was implemented in policy portfolios for corporate bonds (9 CBs), SSA and equities (6 CBs each), and covered bonds (3 CBs). On the other hand, the best-in-class strategy was only applicable within the policy portfolios by 2 CBs for corporate bonds and 1 CB for equities ([NGFS, 2020e](#)).

In terms of nonfinancial investment objectives, Banque de France significantly modified its SAA by deciding that investments in dedicated funds should prioritize unlisted funds, as they offer a more direct way to finance energy and ecological transitions. Previously, its SAA included only listed asset classes. This decision was a result of Banque de France's SRI strategy, which is organized around three pillars: 1) align investments with France's climate commitments, 2) include ESG criteria in asset management, and 3) exercise its right to vote and influence issuers. This SAA change is not necessarily aligned with ERA, and this information was not specifically provided ([NGFS, 2019b, 2020e](#)).

Furthermore, the DNB signed the Principles of Responsible Investment (PRI)<sup>1</sup> for foreign exchange reserves and its portfolios. The DNB applies four key SRI strategies for IR management: 1) exclusion of controversial weapons, 2) screening on the basis of the UN Global Compact Principles, 3) ESG integration in investment decisions, and 4) voting and engagement ([NGFS, 2019b](#)). The SRI strategies have possible SAA implications aligned with positive-impact investment objectives but are not necessarily connected

<sup>1</sup> PRI is the world's leading proponent of responsible investment. The PRI signatories are committed to six principles that offer a menu of possible actions for incorporating ESG issues into investment practice.

to ERA. However, DNB performed a climate stress test on its balance sheet, based on the methodological framework developed for supervisory purposes by its Financial Stability (FS) Department (NGFS, 2020e).

On the top of that, the Swedish CB divested from bonds issued by the Canadian province of Alberta and the Australian states of Queensland and Western Australia due to the large climate footprint of these issuers (Sveriges Riksbank, 2019). The main motivation behind the bank's deputy governor's speech was a positive impact action, but this did not jeopardize eventual ERA considerations. As demonstrated by Battiston and Monasterolo (2019), sovereign bonds' portfolio alignment to a credible 2C trajectory can strengthen the sovereign fiscal and financial position by decreasing the climate spread, while a misalignment with a 2 °C trajectory can increase it, with financial risk implications for its investors.

In parallel, a recent BIS survey focused on CBs' ESG investing practices (Fender et al., 2019), which gives some insights into IR management but is not necessarily related to the risk-return investment perspective. According to a survey answered by 67 CBs, 62.7% of respondents do not include sustainability considerations in the pursuit of policy objectives (related to one of the four types of portfolios managed by CBs, as stated by the NGFS). However, 62.7% see the scope as including sustainability as a reserve management objective. Additionally, according to UBS (2018), 36% of IR managers did not consider sustainable and responsible investment aspects in the IR investment process, while 32% considered them but had not implemented yet, 27% considered them but only used exclusion criteria, and 5% considered and allocated certain assets accordingly.

On this point, Jones (2018) understood that ESG concerns are not applicable to IR managers. This information was presented in a taxonomy proposal on constraints to IR management, but the reasons for this conclusion were not discussed. This understanding contradicts other studies detailed in the previous sections of this paper. According to these other studies, ESG factors may represent relevant financial risks, and they are thus applicable to IR management.

According to Fender et al. (2019), "green bonds may not be eligible for the liquidity or working capital tranches of central banks' reserve portfolios" (...) because "bid-ask term structures suggest that green bonds tend to be more costly to buy and sell, trading with wider spreads than their conventional counterparts" (p. 56), with similar results across the entire market. However, despite the liquidity concern, overall "sustainability objectives can be integrated into reserve management frameworks without foregoing safety and return" (p. 62). For the authors, the integration of sustainability into the management of reserves by CBs involves "additional trade-offs, turning the classical triad of liquidity, safety and return into a tetrad of reserve management objectives" (p. 61), including the sustainability factor. Furthermore, the results of an illustrative portfolio construction exercise performed by the authors "suggest that adding both green and conventional bonds can help generate diversification benefits and, hence, improve the risk-adjusted returns of traditional government bond portfolios" (p. 62).

