Central Banks and Sustainability: A Comprehensive Review of Green Mandates, Speeches, and Actions*

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In recent years, public attention to environmental issues, particularly climate change, has grown significantly. This increased awareness has prompted both public and private entities to take various actions, with central banks around the world being no exception. In most cases, the initial motivation for central banks to begin integrating environmental concerns into their policies has

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been the financial stability risks posed by environmental factors. However, as the discourse evolves, there is also an emphasis on how monetary policy should integrate climate change and environmental considerations. This paper aims to examine the various ways central banks are addressing these issues.

Our study explores central banks' responses to environmental challenges in three key areas: the integration of environmental issues into central bank mandates, the discourse among central bankers on this topic, and the practical actions central banks have taken in this realm. We accomplish this by thoroughly reviewing the formal mandates, public discourses, and practical actions of numerous central banks. We begin by compiling the official mandates of 125 central banks (123 countries and two monetary unions), classifying them based on their approach to climate-related risks and support for mitigation and adaptation policies, and analyzing how these differences relate to various country-level factors. Next, we analyze the timing and content of 290 speeches addressing climate change issues from 24 central banks (including those of G20 countries), conducting a Topic Modeling Analysis (TMA) to scrutinize the prevalent themes in these speeches. Finally, we examine the "green" actions implemented by central banks in two ways: first, by analyzing the specific topics covered by 361 green papers from 44 central banks and, second, by documenting and classifying various activities and initiatives undertaken by 125 central banks, for which we compute a bank-specific "greenscore" metric to measure the extent of their involvement in diverse environmentally conscious initiatives.

Our main findings can be summarized as follows: Firstly, central banks are progressively incorporating environmental themes into their mandates, either explicitly or implicitly, often aligning their policies with the guidelines provided by national governments or supranational organizations. An outstanding example is the case of the central banks within the European Union. Secondly, based on our analysis of speeches, we find that central bankers have increasingly addressed environmental issues in their speeches, though since 2022—coinciding with the rise of inflation—these references have notably declined. Thirdly, as we analyze the research conducted by central banks on environmental matters, we find a significant increase in research papers addressing various green topics, which we interpret as indicative of a heightened interest in gaining a deeper understanding of environmental challenges and exploring the potential roles that

central banks can play in addressing them. Finally, our assessment of concrete actions reveals a greater degree of activity among central banks in wealthier and larger countries and identifies a negative correlation between the level of environmental engagement by central banks and certain country characteristics, such as inflation and reliance on natural resources. Additionally, we observe heightened environmental participation in countries with robust democracies and greater exposure to environmental risks. Surprisingly, we find weak or negligible connections between central bank mandates and their environmental initiatives. Furthermore, the level of central bank independence does not appear to significantly influence their environmental actions.

1. Related Literature

Our paper contributes to the literature on green central banking by providing a comprehensive analysis of central banks' roles and actions in the context of environmental issues, offering insights into the evolving nature of monetary policy in the face of global environmental challenges. For our analysis of mandates, we build upon the work of Dikau and Volz (2021). While their study provides a critical examination of central bank mandates in the context of sustainability—emphasizing legal frameworks and policy implications—, our research delves deeper into the practical execution of these mandates. Their analysis, grounded in the 2017 IMF's Central Bank Legislation Database, is updated in our study to include data up to 2023, with a meticulous examination of each central bank's mandate. We follow these authors in classifying banks based on how their mandates "address climate-related risks and support policies for mitigation and adaptation." Our comparative analysis with Dikau and Volz's (2021) data reveals a more nuanced and gradual incorporation of environmental themes into central bank mandates in recent years, particularly among larger and more independent banks. Interestingly, while Dikau and Volz (2021) assert that central banks should integrate climate-related risks into their policy frameworks, our findings suggest that the existence of such mandates does not consistently dictate the banks' proactive engagement in environmental issues.

Our research makes a distinctive contribution to the limited scholarly exploration of the interplay between discourses and climate change. Neszveda and Siket (2023) explore the impact of the

European Central Bank's (ECB) green speeches on stock returns, taking into account the company's performance in emissions reduction. Meanwhile, Arseneau and Osada (2023) investigate the role of mandates in shaping central bank communication on climate change, employing different methodologies to identify speeches addressing this issue. Our work differs from theirs in two main aspects. Firstly, we pre-filter speeches exclusively focused on climate change issues and extend our sample to include 24 central banks. Secondly, we focus on identifying the most critical communication topics and their temporal dynamics, irrespective of mandates or market-impact considerations. We analyze green speeches from central banks employing Natural Language Processing (NLP) techniques to delve into the topics and their temporal evolution. Our study aligns with a growing literature that employs text analysis tools to explore different aspects of central bank documents. This literature includes the correlation between mandates and speech sentiment—Bohl and others (2023)—, studying implicit preferences and objectives of central banks—Shapiro and Wilson (2022)—, and employing NLP to extract signals indicating the health of the economy and financial market—Petropoulos and Siakoulis (2021), Park and others (2023), Ahrens and others (2023), Masawi and others (2014). Similar to our paper, Feldkircher and others (2021), Warin and Sanger (2020), and Carboni and others (2020) also employ text analysis to delve into the messages conveyed and underlying themes of central bank speeches.

In addition, we review the environmental actions reported by central banks on their official websites until November 2023. This review, detailed in Section 4, focuses on: (a) participation in international climate change initiatives (e.g., the Network for Greening the Financial System—NGFS); (b) research, organization, and participation in workshops; (c) development of "green" statistics; and (d) actions to mitigate negative impacts within the banks' internal operations. Based on this information, we introduce a "greenscore" metric in our study, which provides a comprehensive and multidimensional analysis of central banks' responses, encompassing both their actions and discourse. This approach not only extends the discussion initiated by Dikau and Volz (2021) but also sheds new light on the complex interplay between theoretical commitments and practical actions in the domain of green monetary and financial policies. We also use NLP to analyze the core topics in climate change research papers published by central banks. Inspired by works from different branches

of knowledge,[1] our aim is to uncover the five main research themes and track their temporal evolution. The ultimate goal is to examine the mandates of central banks, scrutinize their communications, delve into their research focus, and study the coherence between these actions.

To some extent, this work is conceived as a complementary initiative to the extensive survey conducted by members of the NGFS in the second half of 2022.[2] Published in July 2023, the survey results encompass responses from approximately two-thirds of the NGFS members, exploring areas such as physical impacts, the transition to a net-zero economy, the integration of climate variables into macroeconomic models, and climate considerations in monetary policy operations. Our contribution, in this regard, lies in the analysis of publicly available information extracted from the websites of each central bank. The challenge is twofold: on the one hand, the immense heterogeneity in the ways information on climate change is published meant a meticulous site-by-site search; and, on the other hand, it involves considerable effort in the systematization and organization of the information for subsequent analysis.

The structure of this paper is as follows: Section 2 analyzes environmental issues within central banks' mandates. Section 3 examines central bankers' speeches on this topic. Section 4 explores the actions taken by central banks regarding environmental issues. As a result of this section, we propose the green-score involvement measure to provide a quantitative assessment of features defining a bank's green involvement actions. Finally, Section 5 provides concluding remarks.

2. Mandates: Central Banks' Formal Responsibilities Concerning the Environment

The question of whether central banks should engage in environmental matters is increasingly pertinent. Central banks are generally governed by specific legislation that defines their mandates—the objectives that justify their actions and the main instruments for achieving these goals. Typically, these mandates prioritize inflation control and financial stability. Some argue that fulfilling these primary objectives justifies central banks' involvement

1. See for example Anupriya and Karpagavalli (2015), Sun and Yin (2017), Choi and others (2017), and Cho and others (2017).

2. As of 13 June 2022, the NGFS consisted of 127 members and 20 observers.

in environmental issues due to their potential impact on prices and financial stability. Others believe that central banks' responsibility towards environmental concerns should be explicitly stated in their mandates. This section analyzes the extent to which environmental issues have been formally incorporated into the mandates of monetary authorities.

Our analysis aligns with that of Dikau and Volz (2021), who examine how climate change mitigation and adaptation policies fit within central bank mandates. Utilizing the IMF's Central Bank Legislation Database (2017 version), these authors analyze the mandates of 135 monetary institutions globally,[3] classifying these mandates based on their approach to climate-related risks and support for mitigation and adaptation policies.[4]

Building on this approach, our work updates the categorization of mandates. Unlike Dikau and Volz (2021), who rely on information included in the IMF's database, we conduct our analysis through direct examination of information made publicly available by the central banks on their official websites. We perform an online search for the legal acts or norms governing each central bank, scrutinizing whether they contain references to engagement in climate change, environmental issues, or sustainable development. Based on this analysis, we categorize the mandates as *explicit*, potentially *implicit*, or *none* (non-mandated).

The database for this section includes 125 central banks (123 countries and two monetary unions), comprising 100 banks from the lists in Tables 1 and 2 of Dikau and Volz (2021),[5] and 24 additional central banks selected for their relevance to our analysis.[6]

3. Dikau and Volz (2021) focus much of their analysis on central banks that have neither explicit nor implicit mandates and find that a majority of these are undertaking some form of "green" action, despite not being explicitly mandated to do so. A relatively smaller share of central banks (25%) are neither mandated nor taking any action.

4. Dikau and Volz (2021) identify three types of mandates: explicit, implicit, and none. Within the last group (non-mandated), they differentiate between central banks that continue to address environmental issues (despite not being mandated) and those that do not.

5. It is important to mention that Dikau and Volz (2021) do not identify the 34 central banks in their study that do not have a mandate (explicit or implicit) and are not actively working on environmental issues.

6. Most of the new institutions analyzed are located in the Americas. A detailed comparison of our work with Dikau and Volz (2021) can be found in Appendix A. The specific list of countries covered in Dikau and Volz (2021) and in our sample can be found in the appendix.

2.1 Classification of Central Banks According to Mandates

After reviewing the websites of these central banks, we classify them into three categories according to their mandates, in line with Dikau and Volz (2021):

1. **Explicit Mandate:** Mandates that actively enhance, promote, or support "sustainability" or sustainable development/growth. A notable example is the ECB, which recently reevaluated its secondary mandates to address climate change issues.

2. **Implicit Mandate:** Mandates that underpin the government's economic objectives or policy goals related to environmental sustainability. Generally, following Dikau and Volz (2021), a potentially implicit mandate is seen as support (not just promotion) for the government's general goals, particularly sustainable economic growth. For example, the German Central Bank's website states: "We are factoring in the effects of climate change on price stability and the stability of the financial system."

3. **Non-mandated:** Mandates that do not address sustainability or related policies.

Within the third group, Dikau and Volz (2021) further distinguish between (a) central banks that address environmental issues without a mandate, and (b) those that neither have a mandate nor mention any related actions on their websites. A clear example of subgroup (a) is the Federal Reserve of the United States (Fed), which has stated it lacks a mandate or adequate tools for environmental issues,[7] yet still undertakes actions to understand the phenomenon and its implications.[8] Our analysis indicates that the percentage of central banks in subgroup (b) (6 percent) is much lower than in Dikau and Volz's (2021) sample (25 percent), which suggests an increasing trend towards greater institutional involvement in these issues.

2.1.1 Changes in the Distribution of Central Banks' Mandates

Comparing the information from Dikau and Volz (2021) with our data collected from the official websites of various financial institutions, we observe a noteworthy shift. The number of central

7. See the speeches of Waller (2023), Powell (2023).
8. See Brainard (2021).

banks with explicit environmental mandates increased from 16 (11.9 percent) to 31 (24.8 percent), as shown in Table 1. This increase is particularly prominent among European economies, reflecting their progression in incorporating environmental aspects into their mandates and missions. This trend towards explicit mandates has resulted in a decrease in the number of central banks with implicit mandates, from 53 (39.3 percent) to 44 (35.2 percent), and those without any mandate, from 66 (48.9 percent) to 50 (40 percent).

