Environmental Risk Analysis (ERA) in the Strategic Asset Allocation (SAA) of the International Reserves (IRs) managed by Central Banks (CBs).

Abstract

This study addresses how to consider environmental risks in the Strategic Asset Allocation (SAA) of the 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. This Environmental Risk Analysis (ERA) is deployable in the IRs Traditional SAA Model, that in turn is connected to a Green Strategic Asset Allocation (GSAA) Model. Climate physical and transition risks are resulting in a range of financial risks. ERA is still incipient in the financial investment sphere, especially among CBs. The main argument is that ERA should be included in the traditional approach for SAA in CBs. Therefore, each viable portfolio should also be evaluated based on an ERA, considering scenarios of environmental risks along probabilities and potential impacts. The risk and return relationships of the portfolios in each scenario should be evaluated based on the environmental physical and transition factors. In addition to traditional IR framework, the CBs should also take environmental risk into account.

Keywords: Environmental Risk Analysis; Strategic Asset Allocation; Central Banks; International Reserves; Sustainable Finance; ESG investment.

1. Introduction

Effective risk management, including risk identification, measurement and control, is essential for efficient operation on 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, UNEP and CISL, 2017; Andreeva and Voysey, 2016; Caldecott, 2014a).

Even though proper risk management is essential for efficient investment management, Environmental Risk Analysis (ERA) is incipient in the financial investment sphere, especially among Central Banks (CBs). The theoretical and practical gaps in this subject were highlighted in the first reports of the newly created group of CBs, the Network for Greening the Financial System (NGFS, 2018 and 2019).

The management of environmental risks has not been a primary objective of the IRs management (NFGS, 2018 and 2019). Possibly for this reason, CBs are not significantly addressing environmentally sustainable management and the Green Finance market from the perspective of International Reserves (IR) managers (Sevillano and Romo, 2018). However, the physical and transition environmental risks are beginning to be understood as sources of financial risks, which may affect the investments performance (Bank of England, UNEP and CISL, 2017; Andreeva and Voysey, 2016). As a result, the management of environmental risk exposure of the IRs is important for CBs.

The IRs are investments held by CBs in 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, 2011; Hawkins, Rangarajan, 1970; Kohlscheen, O'Connell, 2004; Detragiache, 1996; AIzenman, 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.

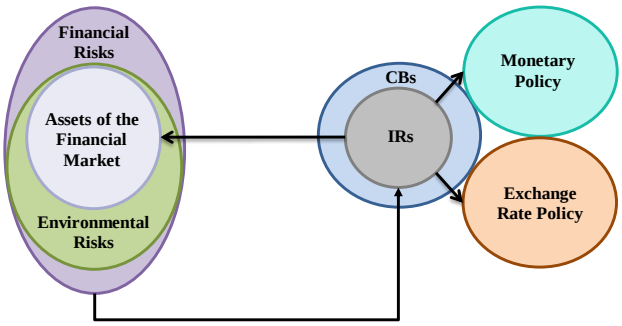
In December 2017, the Network for Greening the Financial System (NGFS) was established among CBs to define and promote the implementation of best practices inside and outside NGFS Members, and to develop analytical work on green finance. On 2019, the NGFS encouraged CBs to lead by example and to integrate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

The ERA is prominently linked to the Strategic Asset Allocation (SAA) by means of the 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 climate physical and transition risks to which CBs are exposed as managers of the 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.

The problem can be better understood through the figure 1, as follows:

Figure 1- Problem situation.



Source: prepared by the authors.

Other studies, which 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 as oversight agents, but not as IR managers (e.g.: Campliglio et al, 2018). The theoretical studies of ERA, detailed in the following section, were generally focused on other investors.

For the scope of this study, it must be clarified that it addresses climatic and more broadly environmental factors (e.g.: biodiversity), discusses governance matters related to this approach, but does not includes social and more broadly governance factors, which are typically also included in ESG (Environmental, Social and Governance) and SRI (Sustainable and Responsible Investing) analysis.

This paper proceeds as follows: the five first following sections detail results of literature review. Section 2 is about the Environmental Risk Analysis (ERA) and concludes with an ERA Framework from Theory and to Praxis. Section 3 covers the International Reserves (IRs) management. Section 4 detail the results related to Green, ESG and SRI considerations in IR management. Section 5 approach the concept of a Green Strategic Asset Allocation (GSAA) and Active Ownership. Section 6 presents the multicriteria analytical model. The paper concludes in Section 7 with an outlook for future research.

2. The Environmental Risk Analysis (ERA)

In addition to the usual risks already considered by financial market managers, the environmental risk sources are being associated with a range of financial risks. Environmental and climate challenges pose material risks for real economies and financial stability (Dafe and Volz, 2015 and Volz, 2017). Evidence indicates that environmental physical and transition factors are resulting in business, market and credit, risks. All these risks have financial implications that can be non-linear and disruptive (TCFD, 2017; Bank of England, UNEP and CISL 2017; G20 GFSG, 2016).

The dimensions of the environmental physical risks are climatic, geologic and ecosystemic (Bank of England, UNEP and CISL 2017). Physical risks include shock events and changes in trends. According to *The Global Risks Report 2017*, prepared by the World Economic Forum, four of the five top risks in terms of impact are environmentally related. Three of them are physical (extreme weather events, water crises and major natural disasters) and one is transitional (failure of climate change mitigation and adaptation).