For investment in green bonds, a notorious alternative for CBs to consider in IR management is the BISIP Green Bond fund (BIS, 2019). It is an open-ended fixed income fund for CB investments in green bonds, denominated in USD and managed in-house by BIS Asset Management. Eligible bonds have a minimum rating of A- and comply with the International Capital Market Association's Green Bond Principles and the Climate Bond Standard from the Climate Bonds Initiative.

Finally, as Volz et al. (2020) stated well, CBs "need to understand their exposures to other countries' sovereign risks arising from climate change if they hold those countries' government bonds" (p. 40). Thus, ERA is critical to the SAA of IRs as IRs are mainly invested in SAA bonds, which are highly exposed to sovereign risks, and which are also highly impacted by climatic and other environmental factors (Fig. 7).

Building off the concepts presented so far, a concept map for this study was constructed as detailed in the Fig. 7:

## 5. The multicriteria analytical framework

The environmental risks (Section 2) to which IRs (Section 3) are exposed need to be assessed and quantified to enable a proper risk management process, including eventual changes in the SAA (Section 4) to allow the achievement of the CB's objectives. For this purpose, a multicriteria analytical framework was developed for the evaluation of these environmental risks and incorporation in the risk management process with outputs to the IR's SAA, as outlined in Fig. 8:

The ERA (Fig. 9) is based on the analysis of scenarios to support the assessment of the environmental risk factors and the evolution in time of the associated environmental risk events and trends. Environmental risk factors include both physical and transition risks. The physical risks include climatic, geological, and ecosystem factors such as: global temperature; global precipitation; ice level and snow cover; ocean temperature, level and pH; CO<sub>2</sub> levels; radiative forcing; biodiversity; systemic services; and resource usage. The transition risks include policy aspects such as green economy regulations, technological factors such as clean energy technology innovation, and changes in the public's and investors' sentiments toward a sustainable future.

Based on the analysis of environmental risk factors and scenarios, the ERA evolves to the subsequent analysis of the impact on financial portfolios, including financial risks and systemic risks. Financial risks are considered in the following dimensions: business, market, and credit. Systemic risks include the financial system and economy-wide risks.

Measures for assessment value and risks include the following: operational value-at-risk (OpVar); discounted cash flow (DCF) valuation; relative value and performance; value at risk (VaR); portfolio value under various scenarios; credit rating; expected loss; rating level for industry; rating for securitized assets; financial firm exposure, size, and concentration; system-wide losses on different scenarios; impact on GDP, consumption, and financial conditions (scenarios, macro models, and model-based risk assessment-MBRA).

The multicriteria analytical framework for the incorporation of the ERA into the SAA of the IRs is detailed in Figs. 9–12, which follow.

The output of the ERA (Fig. 9) may provide new information to the traditional SAA framework of IRs (Fig. 10). It will be considered alongside the IR's economic objectives and investment guidelines. Thus, the ERA output will be incorporated on top of other main concerns of the IR managers as environmental risk management is not the primary concern of the IR managers. The primary concern is to adequately address the reasons that motivate the IR's existence (which may vary from CB to CB).

Hence, environmental risk exposure will be considered jointly with the concerns for currency, asset type, countercyclicality (for crisis mitigation) and the relevance of each of the three IR investment pillars: security, liquidity, and profitability. The relevance of each of the investment pillars depends on the strategic objectives of each IR manager, which ultimately reflect the reasons for which the reserves are being maintained. For example, SWFs can prioritize profitability to the detriment of liquidity, while emerging countries may need to give more weight to liquidity and security. This also depends on the objective of each specific portfolio, given that the same investor can prioritize different pillars in different portfolios.