Additionally, we extend the characterization of unclassified economies in tables 1 and 2 of Dikau and Volz (2021).[9] We assume that unlisted monetary institutions covered numerically in the study do not engage in climate change activities nor have mandates for such. While direct identification of these economies is not feasible, our examination of the sample suggests an under-representation of economies from the Americas. Out of 27 analyzed economies, three have potential implicit mandates for environmental issues, 20 are engaging in related activities despite lacking formal mandates, and only four appear inactive.

Lastly, Table 2 illustrates the distribution and adjustment of a common sample of 100 central banks across both datasets.[10] The data confirms the increase in explicit mandates and a decrease in those with implicit or non-mandated. Notably, there is no regression in institutional commitment, indicating the growing significance of addressing environmental concerns within central bank policies.

Table 1. Central Banks by Mandate in Each Database

	2020		*2023*	
	N	%	*N*	%
None	66	48.9	50	40.0
Implicit	53	39.3	44	35.2
Explicit	16	11.9	31	24.8
Total	135	100	125	100

Source: Authors' calculations.
Notes: Number and percentage of central banks in each category. "2020" is the estimated statistical closure date for the database by Dikau and Volz (2021). "2023" refers to our database.

9. We are unable to precisely identify the full list of institutions reviewed by Dikau and Volz (2021). Some economies are missing from the list provided in their paper to match the total N of the analysis. Therefore, to enable a more accurate comparison, we have also compiled a sample of countries that align between their database and ours. Table 2 illustrates this match.

10. See footnote 9 for details.

Table 2. Distribution of Central Banks in Both Samples

		2023			
		Explicit	*Implicit*	*None*	
	Explicit	16			16
2020	Implicit	15	38		53
	None		4	27	31
		31	42	27	100

Source: Authors' calculations.
Notes: Distribution of central banks that are present in both databases. "2020" is the estimated statistical closure date for the database by Dikau & Volz (2021). "2023" refers to our database.
Interpretation: From the 53 central banks with an implicit mandate in 2020, we find that in 2023, 15 of them had an explicit mandate, while the remaining 38 kept an implicit one.

2.1.2 Exploring Mandate Determinants

What factors contribute to the differences in mandates among countries? This question, while important, is challenging to answer and extends beyond the strict scope of our research. Nevertheless, in this section, we attempt to identify some determinants (or correlates) of green-related mandates.

First, we explore how mandates are related to various factors that could potentially influence them. Table 3 compares groups of central banks by mandate type (none, implicit, explicit) in terms of population, income, inflation, and the economy's dependence on natural resources.[11] As discussed later in Section 4.4, where we analyze the determinants of central banks' green actions, there are reasons to believe that differences in these socioeconomic variables could influence how green issues are addressed by mandates.

As shown in Table 3, there are significant differences in the population size, income levels, and inflation rates of countries based on the type of central bank mandate. Comparing the median of each group, it is evident that central banks with explicit mandates generally belong to countries with larger populations, while those with implicit mandates are smaller. Regarding income, the implicit mandate group is wealthier, with the median country nearly doubling the per capita income of the non-mandated counterpart. In terms of inflation, the explicit mandate group stands out, with a median inflation rate exceeding that of the other two groups by one percentage point. Finally, economies with implicit mandates tend to be less dependent on natural resources, though the differences are not highly significant.

11. The annual average for each country from 2015 to 2022 is considered for each variable.

Table 3. Mandates and Economic and Demographic Indicators

	Population		*Income*		*Inflation*		*Nat. Res. Rents*	
	Avg.	*Med*	*Avg.*	*Med*	*Avg.*	*Med*	*Avg.*	*Med*
None	85.9	9.6	24.0	15.8	5.0	2.7	3.6	1.4
Implicit	25.9	7.1	30.5	28.5	4.0	2.7	2.8	0.7
Explicit	39.5	13.1	28.1	26.4	9.3	3.7	3.7	1.1

Source: Authors' calculations and World Development Indicators (WDI).
Notes: Avg. and median values of population size, per capita income (in 2017 USD PPP), inflation rate, and natural resource rents (as a percentage of GDP), for countries categorized by central bank mandates.

Econometric Analysis of Central Banks' Mandates

We now conduct a more formal analysis of the determinants of central bank mandates. For this purpose, we run a series of multinomial logistic regressions, where the dependent variable is the categorical variable "mandate", taking values "none", "implicit", and "explicit". As explanatory variables, we include the four socio-economic variables already mentioned, as well as three additional institutional and environmental variables. Details on the variables included in the regressions and the sample are presented and discussed in sections 4.4 and 4.5.

Table 4 presents the corresponding regression results. The outcomes for the "implicit" and "explicit" mandate categories of the dependent variable are reported, with the "none" (non-mandated) category as the reference (not reported). Thus, the coefficients for "implicit" and "explicit" indicate the change in the log odds of a central bank having either an implicit or explicit mandate as compared to having non-mandated, holding all other variables constant. The first regression (columns (1.1) and (1.2)) suggests that the four variables discussed above (income, population, inflation, and natural resource rents) are not very relevant to the probability that a central bank has an explicit, implicit, or non-mandated. The coefficients are generally not significant, with the only exception being the size of the population, which tends to decrease the probability of having an implicit mandate.

In a second regression (reported in columns (2.1) and (2.2)), three institutional and environmental variables are added: the Democracy index, produced by the Economist Intelligence Unit, Romelli (2022)'s Central Bank Independence Extended (CBIE) index, and the index of risk exposure to extreme natural events by *The World Risk Report 2023*. The results now suggest a very significant effect of the degree of

central bank independence, which positively impacts the probability of shifting to an implicit mandate and, especially, to an explicit one.[12] At the same time, an increase in exposure to the risk of extreme natural events decreases the probability of having both an implicit and an explicit mandate.

Table 4. Mandate's Determinants

	Multinomial Logistic Regressions			
Mandate	*Implicit*	*Explicit*	*Implicit*	*Explicit*
(Ref.: Non-mandated)	*(1.1)*	*(1.2)*	*(2.1)*	*(2.2)*
Per capita Income	-0.234	0.179	-0.039	0.265
	(0.324)	(0.377)	(0.366)	(0.506)
Population	-0.279*	-0.08	0.31	0.636**
	(0.149)	(0.155)	(0.243)	(0.282)
Rents from Nat. Res.	-0.473	-0.269	-0.466	-0.062
	(0.298)	(0.353)	(0.360)	(0.419)
Inflation	-0.227	0.419	-0.461	0.228
	(0.403)	(0.380)	(0.459)	(0.449)
Democracy Index			-0.151	-0.012
			(0.203)	(0.204)
CB Independence			3.542**	5.379***
			(1.672)	(2.056)
Risk Exposure			-0.991***	-1.145**
			(0.369)	(0.456)
Constant	3.836	-2.270	0.687	-7
	(3.706)	(4.202)	(4.066)	(5.715)
Observations	101	101	101	101
Pseudo R-squared	0.048		0.166	
Log PL	-102.9		-90.2	

Source: Authors' calculations.
Notes: Robust standart errors in parentheses. (*** $p<0.01$, ** $p<0.05$, * $p<0.1$). Log PL: Log pseudolikelihood. The table presents results from multinominal logistic regressions where the dependent variable is the central bank's environmental mandate: none, implicit, or explicit, with "none" serving as the omitted reference category. Coefficients indicate the change in log-odds of having either an "implicit" or "explicit" mandate relative to "none" for a one-unit increase in the predictor variable.

12. An increase of one standard deviation in the CBIE multiplies by 1.8 the probability of shifting to an implicit mandate, and by 2.5 the probability of shifting to an explicit mandate.

As a partial conclusion from this analysis, these preliminary results suggest that the inclusion (implicit or explicit) of environmental responsibilities in the mandates of central banks does not seem to respond as much to economic or environmental factors but rather may reflect institutional or political aspects. However, as will be seen later in Section 4.5, these changes in the probability of having one mandate or another do not necessarily impact the concrete actions that central banks end up carrying out in response to environmental challenges.

3. Speeches: Central Banks' Discourse on Environmental Issues

In this section, we examine 290 speeches addressing climate change issues delivered by central banks affiliated with the G20, including the ECB. The sample covers the period from 2015 to September 2023. Our analysis has two main objectives: (i) to provide a comprehensive overview of the quantity and temporal distribution of these speeches, and (ii) to conduct a TMA to scrutinize the prevalent themes in these speeches. This entails exploring the recurrent topics, their relative relevance, and how these themes have evolved over time.[13]

3.1 A Temporal Perspective of Central Bank Speeches on Climate Change

Figure 1 presents the evolution of quarterly speeches related to climate change by G20 central banks, including the ECB. Two aspects of this progression are particularly notable. First, there has been an increasing trend in the frequency of speeches. Despite exhibiting significant volatility, this trend becomes more discernible after applying seasonal adjustments. Second, the peak in the volume of speeches occurs in Q4 2021, followed by a decline that coincides with the period of heightened inflation, which may have influenced the central banks' communication focus. Nonetheless, as further

13. The sample exclusively encompasses speeches addressing climate issues written in English from a total of 24 central banks. See the list in Appendix C. The data collection process involved exploring the climate change section on the respective central bank's website. In cases where the website lacked a dedicated section for these topics, a thematic search was conducted through the site's search engine. Additionally, we performed a search through the Bank for International Settlements (BIS) speech repository, a platform that consolidates speeches from central banks on various subjects, directly provided by the banks themselves.

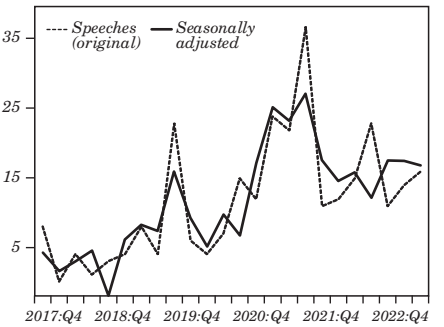
explored in subsequent sections, the volume of research papers and other climate-related initiatives by these central banks continued to grow during this period.

3.2 An Overview of Topic Modeling Analysis

Topic modeling is a suite of algorithms frequently utilized in machine learning and NLP to identify abstract topics within a corpus of documents. These statistical models aim to reveal latent semantic structures embedded in textual data. Topics are conceived as clusters of terms that frequently co-occur across documents, suggesting a shared semantic domain. The underlying premise is that documents focusing on a particular topic will feature related words more prominently than those centered on different topics.

In NLP, the concept of n-grams—a contiguous sequence of n words—is particularly salient. For instance, a unigram refers to a single word, e.g., "economy"; a bigram, to a pair of consecutive words, e.g., "economic policy"; and a trigram, to a sequence of three words, e.g., "federal economic policy". N-gram models predict the probability of the last word in the sequence based on the preceding words.

Figure 1. Central Bank Speeches Related to Environmental Issues



Source: Authors' calculations.
Notes: Speeches delivered each quarter by central bankers from G20 countries, including the ECB. Includes speeches published online in English from Q4 2017 to Q3 2023. Seasonal adjustment performed with X-13ARIMA-SEATS. Based on data collected online.

Topic models extend beyond unigram models, which assume that each word is sampled from a common term distribution. Mixture of unigram models posit that a document is associated with a single topic, with all its words emanating from the corresponding term distribution. In contrast, mixed-membership models, such as Latent Dirichlet Allocation (LDA), permit documents to exhibit multiple topics with varying distributions.

Our analysis employs LDA, a Bayesian framework that groups observations into unobserved subgroups, clarifying the observed data's similarities. This approach assumes that each document is a composite of topics, with each topic being a composite of words. For example, in a model with topics on "monetary policy" and "financial markets", words such as "interest", "inflation", or "currency" may dominate the first topic, while "stocks", "bonds", and "trading" may prevail in the second. Significantly terms can be shared across topics; "investment" might feature in both.