Among the climatic physical risks, global warming is by far the most discussed one, strongly associated with 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 different continents, land degradation and landslide related to extreme weather events, as well as numerous other effects (IPCC, 2013). On the other hand, global warming benefits some nations and regions, like Canada, Alaska and Russia, by expanding arable land and increasing domestic production (Read, 2016).

The exact timing and severity of global warming 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 transmission makes it exceptionally challenging, especially in the context of economic decision-making (UNEP-FI, 2019). However, the effects of global warming are not just long term. The worldwide effort to achieve a low-carbon economy affects virtually all industries and sectors, significantly and even disruptively (TCFD, 2017). Cap-and-trade regimes and Results-Based Financing (RBF) are already stimulating the alignment of the energy market with public policies aimed at sustainable energy production and reduction of carbon emissions. The change in the energy matrix, incorporating clean technologies, already exemplifies potential medium-term developments.

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 the investors sentiment. The financial implications of moving to a green economy, with positive impacts on the environment, are significant; it will require reallocations in the order of tens of trillion dollars in investments (Scott, Huizen and Jung, 2017).

The dimensions of the environmental transition risks can be categorized as policy, technological, and sentimental (Bank of England, UNEP and CISL, 2017). The first dimension includes policy actions to mitigate, or adapt to, climate change. In the regulatory field, it includes the establishment of cap-and-trade regimes or carbon tax and government regulatory programs designed to reduce the total level of emissions of certain pollutants, particularly carbon dioxide, because of industrial activity. By contrast, the second dimension of transition risks include clean technologies, as the renewable energy sources and technology innovation in production, transports, and consumption. Finally, the third dimension is related to the sentiment 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 with 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 fossil fuel sensitive stocks. 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 in the stocks of companies active in energy efficiency markets.

Boissinot and Samama (2019) 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.

Cahen-Fourot, L. et al (2019) developed a novel methodological framework to investigate the exposure of economic systems to the risk of physical capital stranding. Combining Input-Output (IO) and network theory, the authors defined measures to identify both the sectors likely to trigger relevant capital stranding cascades and those most exposed to capital stranding risk. The authors show how, 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.

The environmental physical risks and the associated transition risks may increase market volatility and sector instability, driving potential financial losses. For instance, physical shock events, 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 like 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, UNEP Enquiry and CISL, 2017). In case of a fast transition process towards a low-carbon system, the possibility that this risk exposure may spread across the financial system shouldn't be underestimated (Faiella, I.; Bernardini, E.; Poli, R.; Di Giampaolo, J., 2018).

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

Meanwhile, the concept of ERA contemplates 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 to investment portfolio) and management (actions to mitigate or transfer risks). According to Caldecott, Tilbury and Carey (2014, p.2):

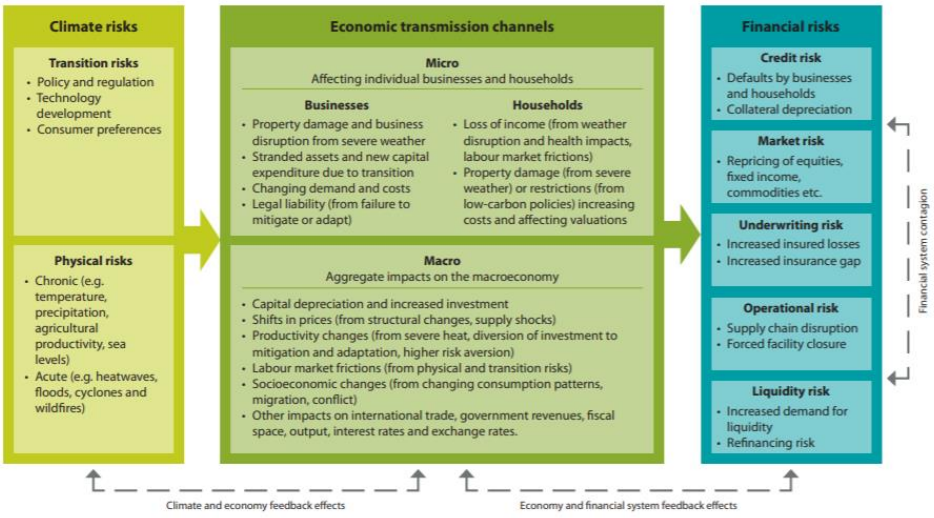
> "Stranded assets" are assets that have suffered from unanticipated or premature write-downs, devaluations or conversion to liabilities. They can be caused by a range of environment-related risks

and these risks are poorly understood and regularly mispriced, which has resulted in a significant over-exposure to environmentally unsustainable assets throughout our financial and economic systems.

These authors identified nearly 80 published scenarios from respected public and private institutions which could be relevant to the stranded assets agenda, thus serving as an information source to investors and decision-makers. An important study on climate change scenarios and its implications for SAA was published by Mercer (2011) and addresses the investments impacts by asset classes and geographic regions. Examples of portfolio climate risk assessment tools are Mercer TRIP model and Sustainable Energy Investment Metrics (WWF, 2017). For carbon asset risk, a reference is the report issued by WRI and UNEP-FI (2015).