The IRs' traditional SAA framework, as explained above, is detailed in Fig. 10:

Based on the analysis of the ERA outputs considered in the traditional IR SAA framework, CBs can evaluate the adequacy to adjust the framework to include the environmental factor as a fourth pillar of IR management objectives, what may possibly generate diversification benefits and improve risk-adjusted returns (Fig. 11).

In the above context, environmental risk and opportunities are considered without undermining the perspectives of other CBs. To better clarify, the purpose of an ERA is to quantify the financial risk exposure related to environmental factors in an IR's assets and portfolios. The purpose of SAA is to identify the best risk-return profile for IR allocation according to IR objectives (liquidity, safety, return). The combined assessment of financial and environmental risks as an input on the SAA may guide an asset allocation for IR which is sound from these two risk viewpoints. The decision is supported by the CB's risk tolerance and appetite.

Traditional SAA is adjusted to incorporate environmental considerations alongside the traditional investment guidance of IRs as asset classes, currencies, issuers, regions or countries, asset maturity, liquidity (bid-ask spread, turnover), and market depth (outstanding). On the top of that, specific environmental variables would be included to achieve an efficient investment portfolio, which may require a multi-objective optimization (this point is explored in more detail in a second study by these authors, focused on the positive impact perspective). This investment guidance may direct the partial allocation of the IRs in green assets or indicate a rebalancing among existing assets. Thus, the ERA could measure risks and contribute to reweighting in SAA without necessarily implying any green strategy.

To sum up, the practical, possible ERA impacts on the SAA of the IRs are demonstrated in Fig. 12.

The ERA (Fig. 9) allows the identification of the main concepts, relationships, and tools to be considered by the CBs. Furthermore, the multicriteria analytical framework supports the inclusion of the ERA outputs in the SAA analysis of the IRs by the CBs (Figs. 10–12).

A short example of how to apply the framework is discussed here. Consider a developing country that imports oil. The CB of this country performs a traditional SAA and decides to invest in government bonds, agencies and supnationals in an asset/liability management approach. Furthermore, consider that the CB decides to have a small amount of IRs invested in assets that are positively correlated to oil prices in order to hedge its exposure to the commodity. An ERA should consider the transition effects related to climate change and technology, which may imply in stranded assets in the oil and gas (O&G) sector with appreciation of clean-energy investment alternatives. In this case, the ERA may show that the real exposure of the country is energy instead of oil asset prices, or even a sovereign or systemic exposure. Hence, the country may benefit more from investing in green energy than in oil, or even from splitting investments in both energy sources as a way of diversifying investments. Moreover, in some scenarios, some sovereign assets may be revalued, as well as some green ones. Of course, the discussion is not that simple, and this example helps only to understand the application of the framework discussed here.

A specific exercise could be performed with Brazil as a case study. Brazilian IRs totaled US\$356.89 billion in 2019, representing 19% of the national GDP and 160% of total annual merchandise exports. Food and agriculture represented 40% of exports, and fuel accounted for another 14% (11% crude oil). According to the Assessing Reserve Adequacy (ARA) metrics of the International Monetary Fund (IMF, 2020), 5% of total exports should be covered by IR assets allocated to hedge sudden stops in capital flows. In the Brazilian case, this would account for US\$11.13 billion. Thus, a 40% hedge for food and agriculture on total exports would account for US\$4.44 billion and a 14% hedge for fuel on total exports totaling US\$1.53 billion. Environmental risks have a direct impact on exports, capital flows and, in this perspective, an indirect impact on IRs, considering the economic objectives of the execution of payments, besides intervention in forex markets. In an ERA for the SAA of the IRs, the environmental factors would be mainly food, agriculture, and energy. Fig. 13 shows the details of this exercise.