The selection of the number of topics, k, must be determined prior to the analysis and is dependent on the corpus' granularity. Too small a k may oversimplify the semantic landscape, while too large a k could result in overlapping or indistinct topics. Although the literature proposes various methods to ascertain the appropriate number of topics, the final decision hinges on the analyst's interpretive judgment, shaped by their expertise, the data's nature, and the specific objectives of the research.

3.3 Topic Modeling Analysis of Central Bank Speeches

In this section, we use TMA to examine the corpus of speeches in our database. Our objective is to unravel the narratives and communication strategies central banks employ concerning climate change and environmental issues. Moreover, this analysis aims to trace the evolution of these discussions, offering insights into the dynamic discourse of central banks on green matters.

3.3.1 Word Cloud of Central Bank Speeches

We applied an LDA model, identifying six distinct topics.[14] Figure 2 presents word clouds for each topic, illustrating their thematic focus.

14. The number of topics, $k = 6$, was selected after conducting several analyses with varying topic counts, ensuring minimal overlap and optimal thematic distinction.

In Topic 1, prominent words like "risk" and "finance" with "scenarios", "transition", and "understand" suggest a focus on financial risk scenarios and their implications. Topic 2 is populated by terms such as "bank", "financi", "system", "institution", "innov", and "regul", indicating discussions around the institutional and regulatory aspects of the financial system. Topic 3 highlights "green", "sustain", "financ", "invest", "sector", and "develop", aligning with green investments and sustainable finance topics. Topic 4 highlights "bank" in conjunction with "risk", "supervisor", "manag", "action", "plan", "report", and "publish", hinting at themes pertaining to risk supervision within banking systems. Topic 5 centers on "price", "inflation", "energy", and "shock", thus suggesting a focus on inflation-related concerns, particularly those arising from shifts in the energy sector. Topic 6 features "polici", "monetary", and "central", reflecting concerns related to Central Bank monetary policy.

3.3.2 Topics in Green Central Bank Speeches

Table 5 provides an overview of the most probable terms within each identified topic, their respective rankings by probability in the overall collection, and a descriptive label that captures the latent thematic structure.

The topic with the highest average occurrence in the entire collection, at 20 percent, is Financial Risk Scenarios. This is closely followed by Green Investments, and Regulation and Innovation in the Financial System, each with probabilities of around 18 percent and 17 percent, respectively. The fourth and fifth spots are occupied by Banking Risk Supervision and Energy-Related Inflation, each with a probability of about 15 percent. The topic of Central Monetary Policy is in the sixth position, holding a probability slightly below 15 percent.

Significantly, the three topics related to financial matters[15] collectively represent a 53.9 percent occurrence probability in the speeches. This underscores a significant emphasis on financial issues in the analyzed speeches. While the primary focus of this document does not specifically center on financial policy issues, it is important to note that, at least at the discourse level, there is a relatively more substantial presence of topics associated with financial aspects. Our objective is to illustrate that, in terms of communication, these topics

15. Specifically, Financial Risk Scenarios, Regulation of the Financial System, and Supervision of Banking Risk.

have centered on risk scenarios, regulatory issues, and themes related to banking supervision.

Figure 2. Most Frequent Terms by Topics in Speeches Related to Environmental Issues

(a) Topic 1

(b) Topic 2

(c) Topic 3

(d) Topic 4

(e) Topic 5

(f) Topic 6

Source: Authors' calculations.

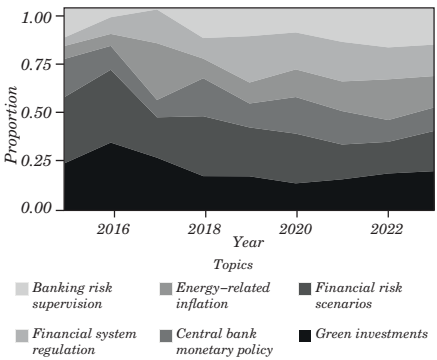
Notes: Word clouds represent the most frequently occurring terms within each of the six identified topics in the analyzed speeches of central bankers. The size of each term in the word clouds corresponds to its relative frequency within the respective topic, visually indicating the prominence of specific terms.

Table 5. Terms and Probabilities of Research Topics in Green Central Bank Speeches

Rank	*Prob*	*Term 1*	*Term 2*	*Term 3*	*Term 4*	*Term 5*	*Latent Structure*
1	0.197	risk	scenario	insur	financi	manag	Financial Risk Scenarios
2	0.178	bank	financi	system	innov	regul	Financial System Regulation
3	0.171	green	financ	sustain	invest	carbon	Green Investments
4	0.164	risk	bank	ngfs	supervisori	manag	Banking Risk Supervision
5	0.150	inflat	price	rate	energi	shock	Energy-Related Inflation
6	0.140	polici	monetari	central	price	bank	Central Bank Monetary Policy

Source: Authors' calculations.
Notes: The table presents the terms, probabilities and ranks associated with topics obtained from the estimation of a Latent Dirichlet Allocation (LDA) topic model (with a k parameter set to six) applied to 290 speeches of a group of G20 Central Banks. The last column includes the likely latent topic structure associated with each topic's terms.

Figure 3. Temporal Evolution of Topics in Central Bank Speeches



Source: Authors' calculations.
Notes: Annual relative proportion of each theme in green speeches produced by central banks between 2015 and 2023.

Temporal Dynamics of Topics in Central Banks' Speeches

The temporal progression of topics is depicted in Figure 3. Notably, the theme of Green Investments initially held significant prominence before 2018 but saw a decline until 2020. This trend reversed post-2020, with Green Investments re-emerging as a predominant theme in central bank communications, especially evident in 2023.

In contrast, the Central Monetary Policy theme shows an inverse pattern. Initially, it had a subdued presence, barring the year 2016. However, from 2018 onwards, it gained increased emphasis until 2020, followed by a gradual decline, making it the least intense topic in 2023.

The focus on energy-related inflationary issues has been ascending in central bank speeches since 2018, peaking in 2022, with a slight decrease in 2023. Notably, this theme was also significantly highlighted in 2017, differing from the earlier years of the analyzed period.

Regarding financial topics, speeches predominantly centered on Financial Risk Scenarios, particularly between 2015 and 2016. While maintaining considerable focus, these discussions gradually shifted towards financial Regulation and Supervision themes. Collectively, these three financial topics—Risk Scenarios, Regulation, and Supervision—make up a substantial part of central bank speeches over time.

In brief, Green Investments and Monetary Policy related to climate change collectively constitute a consistent segment of communication in speeches, comprising close to a third of the relative proportion of topics over time. However, their dynamics since 2018 exhibit a contrary trajectory, marked by a decrease in the Green Investment topic and a corresponding increase in the Central Monetary Policy topic, a pattern that has reversed in the last two years. The broader financial topic occupies nearly half of the relative portion of topics, yet its distribution is heterogeneous over time. The Financial Risk Scenarios topic emerges with the highest intensity; however, starting in 2021, matters related to regulation and, in recent years, financial supervision assume a more prominent role. Finally, Energy-related Inflation demonstrates an escalation in the relative proportion of speeches from 2021 onwards, aligning with the global context of heightened inflation and shocks stemming from geopolitical events.

4. Actions: Central Banks' Initiatives Regarding Environmental Issues

This section examines the specific actions central banks are implementing in response to climate change and related environmental concerns. Our objectives are twofold: first, to identify the range of initiatives undertaken by various central banks, particularly in terms of green research; and second, to devise a central-bank-specific

metric that effectively quantifies these green actions, facilitating a comparative analysis across banks while accounting for factors influencing their environmental engagement.

In line with these goals, the section is structured into two primary segments. The initial segment provides an overview of the primary dimension in which central banks engage with environmental issues: research. The latter segment focuses on evaluating and quantifying the policies and measures central banks have adopted to confront environmental challenges. This analysis leads to the development of a greenscore, which allows for comparisons across central banks. The greenscore encapsulates actions and classifies them into ten distinct categories. Concluding this section, an econometric analysis is conducted to discern the key factors that drive central banks' proactive engagement in environmental matters.

It is important to note that during the information-gathering process for this study, we identified a series of activities and methods employed by central banks in this domain. Each of these actions and research outputs is reported in Appendix D. We encourage readers to refer to this appendix for a better understanding of the genesis of the greenscore.

4.1 Central Bank Green Research

Research constitutes a pivotal area where central banks are integrating green issues into their analytical frameworks. Recognizing that a comprehensive understanding of these emergent topics is vital for the formulation and execution of effective policies, this section delves into the research papers produced by central banks. Central banks' research departments have increasingly focused on producing working papers, particularly regarding climate change. This material forms the core of our discussion in this section.

Our analytical approach is twofold. Initially, we assess the overall volume of literature pertaining to climate change and environmental issues. We trace the evolution of publication frequency over time and its distribution among central banks with different mandates. Additionally, we identify the institutions with the most substantial contributions to this body of work, highlighting the most cited papers within this domain. Following the methodology applied to speeches in Section 3.3, the second phase involves a TMA of paper abstracts. This enables us to elucidate the primary research themes addressed by central banks and track their development over time.

4.1.1 Data and Sample Considerations for Working Papers Analysis

Our analysis focuses on working papers and academic publications related to climate change, primarily published between the 2015 Twenty-first Conference of Parties (COP 21) and August 2023.[16] Our analysis encompasses a subset of central banks previously examined in the mandates analysis,[17] consisting of 44 institutions and a collective total of 361 papers. This selection includes members of the NGFS network alongside additional entities relevant to our study. The complete list of these central banks is provided in Appendix C.

Our manual search process involved a detailed exploration of each central bank's website, focusing on sections dedicated to green and climate change issues. In cases where such specialized segments were absent, we broadened our search to include general research and working papers areas. To enhance our search comprehensiveness, we also employed targeted Google Scholar queries specific to each bank's domain.[18]

For each relevant document identified, we documented its title, abstract, publication year, hyperlink, authors, central bank affiliation, and Google Scholar citation count. When multiple versions of a document were available, we recorded the oldest version and combined citation counts from all versions.

To ensure uniformity and comparability, we included only those publications with English abstracts, such as Spanish-language working papers from the Central Bank of Colombia that have an English abstract. This criterion allowed us to include a broader spectrum of international research while maintaining a consistent approach.

Keywords used in our search included "climate change", "greenhouse gases", "green transition", "adaptation", "renewable energy", "extreme weather", "natural disaster", "carbon emissions", "biodiversity", "Paris Agreement", and "environment".[19]

16. While outside our time range, it is worth noting that some banks engaged in climate research prior to 2015. Examples include the Bank of Nigeria, which published an article about the effects of climate change on its agriculture in 2011 (Apata, 2011), and the Central Bank of Barbados, which presented a paper relating macroeconomic policies and the environment in the Caribbean (Worrell, 1994).

17. See Section 2.

18. We use the "site": operator, for example: ("Climate change" OR green OR sustainable) site: www.snb.ch/en/.

19. Papers that only mentioned these keywords without focusing primarily on climate change-related topics were excluded.

Despite the meticulous nature of our search method, the manual aspect of data retrieval implies that our dataset, while comprehensive, may not encompass every applicable document from the central banks in our study. However, the dataset is representative enough to highlight significant trends and key themes within the central banks' green research initiatives.

4.2 Central Bank Green Research

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4.2.1 Overview of Green Papers

Figure 4a illustrates the trajectory of working and published papers on environmental topics by central banks in recent years. There is a marked increase beginning in 2019, which gains momentum during the pandemic period. The volume of green research documents increased fivefold from 2019 to 2020 and continued to rise into 2023.[20] This trend is evident across all types of central bank mandates, as shown in Figure 4b. The presence of a specific mandate does not necessarily correlate with the volume of research produced. In fact,

20. The observed decline in the number of papers published (solid line) for 2023 is due to the data collection cutoff in September 2023. The dotted line represents a projection of the total annual output, extrapolated from the documents available up to that point.

central banks with explicit mandates for environmental issues tend to have lower publication counts as compared to those without such mandates.