The NGFS (2020a) published climate scenarios (NGFS,) that cover one of the following dimensions: orderly, disorderly, and hot house world. The first two scenarios explore a transition which is 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 from transition risk in the scenarios are relatively small (4% GDP loss by 2100). In a disorderly scenario, the impact would be 9% GDP loss in the same period. In the hot house world scenario, impacts from 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 were detailed as follows:

Figure 2- Transmission channels from climate risks to financial risks.



Source: NGFS (2020)a.

The NGFS (2020)a provided a range of data on transition risks, physical risks and economic impacts, produced by a suite of models aligned and organized as Phase I (see Figure 3). In Phase II, the NGFS will continue to work with academic partners to refine the scenarios and expanding the set of macroeconomic indicators.

Also, on June 2020, 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 steps 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 CB's own balance sheet, focusing on credit and market risk analysis and stress testing. This would support managing risks to own operations and communicating exposures according to TCFD standard (the Financial Stability Board Task Force on Climate-related Financial Disclosures).

Figure 3- Summary of the key aspects of NGFS Climate Scenarios - Phase I.

Comparison	Chronic climate impacts	Transition pathways
Scenarios[2]	**Orderly** (*Representative:* Immediate 2°C with CDR [GCAM]. *Alternate:* Immediate 2°C with limited CDR, Immediate 1.5°C with CDR) **Disorderly** (*Representative:* Delayed 2°C with limited CDR [REMIND]. *Alternate:* Delayed 1.5°C with limited CDR, Delayed 2°C with CDR) **Hot house world** (*Representative:* Current policies [MESSAGE]. *Alternate:* Nationally Determined Contributions)	
Models	Models participating in the ISIMIP project.[3]	3 Integrated Assessment Models (REMIND-MAGPIE 1.7-3.0, GCAM 5.2, MESSAGEix-GLOBIOM 1.0)
Database	ISIMIP	IIASA
Outputs	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
Time horizon	All variables are projected on incremental steps of 5 years, up to 2100	

Source: NGFS (2020)a.

Currently, to perform the ERA is still a big challenge. The analysis involves the identification of environmental factors and the evaluation of the 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 withing the IR management are further detailed in section 5, dedicated to a Green SAA. As an example, transition scenarios may consider complex climate-economy models as IPCC (2014) or IEA (2016). Some ERA tools already in use to manage the financial risks associated with environmental risk factors are detailed in figure 4.

Figure 4- Summary of Case Studies on ERA.

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 transitions risks on SAA	Integrated assessment model incorporated in asset allocation investment model	Median additional annual returns to 2050
Physical (Climate Change)	Assessing physical effects of climate change on sovereign issuers	Consideration of climate change factors within Sovereign Rating Model	Assessment of susceptibility of sovereigns to climate change risks

Source: prepared by the authors, based on Bank of England, UNEP and CISL 2017.

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 depend upon the asset classes and risk type exposure. For instance, fixed income investors may be most concerned with credit risk. In addition, especially for longer-dated securities, the impacts of environmental factors on future cash flow analysis receive more attention, including in rating decisions. Examples of ERA at individual asset, portfolio and systemic levels are summarized in figure 5:

Figure 5- Examples of ERA at individual asset, portfolio and systemic levels.

	Market risk		Credit risk		Financial system	Economy Wide
Analysis level	Asset	Portfolio	Asset	Portfolio	Systemic	Systemic
Environmental factor in focus	Transition: climate regulation and introduction of carbon price	Identify high-risk factor	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

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

The sovereign credit risk is particularly relevant for the management of IRs due to the large share of sovereign bonds in the CBs investment portfolios, as detailed in the next section. The Moody's Investor Service (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 migrations due to severe climate impacts in their homelands.

Battiston and Monasterolo (2019) developed a climate risk assessment methodology under uncertainty to price climate risk of sovereign bonds' portfolio. 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 integrate them in a climate enhanced financial pricing model for sovereign bonds. Third, the authors introduced climate in the calculation of the bonds spread considering specific country's debt conditions and the carbon-intensity of revenues. Finally, the authors assessed the largest losses (gains) on the Austrian National Bank's portfolio. The conclusion was that investments alignment to a credible 2C trajectory can strengthen the sovereign fiscal and financial position by decreasing the climate spread, while a misalignment to 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 analysis of their portfolios in line with the recommendations of the TCFD- Task force on Climate-related Financial Disclosure (UNEP-FI, 2019). The investors explored, enhanced and applied the Carbon Delta methodology to road-test a 'Climate Value at Risk' (CVaR) for listed equities, corporate debt and real estate under several future scenarios. Inputs to SAA decisions are further detailed in section 5, dedicated to a Green SAA.

Also, a BIS (the Bank of International Settlements) and Banque de France (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 which 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.

Based on the concepts presented so far, the ERA synthesis is comprised of the stages presented in figure 6:

Figure 6- ERA Framework from Theory to Praxis.