The relevant scenarios may contemplate *climate-change transition risk* and *climate-change physical risk*. The related environmental risks, with financial percentage impacts in some specific time horizons, could be increased CO<sub>2</sub>-emission costs as well as a crop break due to impact on the physical climate. Some expected asset-price movements due to crisis scenarios would reduce country exports and would have an impact on the foreign exchange rate. The SAA exercise may consider portfolios for the investment of the IRs that are more resilient to these scenarios.

The SAA should drive the choice of currencies in the portfolio to those currencies that are less correlated to the Brazilian real in the relevant scenarios, to avoid procyclicality. The ERA analysis helps to quantify the size of the impact on the economy and the dimension of this impact in the investments of IRs. Furthermore, the choice of asset classes should consider those related to clean energy and eco-friendly agriculture. The choice of the currency is easier from a traditional perspective. On the other hand, the choice of asset classes is more difficult due to liquidity issues, since green asset classes eligible to CBs are traditionally agencies,

supranationals, and some issuers of sovereigns. However, it would be possible to search for small amounts of investments in these kinds of asset classes.

### 6. Conclusions

This study discussed the environmental risk exposure of IRs and developed a multicriteria analytical framework to consider environmental risk in the SAA by CBs. The study is relevant to the construction of the investment portfolio of the IRs because of the different angles that must be considered in the allocation among countries and instruments.

The main argument is that ERA should be included in the traditional approach for SAA by CBs due to the relevance of environmental risks to which the IR are exposed. Therefore, each viable portfolio should also be evaluated based on an environment risk analysis. This environment risk analysis should consider scenarios for environment risks along with probabilities and potential impacts. The risk and return relationships of the portfolios in each scenario should be evaluated based on the factors discussed in this paper. In addition to traditional IR objectives, like hedging liabilities and evaluation of countercyclicality to market movements, the CBs should also take environment risk into account.

This study only addresses the environmental aspects of the ESG factors. Moreover, this research focuses on the management of environmental and financial risks, not on the non-financial investment objectives so as “to create a positive impact on the environment and society alongside financial returns” (NGFS, 2019b). Further studies could focus on social and governance factors, as well as on non-financial investment objectives under the management perspective of an IR.

### Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

### Appendix

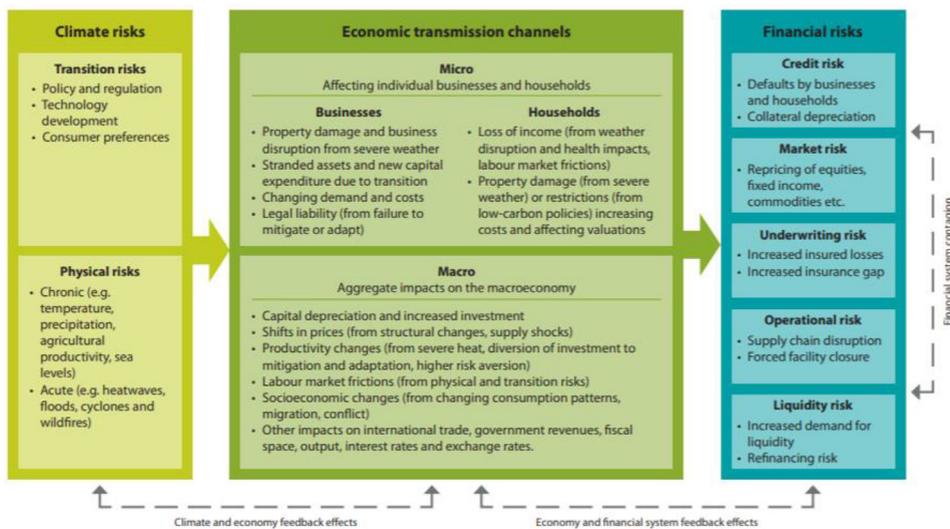


Fig. 1. Transmission channels from climate risks to financial risks. Source: NGFS (2020a).