A detailed examination of central banks with extensive publication records reveals that the top ten are primarily European, including the ECB, along with the U.S. Federal Reserve and its regional entities. The list also features the Reserve Bank of India and *Banco de la República* of Colombia. Combined, these institutions account for nearly 70 percent of the research documents in our sample.[21]

Regarding the impact of this research, 74 percent of the total citations, tallying 4,454, display a temporal distribution similar to the paper counts. The 14 most cited papers, each receiving over 100 citations, collectively accumulate 2,560 references. A preliminary review of the titles suggests that the dominant themes are: the impact of natural disasters and climate extremes (1,018 citations), comprehensive reviews and state-of-the-art surveys (692 citations), financial sector-related issues (497 citations), and stress testing and scenario analysis (353 citations).

The relevance and variety of questions motivating the "green" research agenda at central banks are noteworthy, as evidenced by the diverse range of terms and topics these papers encompass. Several studies focus specifically on the role of central banks in mitigating climate change. They explore why central banks should be concerned about environmental issues and assess potential mitigation strategies.[22] Other studies address climate scenarios and financial stress testing. They construct analytical frameworks to quantify the impacts of climate policy and transition risks, addressing various plausible climate change scenarios. These efforts aim to assess the economy's resilience and adaptability within these contexts.[23]

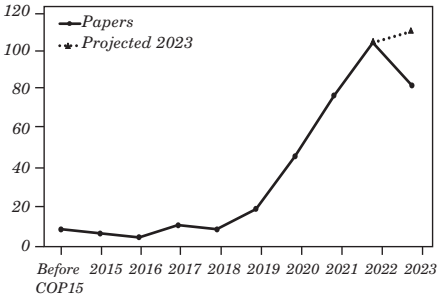
21. Refer to Table C.3 in Appendix C for detailed data.

22. For instance, the work by Arndt and others (2020) highlights the vulnerability of developing economies to climate change and discusses the measures central banks can take to ensure economic stability.

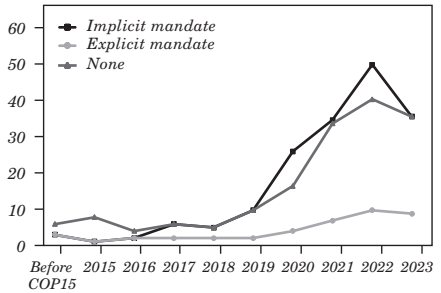
23. For example, Allen and others (2020) propose a framework for France relying on a suite of models, calibrated on the high-level reference scenarios of the NGFS. These scenarios were submitted to a group of voluntary banks and insurance companies to conduct the first bottom-up pilot climate-related risk assessment. In another context, Anvari and others (2022) offer an overview of the modeling frameworks available for assessing climate change impacts in South Africa. This comprehensive examination encompasses both local and global models, providing a thorough understanding of the tools and approaches utilized in assessing the effects of climate change on the region.

Figure 4. Central Bank Papers on Climate Change

(a) Green papers by year



(b) Green papers by mandate and year



Source: Authors' calculations.
Notes: Number of working and published papers addressing climate change or related environmental issues, based on papers with English abstracts published online by a select sample of 44 central banks. The dataset extends up to 2023, with projected figures included for the final year.

In the following section, we provide a more detailed analysis of the variety of topics covered by these papers, offering deeper insight into their content.

4.2.2 Topic Modeling Analysis of Research Abstracts

Venturing deeper into the investigation of central banks' research focuses, we utilize TMA on the abstracts of our research sample.[24] This analysis gauges the prominence of themes and tracks their evolution over time. An LDA topic model with a k parameter set to five was

24. Refer to Section 3.3 for TMA methodology applied to green speeches.

estimated.[25] Just as we did in Section 3, we start by presenting the word cloud for each topic delineated in the analysis.

The word cloud for Topic 1 highlights terms such as "impact", "effect" "disaster", "weather", and "flood". All concepts allude to the Impact of Natural Disasters and the effects of extreme weather events. In Topic 2, the emphasized words include "risk", "financi", "bank", "exposure", "system", and "assess", suggesting a thematic proximity to Exposure Risks within the Banking and Financial System. Topic 3 encompasses terms such as "carbon", "emiss", "energi", "tax", "sector", and "model", collectively encapsulating research related to Carbon Tax Emissions. Topic 4 incorporates terms such as "economi", "polici", "develop", "transit", "global", and "model", indicative of research on Economic Policies for Transition. Finally, Topic 5 is centered around terms like "green", "bond", "market", "firm", "invest", "data", and "environment", whose focus is on investments in the Green Bond Market. Table 6 presents the terms associated with each topic, their probability rankings within the corpus, and a summarizing label for the latent themes.

Table 6. Terms and Probabilities of Research Topics in Central Bank Papers

Rank	*Prob*	*Term 1*	*Term 2*	*Term 3*	*Term 4*	*Term 5*	*Latent Structure*
1	0.247	effect	impact	temperature	disast	flood	Impact of natural disasters
2	0.216	risk	financi	bank	relat	transit	Financial exposure risk
3	0.194	carbon	emiss	energi	tax	sector	Carbon tax emissions
4	0.186	polici	economi	develop	transit	econom	Transition economic policies
5	0.156	green	firm	market	bond	invest	Green bond market

Source: Authors' calculations.
Notes: The table presents the terms, probabilities and ranks associated with topics obtained from the estimation of a Latent Dirichlet Allocation (LDA) topic model (with a k parameter set to six) applied to the abstracts of the 361 green papers in the sample. The last column includes the likely latent topic structure associated with each topic's terms.

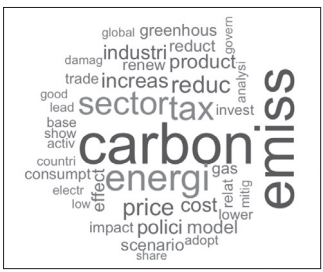
25. Multiple analyses with varying k values were conducted. A $k = 5$ offers a balanced delineation of themes without overlap.

Figure 5. Most Frequent Terms by Topics in Abstracts of Research Papers Related to Environmental Issues

(a) Topic 1

(b) Topic 2

(c) Topic 3



(d) Topic 4

(e) Topic 5

Source: Authors' calculations.

Notes: The *word clouds* display the most frequently occurring terms within each of the five identified topics in the analyzed abstracts of research papers on environmental issues from central banks. The size of each term within the word clouds corresponds to its relative frequency within its respective topic, visually emphasizing the prominence of specific terms.

The probability distribution across the topics is as follows: The Impact of Natural Disasters topic holds a probability of 0.25, indicating an average likelihood of one-quarter presence in each document. The Financial Exposure Risk topic closely follows, with an average

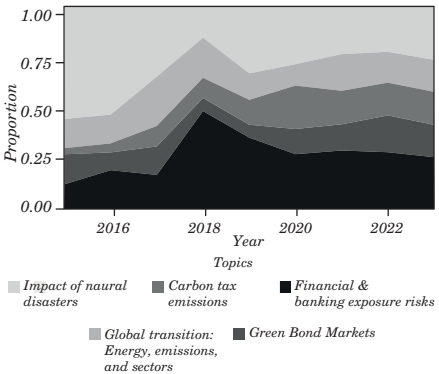
probability of 0.22 within the entire collection. The research topics associated with Carbon Tax Emissions and Transition Economic Policies are both in close proximity, each with a probability of 0.19. Lastly, the topics related to investments in the Green Bond Market are situated not too far behind, with an average probability of 0.16, indicating their likelihood of appearing in the complete collection of documents.

A supplementary method for gauging topic relevance, termed Rank-1, involves determining how often a topic is the most dominant within an abstract. This methodology results in a similar ranking, with slight discrepancies in counts, underscoring the robustness of the identified themes.

4.2.3 Temporal Dynamics of Topics in Green Central Bank Papers

The temporal progression of these topics is depicted in Figure 6, which portrays the annual relative proportion of each theme, indicating shifts in central banks' research focus. The figure elucidates distinct patterns: initial emphasis on Natural Disaster Impact waned after 2017, while research on Financial and Banking Exposure Risk related to Climate Change has surged since 2018. Starting from 2020, there has been an uptick in papers on Carbon Tax Emissions. Meanwhile, the focus on Transition Economic Policies and the Green Bond Market has remained relatively stable, signifying consistent interest since 2015.

Figure 6. Temporal Evolution of Research Topics in Central Bank Papers



Source: Authors' calculations.
Notes: Annual relative proportion of each theme in green papers produced by central banks.

In summary, central banks' climate-related research has predominantly focused on Financial Risk and Natural Disaster Impact, together accounting for nearly half of the identified themes. However, the distribution of these themes has shifted over time, with a recent emphasis on Financial Risk and a decreased focus on Natural Disasters. Other topics such as Carbon Tax Emissions, the Green Bond Market, and Transition Economic Policies have remained steadfast in central banks' research agendas.

4.3 Measuring Central Banks' Green Actions: The Greenscore

Assessing the policies and measures central banks have implemented to address environmental issues poses a notable challenge, primarily due to the difficulty in quantifying these typically qualitative initiatives. This challenge led us to expand upon the work of Barmes and Livingstone (2021), who developed a scorecard to evaluate the "greenness" of G20 central banks and financial supervisors based on their climate change measures. Complementing our extensive analysis of central bank mandates, speeches, and various actions in this paper,[26] we broadened our examination to include "green" policies and measures adopted by 125 central banks. These measures are grouped into ten distinct categories, collectively forming an aggregated indicator that we call the "Greenscore", which is designed to synthesize and quantify central banks' green actions.

The primary aim of the Greenscore is to systematically and clearly represent the contributions of central banks to environmental issues. It facilitates comparative analysis, underscoring the relative engagement of different banks in environmental matters. As a comprehensive metric, the Greenscore encapsulates the wide range and multifaceted nature of green initiatives undertaken by central banks around the world.

4.3.1 Coverage and Selection of Economies

The Greenscore distinguishes itself through its expansive coverage, which includes 125 economies. This extensive inclusion is significant as it provides a comprehensive view of the global central banking

26. See Appendix D for a comprehensive review of actions, activities, and other research outputs in which central banks engage in climate change issues.

landscape in terms of environmental engagement. The criteria for selecting these 125 economies are designed to ensure a sample that is both diverse and representative:

• **Economic Significance**: Priority is given to economies that exert significant economic influence, both on regional and global scales.

• **Geographical Distribution**: A balanced representation from diverse geographical regions is maintained, offering a comprehensive global perspective.

• **Data Availability**: Selection favors economies with accessible and reliable data concerning the environmental actions of central banks, ensuring the Greenscore's accuracy.

• **Diversity of Central Bank Policies**: The inclusion of economies with varied central bank policies and approaches to environmental issues broadens the scope of the Greenscore, capturing a wide array of green initiatives.

4.3.2 Greenscore Methodology

The methodology for computing the Greenscore involved organizing a wide range of central banks' policies and measures into ten distinct areas.[27] These areas are as follows:

1. **Research**: Assesses whether central banks engage in academic research, such as working papers or publications in scientific journals. Detailed in Appendix D.

2. **Reports**: Evaluates the production of documents, speeches, interviews, or press releases by central banks that recognize the significance of climate change on the economy, their related efforts, or progress made. Analyzed in Appendix D.

3. **Education**: Measures educational initiatives addressing climate topics, such as organizing or participating in conferences, workshops, and training sessions.

4. **Statistics**: Checks if central banks compile and disseminate statistical data related to climate change.

27. The process of data collection for the Greenscore was comprehensive and meticulous. It involved a detailed search on the official websites of each central bank, focusing on information available in English and Spanish. This primary search was supplemented with data from the research of Dikau and Volz (2021). Additionally, we expanded our data gathering to include information from reliable sources on the internet. This included reputable local and international institutions, organizations, and media outlets. This broad approach ensured a thorough and diverse collection of data, crucial for accurately assessing the environmental actions and policies of the central banks.