ERA components:	Sub Components:	References:
1)Environmental risk factors:	Physical	Andreeva, N, Voysey, A. (2016); Bank of England, UNEP and CISL (2017); Campiglio et al (2018); Dafe and Volz (2015); IPCC (2013 and 2014); FTSE Russel (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); CISL (2015); Lamperti et al (2019); McKinsey (2020); Mercer (2011); NGFS (2020)a; NGFS (2020)b; TCFD (2017) and Scott, Huizen and Jung (2017).
	Regulation, carbon-market and other transition ones	
3) Risk assessment tools in each impact dimension:	Financial (business, market and credit)	Andreeva, N. and Voysey, A. (2016); Battiston and Monasterolo (2019); Bank of England, UNEP and CISL (2017); Benedetti et al (2019); Bolton et al (2020); CISL (2015); Dietz et al (2016); G20 GFSG (2016 and 2017); Moody´s (2016); UNEP-FI (2019); WWF (2017).
	Reputational	
	Systemic	

Source: prepared by the authors.

3. The International Reserves (IRs) Management

The objectives of IR management vary among CBs and among portfolios within the same investment manager. For some of them, the main objective is to hold liquid and safe FX assets for forex 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 over 30 IRs managers, the primary investment objectives of IR management is capital preservation (74% of the answers), liquidity (52%), and 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 in 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 IRs management, 94% of respondents included Supranationals in their list, which was followed by Sovereign Eurobonds (85%), US Agencies (85%), Inflation Protected Bonds (73%), Corporates (61%), Asset-Backed Securities (ABS)/ Mortgage-Backed Securities (MBS) (58%), Covered Bonds (45%), Banks Debt (45%), Emerging Market (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 (i.e. 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 of the IRs are primarily composed by US government debt, i.e. US Treasury bills (McCauley, 2019 and Jeanne, 2012). The RMB is expected to become a leading reserve currency, on the level of USD and EUR today, according with 38% of over 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 US dollar and euro, baskets of currencies called the Special Drawing Rights (SDR) are also present in IR portfolios. SDR are foreign-exchange reserve assets created by the International Monetary Fund. Since 2015, the SDR currency basket consists of five currencies: the US dollar (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 about CBs' portfolio management (2019) divides the CB´s investments in four typical portfolios, as detailed in the figure 7. The IRs would be mainly found in

the policy portfolio but, depending on the CB´s legal mandates, the third-party portfolio may also be the case (i.e. when the CB manages IR on behalf of the government). An idea of the representativeness of each portfolio for the whole CBs community may be based on the status of the 27 respondents of the NGFS SRI portfolio management survey 2019 (NGFS, 2019b). In total, the surveyed CBs manage 68 portfolios: 24 policy portfolios, 12 pension portfolios, 15 third-party portfolios, and 17 own portfolios (two respondents have 2 separate own portfolios). The survey only included pension portfolios that are part of CBs' balance sheets. This means CBs' pension portfolios managed by an independent entity are not represented.

Figure 7: NGFS typical CB portfolios and its characteristics

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).

Source: NGFS (2019)b.

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

4. Green, ESG and SRI considerations in IR management

SRI comprises a broad range of sustainable investment strategies, including ESG criteria (NGFS, 2019)b. It incorporates ESG factors into investment decisions and active ownership. It considers both how ESG might influence the risk-adjusted return of an asset

and the stability of an economy, as well as how investment in and engagement with assets and investees can impact society and the environment (CFA UK, 2020).

According to the NGFS (2019b), CBs may choose to adopt SRI to mitigate environmental risks in their portfolio, or to create a positive impact on the environment and society alongside financial returns. These objectives can be translated into different investment strategies. Based on NGFS SRI portfolio management survey (NGFS, 2019)b, with 27 respondents, roughly half of them indicate that CBs have adopted, or are considering adopting, SRI principles in the policy portfolios, pension portfolios and third-party portfolios.

In parallel, recent BIS survey focused on ESG investing practices by CBs (Fender et al, 2019). According to this survey answered by 67 CBs, 62,7% of the respondents do not include sustainability considerations in the pursuit of its policy objectives (related to one of the four types of portfolios managed by CBs, as stated by NGFS). However, 62,7% think there is scope to include sustainability as a reserve management objective.

According to UBS (2018), 36% of IR managers do not consider sustainable and responsible investment aspects in the IR investment process, while 32% considered but have not implemented yet, 27% consider but only use exclusion criteria, and 5% consider and allocate certain assets accordingly.

In this point, Jones (2018) understood that the ESG concerns are not applicable for IRs managers. This information was presented in a taxonomy proposal of constraints to IR management, but the reasons for this conclusion were not discussed. This understanding contradicts with the other studies detailed in the previous sections of this paper. According to the others, the ESG factors may represent physical and transition financial risks with medium- and long-term impact, thus applicable to IR management.

In the other hand, Clark at al (2015) meta-study categorized more than 200 different sources and found a high correlation between diligent sustainability business practices and economic performance. A total of 80% of the reviewed studies demonstrate that prudent sustainability practices have a positive influence on investment performance. Also, Friede et al (2015) study combines the findings of about 2200 individual studies, searching for a relation between ESG criteria and Corporate Financial Performance (CFP). The results show that roughly 90% of studies find a nonnegative ESG–CFP relation and the large majority of studies reports positive findings. Positive ESG impact on CFP appears stable over time.