Comparison	Chronic climate impacts	Transition pathways
<b>Scenarios<sup>2</sup></b>	<b>Orderly</b> (Representative: Immediate 2°C with CDR [GCAM]. Alternate: Immediate 2°C with limited CDR, Immediate 1.5°C with CDR) <b>Disorderly</b> (Representative: Delayed 2°C with limited CDR [REMIND]. Alternate: Delayed 1.5°C with limited CDR, Delayed 2°C with CDR) <b>Hot house world</b> (Representative: Current policies [MESSAGE]. Alternate: Nationally Determined Contributions)	
<b>Models</b>	Models participating in the ISIMIP project. <sup>3</sup>	3 Integrated Assessment Models (REMIND-MAGPIE 1.7-3.0, GCAM 5.2, MESSAGEix-GLOBIOM 1.0)
<b>Database</b>	<a href="#">ISIMIP</a>	<a href="#">IIASA</a>
<b>Outputs</b>	Chronic climate change impacts including temperature, precipitation, agricultural yields. GDP impacts calculated separately based on 3 damage functions	Energy demand, energy capacity, investment in energy energy prices, carbon price, emissions trajectories, temperature trajectories, agricultural variables, GDP
<b>Time horizon</b>	All variables are projected on incremental steps of 5 years, up to 2100	

Fig. 2. Summary of the key aspects of NGFS climate scenarios – Phase I.  
 Source: NGFS (2020a).

Environmental Risk Factor	Scenario Analysis	Financial Risk Tool	Results
Transition (impact of environmental regulation and carbon price)	Scenario analysis to assess the impact of carbon and energy regulation on margins of carbon-intensive firms	ClimateXcellence model	Impact on company margin in terms of € cent per kWh
Transition (impact of carbon price linked to low-carbon scenario)	Analysis of impacts of transition risks on German electricity utilities	SOTP valuation methodology (DCF + EV/EBITDA)	Total and per-share firm valuation
Transition (climate scenarios linked to various risk factors)	Examining the effect of transition risks on SAA	Integrated assessment model incorporated in asset allocation investment model	Median additional annual returns up to 2050
Physical (climate change)	Assessing physical effects of climate change on sovereign issuers	Consideration of climate change factors within the Sovereign Rating Model	Assessment of susceptibility of sovereigns to climate change risks

Fig. 3. Summary of case studies on ERA.  
 Source: prepared by the authors, based on the Bank of England et al. (2017).

Analysis Level	Market Risk		Credit Risk		Financial System	Economy-Wide
	Asset	Portfolio	Asset	Portfolio	Systemic	Systemic
Environmental Factor in Focus	Transition: climate regulation and introduction of carbon price	Identify high-risk factors	Physical: cyclones and floods	Three scenarios of stricter regulation of air and water pollution	Identify key transition risk sectors	Physical risk: flooding in key coastal cities; transition risk: global carbon pricing agreement
Financial Risk Metric	Reduced profit, DCF-based valuation	Relative performance against alternative portfolio	Impact on sovereign rating	Impact on the credit quality of commercial banks' portfolios	Total exposure of financial institutions	Effect of regulation and physical damages on financial market and GDP

**Fig. 4.** Examples of ERA at individual asset, portfolio and systemic levels.

Source: prepared by the authors, based on GFSG (2016) and Bank of England et al. (2017).

ERA Components	Subcomponents	References
1) Environmental risk factors:	Physical	Bank of England, UNEP, and CISEL (2017); Campiglio et al (2018); CISEL (2016); Dafe and Volz (2015); IPCC (2013 and 2014); FTSE Russell (2019); Moody's (2016); Scott, Huizen, and Jung (2017); Volz (2017); WRI and UNEP-FI (2015).
	Transition	
2) Scenarios analysis:	Climate and other physical scenarios	Cahen-Fourot et al (2019); Caldecott, Tilbury, and Carey (2014); CISEL (2015); Lamperti et al (2019); McKinsey (2020); Mercer (2011); NGFS (2020a); NGFS (2020b); TCFD (2017) and Scott, Huizen, and Jung (2017).
	Regulation, carbon-market, and other transition scenarios	
3) Risk assessment tools in each impact dimension:	Financial (business, market, and credit)	Battiston and Monasterolo (2019); Bank of England (2020); Bank of England, UNEP, and CISEL (2017); Benedetti et al (2019); Bolton et al (2020); CISEL (2016); CISEL (2015); Dietz et al (2016); G20 GFSG (2016 and 2017); Moody's (2016); NGFS (2020c); NGFS (2020d); UNEP-FI (2019); WWF (2017).
	Systemic	