5. **Webpage**: Verifies the presence of a dedicated webpage or section on the central bank's institutional website about sustainability, providing easy access to climate-related materials.

6. **Advocacy**: Identifies central bank participation in organizations that promote sustainability measures, such as the NGFS or the Sustainable Banking and Finance Network.

7. **Monetary Policy**: Includes green policies influencing both directly and indirectly the mechanisms of monetary policy transmission, along with conventional and unconventional policy tools.

8. **Financial Policy**: Encompasses green policies related either directly or indirectly to measures promoting financial stability. For instance, in 2010, the Bank of Lebanon issued a circular to facilitate financing in green sectors by exempting commercial banks from part of the required reserves, thus enabling the financing of these projects at lower costs. Eco-friendly projects include those classified as energy-related and non-energy-related, such as pollution abatement or waste and water treatment. In 2013, the Bank extended a subsidized loan scheme in green sectors by adding a package of USD 331 million.

9. **Leading by Example**: Pertains to institutional commitments and corporate measures undertaken by central banks to lead by example in sustainability. For example, the National Bank of Belgium has undertaken initiatives to quantify and divulge its operational carbon footprint as part of a strategic endeavor to comprehend its environmental impacts. Other central banks, such as De Nederlandsche Bank, have formed dedicated internal committees, like the Sustainable Finance Office, focusing on climate change and Green Finance.

10. **Reserves**: Focuses on the incorporation of green criteria in the management of international reserves. The Central Bank of Brazil, the Central Bank of Norway, the Sveriges Riksbank, and the Central Bank of Trinidad and Tobago have established different frameworks for their international reserve management. These frameworks incorporate sustainability criteria as integral considerations in the processes of counterparty selection and investment decision-making.

For the categories of Monetary Policy, Financial Policy, and Leading by Example, we further distinguish between policies of low, medium, and high impact levels. Similarly, for Advocacy, we categorize measures as low and medium levels. The remaining categories are grouped into a singular level of impact. The detailed classifications and descriptions of each variable used in constructing the Greenscore can be found in Table B.1 in Appendix B.

4.3.3 Greenscore Scoring Methodology

The Greenscore methodology deviates from that of Barmes and Livingstone (2021), who aggregate the total number of measures implemented within each category. Instead, the Greenscore employs a binary scoring system (0 or 1) for each category and its corresponding impact level. A score of 1 is assigned if the central bank has implemented at least one of the policies or measures in that category and impact level, while a score of 0 indicates the absence of such measures.

This binary scoring approach is favored for a couple of key reasons. Firstly, it is less time-consuming, a crucial consideration given the extensive scope of our study, which covers six times the number of economies analyzed by Barmes and Livingstone (2021).[28] Secondly, this method helps to mitigate the natural tendency of central banks in larger or more affluent countries to implement a broader array of measures, attributable to economies of scale in their operations.[29]

4.3.4 Greenscore Computation

The Greenscore is computed by assigning distinct weights to each of the ten categories and their corresponding impact levels. As indicated in Table 7, measures related to monetary policy, financial policy, and reserve management collectively constitute 60 percent of the index. This allocation underscores the significant macroeconomic impact of these measures. Additionally, within these categories, the high-impact measures exert the most substantial influence on the Greenscore.

28. However, there is a possibility that some measures might have been overlooked during the data collection phase. This could be due to the sheer volume of information to process, low visibility of certain activities, language barriers (information not available in English or Spanish), or cases where details of different measures were not distinctly reported.

29. A key distinction from the work of Barmes and Livingstone (2021) is our reclassification of various policies within categories, aiming to more directly reflect those policies that clearly fall within monetary and financial policy frameworks. Furthermore, we have redefined some items within different impact levels for the four corresponding categories, based on the expected impact of the measure. This evaluation considers two aspects: (i) the policy tools available to central banks and their scope to achieve objectives; and (ii) the policy's impact on underlying financial flows. Table B.2 lists the general types of policies and measures within each category by impact level.

Table 7. Greenscore Weights and Impact Level Breakdown

Category	*Weight (%)*	*Impact Level Breakdown*
Research	10	
Reports	3	
Education	4	
Statistics	2	
Webpage	1	
Advocacy	5	Low (33.3%), Medium (66.7%)
Monetary Policy	25	Low (10%), Medium (20%), High (60%)
Financial Policy	25	Low (10%), Medium (20%), High (60%)
Leading by Example	15	Low (10%), Medium (20%), High (60%)
Reserves	10	

Source: Authors' calculations.
Notes: Category weights reflect the relative importance of each category in the overall Greenscore. Impact levels within each category are weighted to differentiate the extent of influence each level has withing its category.

Incorporating these elements, the Greenscore provides a simple yet comprehensive framework for assessing, comparing, and ranking the environmental engagements of central banks across a wide spectrum of economies.

4.4 Exploring Greenscore Determinants

With the Greenscore as an indicator of central banks' actions regarding environmental issues, we now analyze how this metric correlates with other observable institutional, demographic, socio-economic, and environmental indicators at both the country and central bank levels.

4.4.1 Greenscore and Mandates

We first examine the extent to which central banks' mandates[30] are related to their actions. Table 8 shows the average and median Greenscores for groups of central banks with different types of mandates. Central banks with explicit mandates have a significantly higher average Greenscore than others, while no significant differences

30. See Section 2.

are observed between banks with non-mandated and those with implicit ones. This correlation is consistent with the importance that Dikau and Volz (2021) assign to the need for central banks to have explicit goals concerning climate change to advance concrete actions to address it. However, our econometric results, as discussed later in the document, contradict these correlations, suggesting a more nuanced relationship between central bank mandates and their actual engagement with environmental issues.

Table 8. Greenscore and Mandates Breakdown

Mandate	*N*	*Avg.*	*Median*
None	54	20.5	18.1
Implicit	45	21.2	17.0
Explicit	26	25.5	25.1

Source: Authors' calculations.
Notes: Average and median greenscore values across central bank mandate categories.

Table 9. Average and Median Greenscores across Various Economic and Demographic Indicators by Central Bank Mandate Type

	Population		*Income*		*Inflation*		*Nats. Res. Rents*	
	Avg.	*Med*	*Avg.*	*Med*	*Avg.*	*Med*	*Avg.*	*Med*
Low	19.9	19.9	15.6	11.1	31.4	29.3	32.3	31.7
Medium	22.4	22.3	23.3	20.9	22.6	22.7	22.1	22.2
High	30.7	34	34.2	35.5	18.6	13.2	18.2	13.7

Source: Authors' calculations and World Development Indicators (WDI).
Notes: The table presents average (Avg.) and median greenscore values for countries, categorized into terciles. These terciles are based on the average from 2015 to 2022 of four key indicators: population size, per capita income (in 2017 USD PPP), inflation rate, and natural resource rents as a percentage of GDP.

4.4.2 Greenscore and Demographic and Economic Indicators

While the observed correlation between Greenscores and explicit central bank mandates might suggest a direct link, it's crucial to acknowledge the possibility of this correlation being influenced by other socio-economic and demographic factors. Our analysis therefore includes examining the relationships between Greenscores and various indicators that might affect central banks' environmental actions. Particularly, we hypothesize that central banks from larger economies, marked by substantial population sizes or higher per capita incomes, are likely to be more active in environmental issues. This hypothesis aligns with the concept of economies of scale in monetary and financial policy design and implementation, allowing bigger central banks the flexibility to allocate additional resources to secondary objectives like environmental concerns.

In Table 9, we document the evidence supporting this hypothesis. Central banks actively involved in environmental matters tend to be from countries with larger populations and higher per capita incomes. This relationship appears to be monotonic in both cases. These correlations are also visible in Figure 7, which presents scatterplots of the Greenscore against various economic indicators. To ensure that these correlations are not solely driven by Eurozone countries, which generally have higher Greenscores, the figure distinguishes Eurozone countries in black and non-Eurozone countries in gray. The analysis reveals that the positive correlation of the Greenscore with population is pronounced for both groups, while the correlation with income is predominantly observed outside the Eurozone.

Another potential determinant of central banks' engagement in environmental issues could be the inflation rate. Given that central banks' primary mandate is typically focused on price stability, it's reasonable to expect that higher inflation rates could pose challenges in justifying a strong emphasis on objectives that, even if explicitly stated, are often viewed as secondary to the primary mandate.[31] An exception to this might be instances where high inflation is a direct consequence of climate change.[32] However, even in such cases, given that the impact of green policies on inflation is likely to be medium

31. As illustrated in Figure 1, the decline in mentions of climate-related topics from late 2021 could correlate with the significant rise in inflation during the same period.

32. Many advocates for active central bank involvement in environmental matters argue that, if left unaddressed, environmental deterioration will inevitably lead to inflationary pressures, compelling central banks to intervene.

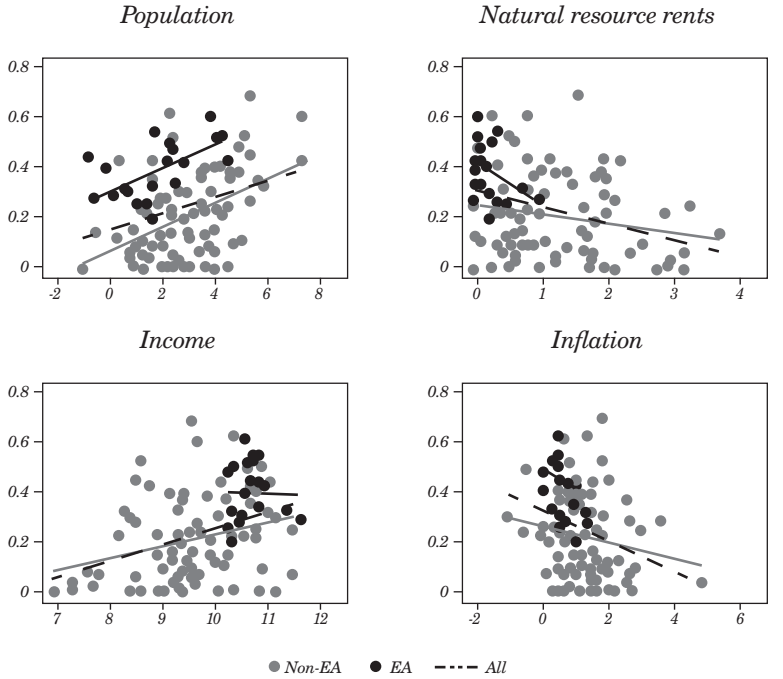
to long-term, central banks might initially focus on addressing the immediate inflationary challenges before re-emphasizing their green policies.

In Table 9, we observe that greenscores tend to be higher in the tercile of countries with the lowest inflation rates in recent years. This score progressively decreases as we move towards terciles with higher inflation rates. This trend is not driven by outliers but is also evident in the median Greenscore of each tercile. The scatterplot of Greenscore against inflation in Figure 7 further clarifies this negative relationship, showing it to be prevalent across all countries, particularly within those of the Eurozone.

Another element that may influence central banks' incentives to integrate environmental initiatives is the economy's dependence on natural resources. The interplay between the Greenscore and a nation's reliance on natural resources offers a multifaceted perspective. Economies heavily reliant on natural resources might prioritize environmental stewardship to guarantee efficient and sustainable utilization of these resources. This prioritization could lead their central banks to enact more proactive environmental policies. However, a counteracting force exists in the short-term incentive to maximize resource extraction, potentially hindering the advancement of green central bank policies.

The data presented in Table 9 indicates a negative correlation between Greenscores and the reliance on natural resources, a trend that intensifies when moving from the second to the highest tercile of natural resource rents as a percentage of GDP. This suggests that economies where natural resource rents constitute a significant portion of the GDP are less active in terms of "green" initiatives. Figure 7 corroborates this finding, showing a negative association between Greenscores and natural resource dependence in both Eurozone and non-Eurozone countries.