5. Green Strategic Asset Allocation (GSAA) and Active Ownership

The SAA is an investment decision taken by asset owners to manage portfolio performance over the long term. In SAA, each of the asset classes presents different opportunities for SRI, ESG and green investors, demanding a multifaceted strategy across the total portfolio. According to Eurosif (2018), the SRI investment policy (also applicable to ESG or green invertors, in an adjusted scope) may vary between exclusions/negative screening; ESG integration; best-in-class; impact investing; norms-

based screening; sustainability themed and engagement and voting, this last one as part of an active ownership investment strategy.

The most prominent sustainable investment strategies adopted by CBs are green bond investments and negative screening for equity and bond holdings (NGFS, 2019b). Also, the best-in-class strategy is applicable (equity and corporate bond), but only within three types of portfolios (own, pension and third-party), not within the policy portfolios. In turn, the ESG integration is applied across all portfolio types, mostly for equity holdings. Further, for impact investing, the NGFS survey indicates that many CBs hold green SSA, corporate and covered bonds in their policy portfolios and own portfolios. Finally, most CB´s which responded to the NGFS survey, apply an engagement strategy within the equity holdings of their own or pension portfolios.

The French and the Dutch CBs (Banque de France and DNB) are already implementing SRI strategies in the management of the IRs.

The Banque de France follows a SRI strategy 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. The Banque de France decided that the investment in dedicated funds should prioritize unlisted funds, as they offer a more direct way to finance the energy and ecological transition. This choice implied a significant change in the Banque de France's SAA, which previously included only listed asset classes. The DNB signed the Principles of Responsible Investment (PRI) for its own portfolios and foreign exchange reserves. 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. 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; 4) voting and engagement (NGFS, 2019b).

According to Fender et al (2019), the integration of sustainability into reserves management by CBs involve "additional trade-offs, turning the classical triad of liquidity, safety and return into a tetrad of reserve management objectives", including the sustainability factor. The authors concluded that "green bonds may not be eligible for the liquidity or working capital tranches of central banks' reserve portfolios", but overall "sustainability objectives can be integrated into reserve management frameworks without forgoing safety and return".

According to the PRI report focused on SAA (2019), it is possible to incorporate ESG investment opportunities and mitigate risks through asset, region, sector and sub asset class allocation. Before that, the asset owners undertake scenario analysis and consider the impact of ESG risks and opportunities on expected risk, return and correlation assumptions. The result of this analysis may lead the review of SAA targets and ranges, including review of the opportunity set, widening the potential investment alternatives universe. However, UNEP-FI investors pilot group members had a different understanding about scenario analysis methodologies informing SAA decisions (UNEP-FI, 2019, p.117).

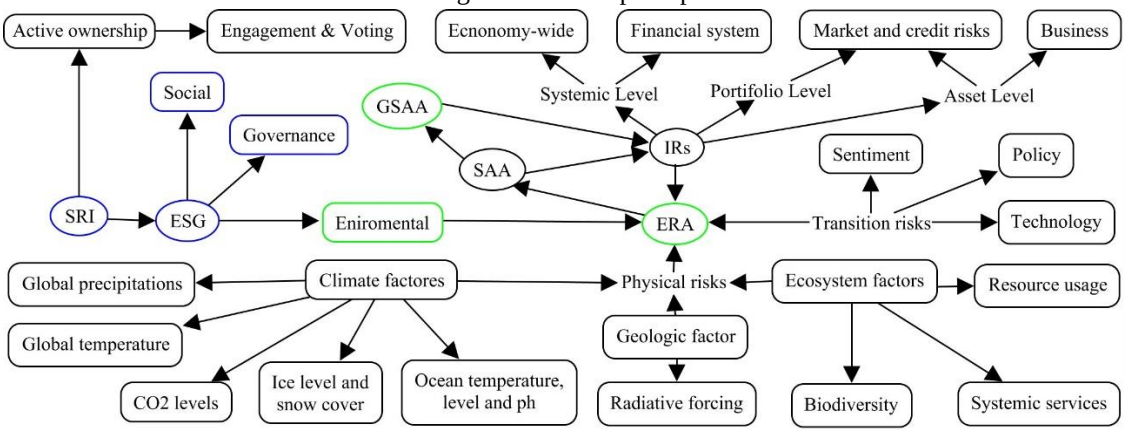
It is critical to each CB to assess the level of reliability required for ERA outputs as an SAA input, considering the relevance of the Environmental Sustainability in the IRs investment policy and the relevance of each investment pillar (Safety, Security, Liquidity + Green Sustainability) for each economic objective of the reserves (Fender et al, 2019). One can then decide to calibrate which asset class is best suited to the four investment pillars given the objective of each portfolio and each CB, in the management of the IRs.

According to the PRI (2019), ESG 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 ESG 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 and rewards at a systemic level.

As stated by Bose et al (2019), despite MPT has facilitated essential aspects of 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 valuable the view that ESG and green investing could involve selecting positive impact securities and selling negative impact securities, generating 'ESG or green alpha' from such security selection. Notwithstanding, it is challenging to implement for largest asset owners, as CBs, given their scale. Finally, the author argues that "investors are beginning to explore new forms of allocation and contracting to ensure the alignment of interest between their long-term goals and the shorter horizon self-interest of financial intermediaries". These initiatives include, for example, new contracts changing control over proxy votes cast, in active ownership investment strategy, exercised through engagement and voting.