**Fig. 5.** ERA framework from theory to Praxis.

Source: prepared by the authors.

Characteristics	Policy portfolios	Own portfolios	Pension portfolios	Third-party portfolios
Dictated by	Policy goal – determined by central bank mandate.	Financial return goal – e.g. to help cover operating expenses.	Fiduciary duty – managed on behalf of beneficiaries.	Third-party mandate – managed on behalf of an external party.
Main objective	To support, implement and maintain confidence in monetary policy and currency management.	To generate returns within set risk tolerance levels. Secondary objective can be to gather market intelligence.	To provide for the retirement pension obligations of the central bank's employees.	Set by a third party. Varies, e.g. financial return, short-term liquidity provision or foreign exchange intervention.
Character	Assets meet high standards in terms of liquidity and credit quality in order to be able to absorb shocks in times of crisis or when access to borrowing is curtailed. Can be subject to market neutrality.	Subject to risk-return considerations. More freedom in investment decisions, but interference with monetary policy or currency management should be prevented.	Long term investment horizon in line with the pension liabilities. Short-term volatility is less of a concern.	Depends on main objective of funds. Cases where central bank manages foreign exchange reserves on behalf of the government.
Asset classes	Limited. Mostly (sub-) sovereigns, supranationals and agency (SSA) and some corporate/covered bonds and equity.	Diverse. Mix between SSA, corporate/covered bonds and equity, and potentially private debt.	Diverse. Mix between SSA, corporate/covered bonds, equity, and private debt.	Diverse. Mainly SSA, followed by corporate/covered bonds, and equity.
Duration	From short to medium term. From 3-6 years for majority. Less than 2 years for one-third of respondents.	Short term. Less than 2 years for majority.	Longer term. More than 6 years for two-thirds of the respondents.	Balanced. Varies from short term (0-2 years), medium term (3-6 years) and longer term (> 6 years).

**Fig. 6.** NGFS typical CB portfolios and its characteristics.

Source: NGFS (2019b).