Figure 7. Greenscore Correlations with Key Demographic and Economic Indicators



Source: Authors' calculations.

Notes: This figure presents scatterplots illustrating the relationship between the Greenscore (vertical axis) and various socio-economic indicators: population size (in millions), per capita income (PPP USD 2017), annual inflation rate (percentage), and natural resource rents as a percentage of GDP. All variables on the horizontal axis are averages from 2015 to 2022 and are represented in their logarithmic forms to moderate dispersion.

Table 10. Institutional and Environmental Indicators and Greenscore

	Democracy Index		*CB Independence*		*Risk Exposure*	
	Avg.	*Med*	*Avg.*	*Med*	*Avg.*	*Med*
Low	16.5	11.8	23.9	23.3	18.2	13.2
Medium	22.6	21.0	19.5	14.3	21.8	19.6
High	34.0	35.5	29.5	29.8	33.1	35.5

Source: Authors' calculations.

Notes: The table presents average and median greenscore values for countries, categorized into terciles (low, medium, high). These terciles are based on the Democracy Index (Economist Intelligence Unit), the CBIE index of Central Bank Independence (Romelli, 2022), and the index of risk exposure to extreme natural events (The World Risk Report 2023).

4.4.3 Institutional and Environmental Factors Influencing Central Banks' Environmental Actions

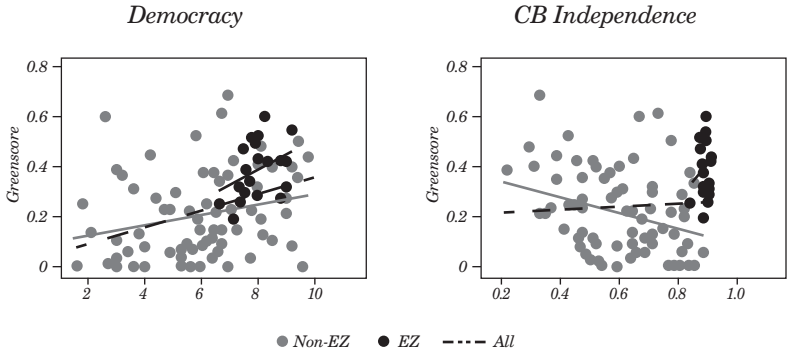
In addition to economic factors, institutional and environmental elements could determine or influence central banks' actions concerning the environment. Here, we examine three such factors: the democracy level of the country, the independence of the central bank, and the country's population exposure to extreme natural events.

Firstly, we assess whether a country's democracy level correlates with how its central banks embrace environmental concerns. There is evidence and arguments suggesting that countries with stronger democracies might be more inclined to embrace environmental policies and rhetoric[33] because democracies often provide more transparent and participatory platforms for environmental policy-making. Democratic governments, accountable to their electorate, might feel more pressure to address environmental issues as public awareness grows. However, there are also counterarguments and many exceptions. Nevertheless, Table 10 suggests a positive relationship between the democracy index of countries and the Greenscore of their central banks. This pattern is marked and consistent across groups with low, medium, and high democracy indices, as well as the average and median democracy index. Figure 8 visually confirms this regularity for both eurozone countries and the rest.

We also analyze the extent to which the degree of independence or autonomy of central banks influences their response to climate change concerns. The answer is not straightforward, as it hinges on how independence interacts with other factors like mandate or level of democracy. For example, central banks with greater independence might possess the discretion to prioritize environmental sustainability within their policy frameworks, but this ultimately depends on their specific mandates and the alignment of environmental issues with their primary objectives. In democratic countries, public and political pressure can influence even independent central banks to address environmental concerns. Furthermore, global, regional, or supranational trends and directives can significantly impact this relationship, exemplified by the central banks in the eurozone. Therefore, the relationship between central bank independence and environmental engagement fundamentally depends on each country's unique economic, political, and environmental context.

33. See, for example, the findings of Bernauer and Koubi (2009).

Figure 8. Greenscore Correlations with Institutional Indicators



Source: Authors' calculations.
Notes: Scatterplots illustrating the relationship between the Greenscore (vertical axis) and the Democracy Index (Economist Intelligence Unit), the CBIE index of Central Bank Independence (Romelli, 2022). Variables on the horizontal axis are averages from 2015 to 2022.

Within our dataset, the overarching relationship between central bank independence and the Greenscore is nonmonotonic, as depicted in Table 10. Nevertheless, upon excluding Eurozone central banks, which uniformly exhibit a high level of independence, a pronounced negative correlation emerges, as illustrated in Figure 8. This trend suggests that central banks with higher degrees of independence tend to be less actively involved in environmental initiatives.

Finally, we assess how central banks' green actions relate to environmental risks, specifically whether exposure to extreme events, such as earthquakes, tsunamis, cyclones, or floods, affects their approach. Table 10 shows that central banks in countries with a larger proportion of the population exposed to environmental disasters generally have a higher Greenscore. That is, they are more active in terms of "green" policy.

4.5 Econometric Analysis of the Greenscore

In the previous section, our focus was on assessing the individual potential of various indicators to explain the environmental actions of central banks. In this section, we expand our analysis to jointly consider the explanatory power of these variables with respect to the Greenscore. We run a series of cross-sectional regressions, with the Greenscore on the left-hand side, and different combinations of

regressors on the right hand side.[34] The variables included in our regressions are presented in Table 11.

Using this approach that simultaneously integrates multiple regressors enables us to more accurately gauge the explanatory strength of each independent variable while effectively controlling for the concurrent effects of other variables.

Table 11. Variables description

Variable	*Type*	*Description*
Greenscore	Dependent variable	Self-constructed index ranging from 0 to 100, representing the extent of environmental engagement by central banks.
Mandate indicators	Independent variable	Classification of central banks as None, Implicit, or Explicit, reflecting the nature of their environmental mandate.
Inflation indicators	Independent variable	Countries are categorized into terciles (low, medium, high) based on their average inflation rate from 2015 to 2022.
Socio-economic controls	Independent variable	Log averages from 2015 to 2022 of: Population size (in millions), Per capita income (in 2017 PPP USD), and Total natural resource rents as a percentage of GDP.
Institutional controls	Independent variable	Two indices: (i) Democracy index, from the Economist Intelligence Unit, and (ii) the CBIE index of Central Bank Independence, as defined in Romelli (2022).
Environmental controls	Independent variable	Two components: (i) Index of risk exposure to extreme natural events (as a percentage of the population), from the WorldRiskReport 2023; (ii) Indicator variables derived from selected components of the index. For each specified risk—tsunamis, riverine floods, and cyclones—countries are categorized into terciles (low, medium, high) based on the proportion of their population exposed.
Eurozone indicator	Independent variable	Dummy variable identifying Eurozone countries.

Source: Authors' research.
Notes: The table presents the dependent and independent variables used in the econometric analysis in the greenscore.

34. We use as regressors the variables described in the preceding section.

4.5.1 Results

The results of our regressions, analyzing the Greenscore against a diverse set of controls, are presented in Table 12. For comparison purposes, all regressions were conducted using a consistent sample of 101 central banks. This sample was selected from the larger set of 125 banks for which the Greenscore was computed, ensuring the availability of all relevant regressors for a robust analysis. The chosen approach facilitates a more uniform and comprehensive understanding of the factors that explain the Greenscore.

We begin our analysis with a specification wherein the mandate serves as the sole explanatory variable, apart from the constant present in all regressions. Column (1) of Table 12 reveals that mandates, when considered in isolation, do not show significant explanatory power with respect to the Greenscore.[35] While the direction of the coefficient signs aligns with our preceding discussion in Section 4.4.1, they do not attain statistical significance.

In Regression (2), we incorporate additional controls for income, population, reliance on natural resources, and inflation. Consistent with the anticipations set forth in Section 4.4.2, a positive correlation emerges between the Greenscore and both a country's income level and population size. The coefficients, significant at the 1-percent level, indicate that a 2.7-fold increase in these variables is associated with an increment of 5.5 points in the Greenscore for income and nearly 5 points for population (from a maximum of 100). Conversely, a similar increase in the proportion of natural resource rents is linked to a 6-point reduction in the Greenscore. Furthermore, the results confirm that central banks in countries experiencing medium and high inflation have a Greenscore 6 to 7 points lower as compared to their low inflation counterparts.

In Regression (3), as detailed in Table 12, we further incorporate institutional and environmental controls. With these additions, per capita income's influence marginally diminishes, while inflation (both medium and high levels) emerges as a more robust predictor of the Greenscore. Consistent with the observations in Section 4.4.3, a higher degree of democracy is found to correlate positively with the Greenscore, exhibiting a statistically significant coefficient at the 5-percent level. However, it is noteworthy that neither central bank independence nor risk exposure to environmental hazards exerts a discernible impact on the Greenscore.

35. In all regressions, only results for implicit and explicit mandates are reported, relative to the excluded base category "None".

Table 12. Greenscore's Determinants

	(1)	(2)	(3)	(4)	(5)
I(Implicit Mand.)	-1.50	-2.03	-0.47	-2.95	-4.43
	(4.14)	(3.53)	(3.80)	(3.64)	(3.36)
I(Exp. Mand.)	1.33	1.27	2.74	0.12	-2.94
	(4.31)	(3.50)	(3.91)	(3.88)	(3.68)
Per capita Income		5.53***	3.22*	3.61*	2.46
		(1.76)	(1.76)	(1.93)	(1.85)
Population		4.73***	4.36***	2.51**	2.98***
		(0.95)	(1.26)	(1.17)	(1.11)
Democracy Index			2.3**	2.25**	1.89*
			(1.04)	(1.07)	(1.03)
Nat. Res. Rents		-5.98***	-4.29**	-4.17**	-3.16*
		(1.82)	(1.88)	(1.87)	(1.87)
CB Independence			-1.32	-1.38	-17.1*
			(9.79)	(9.19)	(8.98)
Inflation					
Medium		-7.25**	-8.77**	-5.64	-3.28
		(3.61)	(3.57)	(3.71)	(3.41)
High		-6.31	-7.32*	-6.62*	-5.22
		(3.95)	(3.89)	(3.64)	(3.32)
Risk exposure			1.26		
			(1.85)		
Tsunamis					
Low				5.31	4.24
				(3.41)	(3.26)
Medium				11.5**	8.96**
				(4.62)	(4.13)
High				8.67	8.13
				(4.36)	(4.07)

Table 12. Greenscore's Determinants (continued)

	(1)	(2)	(3)	(4)	(5)
Riverine Flood					
Low				-1.23	-2.37
				(5.38)	(4.70)
Medium				2.74	1.46
				(5.76)	(5.15)
High				17.6***	13.9**
				(6.56)	(6.31)
Cyclones					
Low				0.274	-0.639
				(5.17)	(4.73)
Medium				-13.60**	-12.40**
				(5.86)	(5.82)
High				-7.1	-6.83
				(5.20)	(5.01)
I (Eurozone)					
Constant	24.6***	-31.4	-25.2	-30.4	-8.91
	(2.70)	(20.40)	(19.90)	(19.80)	(19.60)
Observations	101	101	101	101	101
Adj. *R*-squared	-0.016	0.385	0.405	0.494	0.551

Source: Authors' calculations.
Notes: Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Intrigued by the apparent irrelevance of environmental risk exposure as a determinant of the Greenscore, Regression (4) delves into the specific risks constituting the aggregated index, as detailed in *The World Risk Report 2023*. From our analysis of the index's sub-indices (not reported here), we present only those risk categories that are relevant in explaining the Greenscore, namely, tsunamis, riverine floods, and cyclones. These are introduced as dummy variables indicating low, medium, and high-risk levels, with the base categories (countries with no such risks) not reported. The results reveal that countries with significant portions of their population facing tsunami risks tend to have a higher Greenscore, similar to those with high

riverine-flood risks. Conversely, central banks in countries exposed to cyclones exhibit lower Greenscore levels, a finding for which we currently lack a clear explanation. Regarding the other variables, the influence of inflation is somewhat diminished (with smaller coefficients and reduced significance), while the coefficient for population size decreases in magnitude but remains highly significant. This specific approach, which disaggregates environmental risks, results in a notable enhancement of the model's explanatory power. This improvement is clearly reflected in the increased adjusted R-squared statistics, indicating that environmental risks are a significant driver of central banks' actions. This finding underscores the importance of considering detailed environmental risk factors in understanding the dynamics behind central banks' environmental engagements. Summarizing, our econometric analysis confirms that central banks' mandates are not determinative for their environmental actions. In contrast, factors such as the country's size and income, the level of inflation, and dependence on natural resources are influential. The Greenscore tends to be higher in more democratic countries and, perhaps paradoxically, also in central banks with lesser degrees of independence. It's crucial to consider specific environmental risks, which significantly enhances the explanatory power of our model. Lastly, the results are not driven by the inclusion of Eurozone central banks.