Building off the concepts presented so far, the concept map for this study was constructed as follows:

Figure 10: Concept map

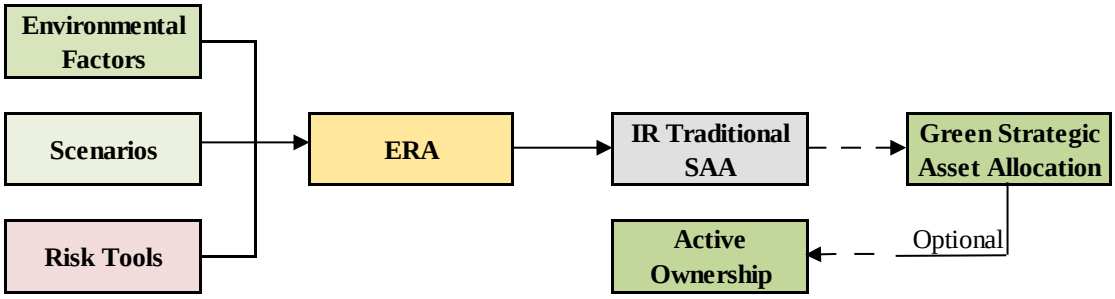


Source: prepared by the authors based on the theoretical references detailed above.

6. The multicriteria analytical model.

The environmental risks to which the investment portfolios of CBs are exposed (section 2) need to be assessed and quantified to enable their management (section 3, 4 and 5). For this purpose, a multicriteria analytical framework for the evaluation of these environmental risks was developed. The output of this ERA model, which is compatible with the investor profile of the CBs, is an input to the IRs traditional SAA model and may lead to a Green Strategic Asset Allocation (GSAA) model and even to an Active Ownership Investment Strategy, as outlined in figure 11:

Figure 11: Multicriteria analytical model for ERA, SAA and SGAA of IRs management



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

The proposed multicriteria analytical framework for ERA on IRs management (figure 12) is based on scenarios analysis to support the assessment of the environmental risk factors and the evolution in time of the associated environmental risk events and trends. The environmental risk factors include both physical and transition risks. The physical risks include the climatic, geologic and ecosystem factors, such as: global temperature; global precipitation; ice level and snow cover; ocean temperature, level and ph; CO2 levels; radiative forcing; biodiversity; systemic services and resource usage. The transition risks include the policy aspects, such as green economy regulations; the technological factors, such as clean energy technology innovation, and changes in the public's and investors' sentiment towards a sustainable future.

Based on the analysis of environmental risk factors and scenarios, the multicriteria analytical model considers the subsequent analysis of the impacts on financial portfolios, including the financial risks, reputational risks and systemic risks. The financial risks are considered in the following dimensions: business, market and credit. The systemic risks include the financial system and the economy-wide risks.

Measures for assessment value and risks include: 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); among others.

The Multicriteria analytical framework for ERA on IRs management, as explained above, is detailed in Figure 12:

Figure 12: Multicriteria analytical model for ERA on IRs management

1) Environmental factors:		3) Measures for assessment value and risks in each impact dimension:					
		Financial:			Reputa-cional:	Systemic:	
		Business:	Market:	Credit:		Financial System:	Economy-wide:
Physical: Climatic Geologic Ecosystem Transition: Policy Technology Sentiment	2) Assessment of environmen-tal risk in time (events and trends), based on scenario analysis.	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.	Reputa-cional risk analysis.	Financial firm´s exposure, size and concentration; system-wide losses on different scenarios.	Impact on GDP, consumption, financial conditions (scenarios, macro models and model based).

ERA

Risk Identification	Financial qualitative analysis of environmental factors.
Risk Analysis	Translating environmental factors into financial risks (transmission channels; general picture of scale and scope; proxies; stress testing, scenario analysis, portfolio and probabilistic modelling etc.)
Risk Management	Actions to mitigate and transfer risks.

Source: adjusted by the authors based on the references from this study, mainly Bank of England, UNEP Enquiry and CISL (2017).

IRs Traditional SAA Model

The output of the ERA model (figure 12) is an input to the IRs Traditional SAA Model (figure 13). It will support the IR investment guidelines based on ERA on the top of the main concerns of the IRs managers. Environmental risk management is not the primary concern of the IRs managers, which is to adequately address the reasons which motivate the IRs existence (which may vary from CB to CB). Hence, the ERA model output addresses environmental risk exposure jointly with the concerns on currency, asset type, countercyclicality and relevance of each of the three investment pillars.

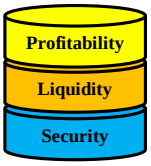
The IRs Traditional SAA Model considers the three investment criteria: security, liquidity and profitability. The relevance of each of the investment pillars depends on the strategic objectives of each IR manager, which ultimately reflect the reasons for which the reserves are being maintained. For example, SWFs can prioritize profitability in 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.

Also, the model includes CBs' IRs preferences on assets (mainly Treasury Bonds, Supranationals, Sovereign Eurobonds, US Agencies, Inflation Protected Bonds, Corporates, MBS/ABS, Covered Bonds and Banks Debt), currencies (mainly American

dollar-USD, Euro-EUR, Chinese Yuan-CNY, Japanese Yen-JPY and Pound sterling-GBP) and the concerns for crisis mitigation (countercyclicality).