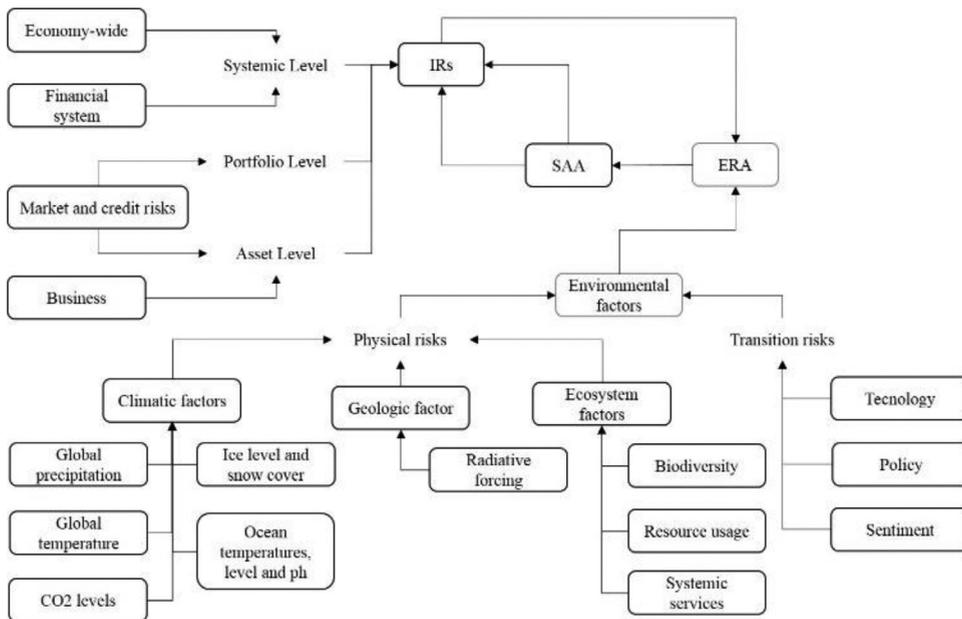


Fig. 7. Concept map.

Source: prepared by the authors based on the theoretical references detailed above.

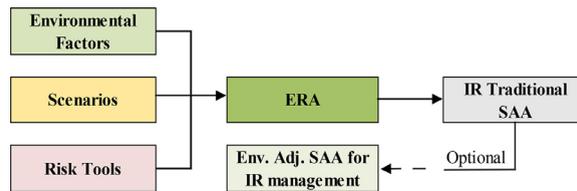


Fig. 8. Multicriteria analytical framework for the ERA and SAA of IR management.

Source: prepared by the authors based on the references of this study.

**RISK IDENTIFICATION**  
Analysis of environmental factors in time and related financial risk metrics.

1) Environmental factors:			3) Measures for assessment value and risks in each impact dimension:				
			Financial:			Systemic:	
			Business:	Market:	Credit:	Financial System:	Economy-wide:
Physical: Climatic Geologic Ecosystem	2) Assessment of environmental risk in time (events and trends), based on stress testing, scenario analysis or other technique.	Risk metrics (e.g: decline in revenues; increase in costs)	Asset level: OpVaR.	Asset level: Discounted Cash Flow (DCF) valuation; relative performance. Portfolio level: VaR; portfolio value under various scenarios.	Asset level: credit rating; expected loss; DCF valuation. Portfolio level: expected loss; rating level for industry; rating for securitized assets.	Financial firm's exposure, size and concentration; system-wide losses on different scenarios.	Impact on GDP, consumption, financial conditions (scenarios, macro models and MBRA).
Transition: Policy Technology Sentiment							

→ RISK ANALYSIS: EXPOSURE AND ASSESSMENT OF IMPACTS AND PROBABILITIES ←  
Translating env. factors into measured financial risks (e.g.: transmission channels; general picture of scale and scope; proxies; stress testing, scenario analysis, portfolio and probabilistic modelling etc.)

Fig. 9. Environmental risk analysis (ERA).

Source: adjusted by the authors based on the references from this study, mainly Bank of England et al. (2017).

IR economic objectives (Fender et al, 2019)	Investment Guidelines	Three pillars of investment:	IRs focus (main exposure):	SAA model approaches:	Concern for crises mitigation:
Intervention in the FX markets; Execution of payments for goods and services; Execution of payments for the government; Granting of emergency liquidity assistance; Support of domestic monetary policy; Underpinning of investor confidence in the country; Investment of excess reserves.	Investment Policy; Investment Strategy; Investment Driver; Investment Objectives		<b>Asset:</b> mainly Treasury Bonds, Supranationals, Sovereign Eurobonds, US Agencies, Inflation Protected Bonds, Corporates, MBS/ABS, Covered Bonds and Banks Debt. <b>Currency:</b> mainly USD, EUR, CNY, JPY, GBP.	Mean-variance optimization (MVO), Factor risk allocation, Total Portfolio Analysis, Dynamic asset allocation, Liability driven asset allocation and Regime Switching Models.	Countercyclicality

Fig. 10. IRs’ traditional SAA framework.

Source: prepared by the authors based on the references of this study, mainly Fender et al. (2019) and IMF (2001).