5. Concluding Remarks

This paper employs a comprehensive mixed-methods approach to examine how central banks have incorporated climate concerns into their operations. Firstly, it scrutinizes the mandates of each central bank, assessing whether these legal frameworks act as constraints or incentives for environmental actions. Secondly, it analyzes central banks' speeches to uncover key topics and their evolution over time. Thirdly, the study explores central banks' actions regarding environmental issues: it analyzes research documents on climate issues to understand how central banks focus on climate change and introduces the Greenscore, a green action index that ranks climate actions and facilitates quantitative analysis of central banks' roles in addressing climate change. This multifaceted approach provides a nuanced understanding of central banks' engagement with environmental challenges.

Our analysis reveals a gradual integration of environmental themes into central bank mandates, especially among larger and more

independent banks. While the presence of such mandates does not always lead to proactive environmental engagement, there is a clear pattern of increased focus on climate-related issues in speeches and research outputs. Financial risk and the impact of natural disasters have been predominant research themes, with a recent shift towards financial risk and away from natural disasters.

The quantitative analysis using the Greenscore indicates that factors such as the country's size, income, inflation level, and dependence on natural resources significantly influence central banks' environmental actions. The Greenscore is higher in more democratic countries and, interestingly, in central banks with lesser degrees of independence. Specific environmental risks, such as tsunamis and floods, also enhance the explanatory power of our model.

In summary, there is a growing consensus on the engagement of central banks in environmental issues. More central banks are incorporating this role into their mandates, communicating, conducting research, and taking concrete actions within their operational frameworks. Recent research efforts are focused on understanding and mitigating the impacts of climate change, forming a foundation for new initiatives and policies.

References

Ahrens, M., D. Erdemlioglu, M. McMahon, C.J. Neely, and X. Yang. 2023. *Mind Your Language: Market Responses to Central Bank Speeches*. Available at SSRN 4471242.

Allen, T., S. Dees, C.M. Caicedo Graciano, V. Chouard, L. Clerc, A. de Gaye, A. Devulder, S. Diot, N. Lisack, and F. Pegoraro. 2020. "Climate-related Scenarios for Financial Stability Assessment: An Application to France." Working Paper No. 774, Banque de France.

Anupriya, P. and S. Karpagavalli. 2015. "LDA-based Topic Modeling of Journal Abstracts." In *2015 International Conference on Advanced Computing and Communication Systems*. IEEE.

Anvari, V., C. Arndt, F. Hartley, K. Makrelov, K. Strezepek, T. Thomas, S. Gabriel, and B. Merven. 2022. "A Climate Change Modelling Framework for Financial Stress Testing in Southern Africa." Economic Research and Statistics Department, South African Reserve Bank.

Apata, T.G. 2011. "Effects of Global Climate Change on Nigerian Agriculture: An Empirical Analysis." *CBN Journal of Applied Statistics* 2(1): 31–50.

Arndt, C., C. Loewald, and K. Makrelov. 2020. "Climate Change and its Implications for Central Banks in Emerging and Developing Economies." Economic Research and Statistics Department, South African Reserve Bank.

Arseneau, D.M. and M. Osada. 2023. "Central Bank Mandates and Communication about Climate Change: Evidence from a Large Dataset of Central Bank Speeches." Technical Report, Bank of Japan.

Barmes, D. and Z. Livingstone. 2021. "The Green Central Banking Scorecard: How Green are G20 Central Banks and Financial Supervisors? Technical Report, PositiveMoney, U.K.

Bernauer, T. and V. Koubi. 2009. "Effects of Political Institutions on Air Quality." *Ecological Economics* 68(5): 1355–65.

Bohl, M.T., D. Kanelis, and P.L. Siklos. 2023. "Central Bank Mandates: How Differences Can Influence the Content and Tone of Central Bank Communication." *Journal of International Money and Finance* 130: 102752.

Brainard, L. 2021. "Remarks on the Economic Outlook and Implications for Monetary Policy." Federal Reserve. Speech delivered in Washington, D.C.

Carboni, M., V. Farina, and D.A. Previati. 2020. "ECB and Fed Governors' Speeches: A Topic Modeling Analysis (2007–2019)." In *Banking and Beyond: The Evolution of Financing along Traditional and Alternative Avenues*. London, U.K.: Palgrave Macmillan.

Cho, K.-W., S.K. Bae, and Y.-W. Woo. 2017. "Analysis on Topic Trends and Topic Modeling of KSHSM Journal Papers Using Text Mining." *The Korean Journal of Health Service Management* 11(4): 213–24.

Choi, H.S., W.S. Lee, and S.Y. Sohn. 2017. "Analyzing Research Trends in Personal Information Privacy Using Topic Modeling." *Computers and Security* 67: 244–53.

Colacito, R., B. Hoffmann, and T. Phan. 2019. "Temperature and Growth: A Panel Analysis of the United States." *Journal of Money, Credit and Banking* 51(2-3): 313–68.

Dikau, S. and U. Volz. 2021. "Central Bank Mandates, Sustainability Objectives and the Promotion of Green Finance." *Ecological Economics* 184: 107022.

Feldkircher, M., P. Hofmarcher, and P.L. Siklos. 2021. "What Do Central Banks Talk About? A European Perspective on Central Bank Communication." Austrian Central Bank's *Focus on European Economic Integration* Q2/21: 61–81.

Ferrari, A. and V.N. Landi. 2023. "Whatever It Takes to Save the Planet? Central Banks and Unconventional Green Policy." *Macroeconomic Dynamics* 28(2); 299–324.

Masawi, B., S. Bhattacharya, and T. Boulter. 2014. "The Power of Words: A Content Analytical Approach Examining whether Central Bank Speeches Become Financial News." *Journal of Information Science* 40(2): 198–210.

Motl, M. and J. Tonner. 2021. "Modelling the Impacts of Climate Change on the Global Economy: Stagflationary Shock Looming." Occasional Publications-Chapters in Edited Volumes, in CNB Global Economic Outlook: 13–22. Czech National Bank.

Neszveda, G. and B. Siket. 2023. "Green ECB Speeches Matter." *Journal of Sustainable Finance and Investment* 15(1): 1–18.

Park, J., H.J. Lee, and S. Cho. 2023. "Hot Topic Detection in Central Bankers' Speeches." *Expert Systems with Applications* 230(4): 120563.

Petropoulos, A. and V. Siakoulis. 2021. "Can Central Bank Speeches Predict Financial Market Turbulence? Evidence from an Adaptive NLP Sentiment Index Analysis using XGBoost Machine Learning Technique." *Central Bank Review* 21(4): 141–53.

Powell, J.H. 2023. Remarks on Central Bank Digital Currency. Federal Reserve. Speech delivered in Washington, D.C.

Romelli, D. 2022. "The Political Economy of Reforms in Central Bank Design: Evidence from a New Dataset." *Economic Policy* 37(112): 641–88.

Shapiro, A.H. and D.J. Wilson. 2022. "Taking the Fed at its Word: A New Approach to Estimating Central Bank Objectives using Text Analysis." *Review of Economic Studies* 89(5): 2768–805.

Sun, L. and Y. Yin. 2017. "Discovering Themes and Trends in Transportation Research using Topic Modeling." Transportation Research Part C: *Emerging Technologies* 77: 49–66.

Svartzman, R., E. Espagne, G. Julien, P. Hadji-Lazaro, M. Salin, T. Allen, J. Berger, J. Calas, A. Godin, and A. Vallier. 2021. "A 'Silent Spring' for the Financial System? Exploring Biodiversity-Related Financial Risks in France." Working Paper No. 826, Banque de France.

Waller, C.J. 2023. Remarks on Central Bank Digital Currency. Federal Reserve. Speech delivered in Washington, D.C.

Warin, T. and W. Sanger. 2020. "The Speeches of the European Central Bank's Presidents: An NLP Study." *Global Economy Journal* 20(02): 2050009.

Worrell, D. 1994. "Macroeconomic Policy and the Environment: Choices for the Caribbean." Pages 923–924 of: Seminar on Economic Policy and the Environment, St Kitts. University of the West Indies, Centre for Environment and Development, Barbados.

Appendices

Appendix A: Comparison with Dikau and Volz (2021)

Table A.1. Comparison of our work on mandates with Dikau and Volz (2021)

Dikau & Volz (2021)	*Our work*
Analysis Year: Before 2020	**Analysis Year:** 2023
Original dataset year is 2017.	- Information compiled until the end of September 2023.
Sample: 135 central banks.	**Sample:** 125 central banks.
- Includes 126 institutions and 4 monetary unions. Adds 9 entities not in the IMF database.	- Includes 101 central banks identified in Dikau & Volz (2021) (excludes 34 central banks not identified in their paper).
	- Represents 70% of all central banks and covers more than 95% of global GDP.
Classification of CBs by Mandate:	**Classification of CBs by Mandate:**
- Explicit (Direct), Implicit (Indirect), None.	- Similar to Dikau & Volz (2021).
Sources:	**Sources:**
- Utilizes the IMF Central Bank Legislation Database (based on 2017).	- We review mandates from the original statutory law and official websites.
- Green mandates from IMF Database and other sources.	- Green activities extracted from Dikau & Volz (2021), bank websites, and other reports.
- Central bank websites for updates.	

Appendix B: Greenscore

B.1 Codebook for Greenscore Categories

Research Indicates whether the central bank has conducted research on climate change.

1: Conducted research on the topic.

0: No research on the topic.

Reports Reflects the publication of reports, speeches, interviews, or press releases on climate action or related central bank activities.

1: Issued at least one relevant publication.

0: No relevant publications issued.

Education Promotes educational measures, training sessions, or conference participation/organization on environmental topics.

1: Engaged in at least one educational activity.

0: No educational activities.

Statistics Develops statistics related to climate change.

1: Produced climate-related statistics.

0: No climate-related statistics produced.

Web Presence Maintains a webpage or section on institutional website addressing sustainable development or climate change.

1: Has dedicated online content on the topic.

0: No dedicated online content on the topic.

Advocacy (Low Impact) Engages in low-impact environmental advocacy.

1: Active in low-impact advocacy.

0: Inactive in low-impact advocacy.

Advocacy (Medium Impact) Engages in medium-impact environmental advocacy.

1: Active in medium-impact advocacy.

0: Inactive in medium-impact advocacy.

Monetary Policy (Low Impact) Implements low-impact monetary policies related to environmental concerns.

1: Implemented at least one low-impact policy.

0: No low-impact policies implemented.

Monetary Policy (Medium Impact) Implements medium-impact monetary policies related to environmental concerns.

1: Implemented at least one medium-impact policy.

0: No medium-impact policies implemented.

Monetary Policy (High Impact) Implements high-impact monetary policies related to environmental concerns.

1: Implemented at least one high-impact policy.