The IRs Traditional SAA Model, as explained above, is detailed in Figure 13:

Figure 13: IRs Traditional SAA Model

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		**Asset:** mainly Treasury Bonds, Supranationals, Sovereign Eurobonds, US Agencies, Inflation Protected Bonds, Corporates, MBS/ABS, Covered Bonds and Banks Debt. **Currency:** 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

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

Based on the analysis of the ERA outputs considered in the traditional IR SAA Model, CBs can evaluate the adequacy to adjust the model to include the environmental factor as a fourth pillar of IR management objectives.

To better clarify, ERA is to quantify the exposure and impact of environmental risks for IR assets. SAA is to identify the best risk/return profile for IR allocation according to IR objectives (liquidity, safety, return). GSAA integrates risk/return considerations with ERA, therefore puts together financial and environmental risks assessment in order to provide an asset allocation for IR, which is sound from the two risk viewpoints. Thus, a Green Strategic Asset Allocation model would state as presented in figure 14.

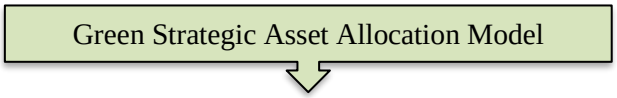
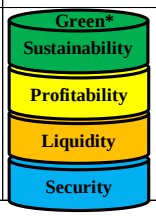


Figure 14: GSAA Model

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		**Asset:** mainly Treasury Bonds, Supranationals, Sovereign Eurobonds, US Agencies, Inflation Protected Bonds, Corporates, MBS/ABS, Covered Bonds, Banks Debt and Green Bonds. **Currency:** 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

*Green or ESG, if in a broader scope.

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

The input to the GSAA Model (figure 14) is the output of the ERA model (figure 12). The decision is supported by CB´s risk tolerance and appetite. Traditional SAA is adjusted by considering environmental risks among asset classes to mitigate them with specific guidelines. The guidelines contemplate the specification of asset classes, currencies, issuers and regions/countries, maturity, liquidity (bid-ask spread, turnover), market depth (outstanding) and other specific environmental variables to achieve an efficient investment portfolio, which may require a multi-objective optimization. These

investment guidelines may direct the partial allocation of the IRs in green assets or indicate a rebalancing among existing assets.

One important step of GSAA, if considered in a broader scope for ESG, is the weighting of the variables among the three sustainable factors: environmental, social and governance. This indicates if the IR management should concentrate the analysis only in climate/environmental issues or in sustainable ones, more broadly speaking.

Also, another important variable is the percentage of the total IR amount to be invested based on the green/ESG criteria, considering risk tolerance and other investment constraints, as well as financial and non-financial motivations. A CB investing with a financial green/ESG objective strives to improve the risk-return profile of the portfolio by considering financially material green/ESG criteria. In turn, the CB investing with an extra-financial green/ESG objective, aims to make a positive tangible impact on society by allocating capital to environmentally sustainable companies or projects, alongside generating financial returns (NGFS, 2019b). Regarding investment limitations, for instance, depending on the size of the total IR amount and the volume to be invested, the market depth may be a constraint.

The investment driver is a key variable to indicate the motivations of the green/ESG investments: diversification; superior returns; institutional reputation; support to green/ESG market growth or green/ESG (e.g.: climate) risk mitigation. This may lead to partial reallocation of IRs portfolio to green/ESG investment alternatives that suit the investor profile of CBs and mitigate their exposure to environmental/ESG risks. Also, CBs may decide to invest in green/ESG assets as a strategy to mitigate the potential economic risks due to global actions taken in order to mitigate and to adapt to environmental/ESG risks (e.g.: changes in the energy matrix with impact in the national economies).

On the other hand, CBs may be careful about green washing associated with the green assets available in the market, linked to other challenges as data gaps, absence of reviewers, market scarcity, or even be aware about the lack of standardization of the green assets available in the market. The green/ESG second opinion providers may minimize the risks associated with the green/ESG investments, as well as the green/ESG data sources, the green/ESG external revisors, the financial data providers and the control procedures stated by the Green Bonds Principles (2018).

The green/ESG investment policy adopted by CB is another variable to be considered, highlighting “exclusions”/negative screening and “green/ESG integration”. In turn, the green/ESG area focus is optional in the model and indicates any specific area of the Green Economy which the CB understand that should be prioritized considering its policies and risk management analysis. If in a broader scope (e.g.: SRI/ESG), it may be related to the United Nations Sustainable Development Goals (SDGs).

The monitoring is important to identify the extent to which the Green/ESG strategy contributes to the specified financial/non-financial investment objectives. As stated in the most recent NGFS report (2019), the risk-adjusted performance of portfolios can be

monitored by indicators such as: tracking error; value at risk; Sharpe ratio and expected shortfall, compared to the standard benchmark; among others.

To sum up, on the top of the data already considered in the traditional SAA model for IRs, the strategical inputs to be considered in a Green/ESG Strategic Asset Allocation Model are details in the following figure 15.