IR economic objectives (Fender et al, 2019)	Investment Guidelines	Four pillars of investment:	IRs focus (main exposure):	SAA model approaches:	Concern for crises mitigation:
Intervention in the FX markets; Execution of payments for goods and services; Execution of payments for the government; Granting of emergency liquidity assistance; Support of domestic monetary policy; Underpinning of investor confidence in the country; Investment of excess reserves	Investment Policy; Investment Strategy; Investment Driver; Investment Objectives		<b>Asset:</b> mainly Treasury Bonds, Supranationals, Sovereign Eurobonds, US Agencies, Inflation Protected Bonds, Corporates, MBS/ABS, Covered Bonds, Banks Debt and Green Bonds. <b>Currency:</b> mainly USD, EUR, CNY, JPY, GBP.	Mean-variance optimization (MVO), Factor risk allocation, Total Portfolio Analysis, Dynamic asset allocation, Liability driven asset allocation and Regime Switching	Countercyclicality

Fig. 11. Environmentally adjusted SAA framework for IR management.

Source: prepared by the authors based on the references of this study, highlighting Fender et al. (2019).

- 1) Inclusion of new asset alternatives:
  - 1.1) Inclusion of Green Asset Classes (eg: Green Bonds, Green Funds, Green Indexes in passive portfolios etc);
  - 1.2) Inclusion of other asset alternatives, as unlisted funds, if appropriate for the environmentally adjusted SAA model;
- 2) Rebalance among existing asset classes, regions/countries, sectors and sub asset classes:
  - 2.1) Divestments from high carbon footprint and/or high temperature alternatives;
  - 2.2) Investments to explore opportunities towards lower carbon footprint and/or lower temperature
- 3) Inclusion of environmental risk management considerations in the selection of asset managers, fund managers and companies.

Fig. 12. Practical, possible ERA impacts on the SAA of IRs.

Source: prepared by the authors based on BoE (2020), BdF (2020), Sveriges Riksbank (2019), PRI (2019), BIS (2019), WWF (2017), Mercer (2011).

<b>CB from Latin America (Brazil):</b>	<b>US\$ billion in 2019</b>
IR	356.89
GDP	1,839.80
% IRs/GDP	19%
Total merchandise exports	222.64
% IRs/Exports	160%
Food & agriculture raw material exports	88.83
% food & agriculture on total exports	40%
Fuel exports	30.50
% fuel on total exports	14%
Total merchandise imports	184.10
% IRs/Imports	194%
Food & agriculture raw material imports	12.70
% food & agriculture on total imports	7%
Fuel imports	25.96
% fuel on total imports	14%
<b>% IR assets allocated to hedge sudden stops in capital flows (ARA IMF- exports)</b>	<b>5%</b>
Total IR assets allocated to hedge of the external liabilities	11.13
40% hedge for food & agriculture on total exports	4.44
14% hedge for fuel on total exports	1.53



### **ERA-SAA Integration**

**Environmental factors:** climate transition (CO<sub>2</sub> emissions) + physical impact on climate (temperature and precipitation, with extreme events)

**Economic sectors:** energy + food & agriculture

**Scenarios:** NGFS climate scenarios for central banks and supervisors (2020)



**Environmental risks with financial impacts:** increased CO<sub>2</sub> emission costs and crop break due to physical impact on climate



**Possible related asset price movements:** stranded-assets in the O&G sector; appreciation of clean energy assets; decrease in average asset prices for non-regenerative agriculture; increase in prices for biodiversity-conservation assets; exports and foreign exchange rate impacts, etc.



**SAA:** hedge to ERA-related asset price movements, considering also other traditional SAA relevant data (e.g., IR economic objectives; investment guidelines and investment pillars)



**Migrate to assets less correlated with agricultural and oil commodities (example of relevant scenario to be mitigated)**

**Fig. 13.** ERA-SAA practical exercise.  
Source: prepared by the authors.

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