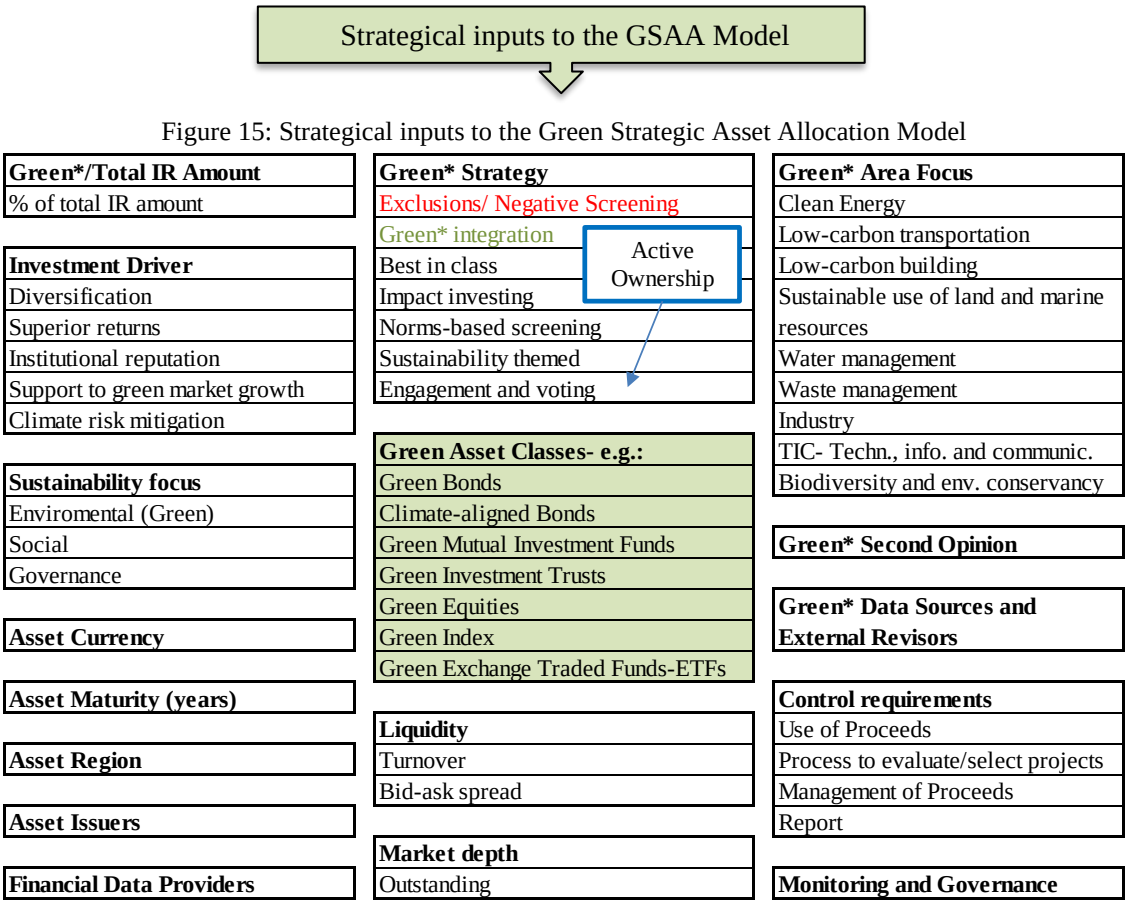


Figure 15: Strategical inputs to the Green Strategic Asset Allocation Model

*Green or ESG, if in a broader scope.

Source: prepared by the authors based on NGFS, 2019; PRI, 2019; Climate Bonds Initiative, 2018; Eurosif, 2018; Green Bonds Principle, 2018; European Commission, 2016 and other references detailed in this study.

The multicriteria analytical model for ERA on IRs management (figure 12) allows the identification of the main concepts, relationships and tools to be considered by the CBs. On the top of it, the model supports the inclusion of the ERA outputs in the SAA analysis of the IRs by the CBs, jointly with the GSAA Model (figures 13, 14 and 15).

A short example of how applying 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 Supranationals in an asset/liability management approach. Furthermore, consider also that the CB decides to have a small amount of IRs invested in assets that are positive correlated to the oil prices, in order to hedge its exposure to the commodity. An ERA should consider the transition effects related to climate change, which may constraint the emission of CO2 by countries, reduce oil prices and increase clean energy ones. In this case, the ERA may show that the real

exposure to the country is energy instead of oil 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. Also, 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 application of the framework discussed here.

7. 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 of environment risks along 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 evaluating countercyclicality to market movements, the CBs should also take environment risk into account.

This study only addresses the environmental aspects of the ESG factors. Also, this research focus is the environmental and financial risk management, not the non-financial investment objectives as "to create a positive impact on the environment and society alongside financial returns" (NGFS, 2019)b.

The framework outlined in this research opens many possibilities for further studies. The major challenges are scenarios analysis and the evaluation of their impacts on portfolio allocation. The link between portfolio evaluation and the multicriteria problem for decision making presents an additional challenge. Also, the agreement on a taxonomy or principles for green activities and related assets are a challenge as well. Further studies may also contemplate the social and governance factors of the ESG triad. Additionally, further research may explore a third dimension of analysis named maximize "real world impact", alongside the risk/return analysis (PRI, 2019), as well as the fourth pillar (related to sustainability) in the current reserves management objectives triad: liquidity, safety and return (Fender, Sahakyan, McMorrow and Zulaica, 2019).

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