0: No high-impact policies implemented.

Fiscal Policy (Low Impact) Executes low-impact fiscal policies targeting environmental issues.

1: Enforced at least one low-impact fiscal policy.

0: No low-impact fiscal policies enforced.

Fiscal Policy (Medium Impact) Executes medium-impact fiscal policies targeting environmental issues.

1: Enforced at least one medium-impact fiscal policy.

0: No medium-impact fiscal policies enforced.

Fiscal Policy (High Impact) Executes high-impact fiscal policies targeting environmental issues.

1: Enforced at least one high-impact fiscal policy.

0: No high-impact fiscal policies enforced.

Leading by Example (Low Impact) Adopts low-impact policies demonstrating environmental leadership.

1: Demonstrated leadership with at least one low-impact policy.

0: No low-impact leadership policies demonstrated.

Leading by Example (Medium Impact) Adopts medium-impact policies demonstrating environmental leadership.

1: Demonstrated leadership with at least one medium-impact policy.

0: No medium-impact leadership policies demonstrated.

Leading by Example (High Impact) Adopts high-impact policies demonstrating environmental leadership.

1: Demonstrated leadership with at least one high-impact policy.

0: No high-impact leadership policies demonstrated.

Reserves Management Incorporates environmental considerations into the management of international reserves.

1: Includes environmental considerations in reserve management.

0: No environmental considerations in reserve management.

B.2 List of Scoring Policies by Impact Level

Advocacy

Level 1: Membership in any relevant international organization related to sustainable economics, other than the NGFS.

Level 2: Membership in the NGFS.

Monetary Policy

Level 1:

• Developing action plans to incorporate climate change considerations into monetary policy implementation.

• Mandatory disclosure of climate-related risks for companies eligible for asset purchase programs.

Level 2: Incorporation of green assets in collateral frameworks.

Level 3:

• Lower interest rates for green loans in financing and refinancing schemes.

• Reduced reserve requirements for green loans.

• Monetary Policy portfolio investments in green bonds.

• Higher interest rates on loans for fossil-fuel-related activities.

• Increased reserve requirements for fossil-fuel assets.

• Monetary Policy portfolio investments exclude or limit investment in fossil-fuel-related activities.

• International reserve management includes sustainability criteria for counterparty selection and investment choices.

Financial Policy

Level 1:

• Publishing guidelines on integrating sustainable finance and developing sustainable financial products.

• Publishing guidelines on incorporating and managing environmental risks.

• Integrating climate risks in regulatory and supervisory expectations, as well as macroeconomic and financial stability assessments.

• Surveys on sustainable finance, climate risks, or climate change.

• Credit schemes including default caused by climate-related events.

• Publishing guidelines for loan programs to sustainable sectors.

• Publishing guidelines for incorporating investments in green bonds.

• Publishing a framework for issuing bonds indexed to climate change indicators.

• Technical support for issuing sovereign green bonds.

Level 2:

• Mandatory disclosure of environmental risks for financial institutions.

• Requirement for financial institutions to incorporate environmental risks into risk management processes.

• System-wide stress testing exercises incorporating environmental risks.

• Incorporating environmental considerations in supervisory review processes.

• Including environmental measures in business outlook assessments.

• Establishing subsidized loan plans for ecological sectors.

• Establishing incentives for investing in environmentally friendly projects.

Level 3:

• Requirement for financial institutions to publish credible zero-carbon goals or carbon emission reduction plans.

• Establishing climate requirements and risk checks that companies must meet for banks to grant loans.

• Requirement for banks to allocate a percentage of sustainable financing to green financing.

• Obligation to implement environmental risk management systems.

Leading by Example

Level 1:

• Measuring and/or disclosing their own carbon footprint in their operations.

• Reducing the carbon footprint in cash production.

• Installing solar panels on their buildings.

• Training courses on adopting climate-related sustainable policies for bank's staff.

• Disclosing environmental risks in monetary and nonmonetary portfolios.

• Disclosing greenhouse gas (GHG) emissions of nonmonetary policy portfolios (NMPP).

• Disclosing climate-related financial information about their NMPP.

• Adopting guiding principles for sustainable finance.

• Voluntary agreements with other entities to promote sustainable finance.

• Sustainable institution certification.

• Commitments made as an institution to address climate change, including a commitment to exclude carbon investments in the future.

• Defining action plans to incorporate climate change considerations into nonmonetary policy application.

Level 2:

- Specialized climate change team.
- Implementation of an internal committee.
- Employee participation in inter-institutional climate-related working groups.

Level 3:

- Investments in green assets from the NMPP.
- Issuance of green bonds in the NMPP.
- Investments in portfolios that include sustainability criteria.

Reserve Management

Level 1: International reserve management includes sustainability criteria for counterparty selection and investment choices.

Appendix C: List of Central Banks for Text Analysis

Table C.1. Number of Speeches by Central Bank

N	*Central Bank*	#
1	European Central Bank	57
2	Deutsche Bundesbank	37
3	Bank of England	34
4	Banque de France	24
5	The Riksbank	19
6	Federal Reserve Board	19
7	Banca D'Italia	18
8	Reserve Bank of India	13
9	Bank of Japan	12
10	Banco de Portugal	9
11	People's Bank of China	9
12	Reserve Bank of Australia	8
13	Bank of Canada	8
14	Banco de Máxico	8
15	Reserve Bank of New Zealand	5
16	Banque de Luxembourg	2
17	Bank of Albania	1
18	Swiss National Bank	1
19	Banco Central do Brasil	1
20	Bank of Indonesia	1
21	Bank of Korea	1
22	Banco Central de la República Argentina	1
23	South African Reserve Bank	1

Source: Authors' calculations.
Notes: List of Central Banks and the associated number of climate related spechees published in the websited and in the BIS speech repository.

Table C.2. Number of Research Abstracts by Central Bank

N	*Central Bank*	#
1	European Central Bank	40
3	Federal Reserve Bank of San Francisco	23
5	Federal Reserve Board	20
7	Deutsche Bundesbank	17
9	Federal Reserve Bank of Richmond	15
11	Reserve Bank of India	14
13	Federal Reserve Bank of New York	10
15	Danmarks Nationalbank	8
17	Bank of England	7
19	South African Reserve Bank	6
21	Bank of Indonesia	5
23	Reserve Bank of New Zealand	5
25	Federal Reserve Bank of Cleveland	4
27	Banco Central do Brasil	3
29	Bank of Korea	3
31	Federal Reserve Bank of Dallas	3
33	Oesterreichische Nationalbank	3
35	Czech National Bank	2
37	Monetary Authority of Singapore	2
39	Banque de Luxembourg	1
41	Federal Reserve Bank of Minneapolis	1
43	Nepal Rastra Bank	1
2	Banca D'Italia	29
4	De Nederlandsche Bank	22
6	Banque de France	18
8	Banque Nationale de Belgique	17
10	Banco de la República | Colombia	14
12	Federal Reserve Bank of Chicago	10
14	Bank of Japan	8
16	Banco de Portugal	7
18	National Bank of Hungary	7
20	Banco Central de Chile	5

Table C.2. Number of Research Abstracts by Central Bank (continued)

N	*Central Bank*	#
22	Bank of Greece	5
24	Banco de México	4
26	Norges Bank	4
28	Bangko Sentral ng Pilipinas	3
30	Central Bank of Barbados	3
32	Federal Reserve Bank of Kansas City	3
34	Bank of Russia	2
36	Federal Reserve Bank of Atlanta	2
38	Sveriges Riksbank	2
40	Federal Reserve Bank of Boston	1
42	National Bank of Georgia	1
44	Reserve Bank of Fiji	1

Source: Authors' calculations.
Notes: List of Central Banks and the associated number of climate related research paper published in English in their websites.

Table C.3. Top Citation Central Banks

Ranking	*Central Bank*	*# Citation*
1	European Central Bank	853
2	Federal Reserve Bank of Cleveland	621
3	Bank of England	563
4	Banque de France	449
5	Federal Reserve Board	426
6	Federal Reserve Bank of San Francisco	398
7	Federal Reserve Bank of New York	327
8	Banca D'Italia	274
9	De Nederlandsche Bank	272
10	Banque Nationale de Belgique	268
11	Danmarks Nationalbank	234
12	Federal Reserve Bank of Richmond	218
13	Bank of Greece	215
14	Reserve Bank of New Zealand	160
15	National Bank of Hungary	151

Source: Authors' calculations.
Notes: List of most cited Central Banks.

Table C.4. Greenscore and Scorecard Comparative Ranking (G20 Central Banks)

Ranking	*Greenscore (2023)*	*Scorecard (2021)*
1	Brazil	France
2	China	Italy
3	France	Germany
4	Italy	Eurozone
5	Japan	United Kingdom
6	Germany	Brazil
7	India	China
8	United Kingdom	Japan
9	South Korea	Indonesia
10	Eurozone	Canada
11	Canada	Mexico
12	Mexico	India
13	Indonesia	South Korea
14	United States	Russia
15	Saudi Arabia	Australia
16	South Africa	United States
17	Turkiye	Turkiye
18	Australia	South Africa
19	Argentina	Argentina
20	Russia	Saudi Arabia

Source: Authors' calculations.
Notes: The table includes the 20 central banks assessed by the 2022 Scorecard, which include G20 countries and the European Union. A comparison is also made with the relative ranking of the same central banks in the 2023 Greenscore. Chile is in 38th place out of 125.

It can be seen that the central banks of countries that ranked highly in the Scorecard also ranked highly in the Greenscore. However, there is a noticeable change in the specific order of the central banks. In particular, the Greenscore shows that the G20 countries making the most progress in the areas they are addressing are Brazil, which is the highest-ranked country, followed by China, France, Italy, and Japan, respectively.[36]

Appendix D: Research Output and Activities at Central Banks

Central banks, beyond their fundamental role in monetary policy, actively contribute to the climate change discourse through a wide array of research outputs. This includes working papers, reports, academic publications, and contributions to conferences, showcasing the diverse approaches these institutions take towards environmental issues. In this section, we present an overview of the various types of research materials and activities central banks are engaging in relative to environmental topics. We start by examining the reports they have published and the events they partake in, before delving deeply into the analysis of paper production and publication. This latter aspect likely represents the most significant and visibly prominent facet of their research endeavors.

D.1 Reports, Activities, and Other Materials

Our analysis in this section encompasses a selection of 38 national central banks, two supranational banks (the ECB and the Central Bank of West African States), and the 12 regional Federal Reserve Banks. The initial set of 18 central banks was selected based on their explicit mandates addressing climate change impacts as stipulated

36. The differences in scores and rankings between the Greenscore and the Scorecard can be explained by methodological differences in the construction of each indicator, as well as by the progress made on the agenda over the past year. For example, according to the Scorecard, most G20 central banks have implemented a wide range of financial policies, which is also one of the components that contribute most to the overall score. If one considers only whether a central bank has adopted at least one measure for each impact level, as the Greenscore does, then the contribution of financial policy to the total score decreases. Therefore, central banks that implement multiple financial policy measures will score lower in the ranking.

in their charters.[37] The rest were included due to their significant contributions to research on climate change impacts.

Although the type and volume of research output vary widely among these banks, it is notable that almost all have produced at least one report or paper addressing climate change. Of the 40 national and supranational central banks in our sample, only four lacked materials related to climate topics available on their website.

D.1.1 Reports

Among the diverse materials produced by central banks on climate change, economic reports are the most common and varied. More accessible and practical than academic papers, these reports are frequently produced and made available by most of the banks in our sample. Given the variety of these reports, topics related to climate change are addressed in a broad manner.

Climate Impacts in Economic Outlooks

Notably, climate change issues are increasingly being integrated into economic outlook reports. A prime example is the Central Bank of Malaysia, which included a section on Climate Change Risks and Opportunities in its *2019 Annual Report*.[38] The Czech National Bank provides another example, incorporating a discussion on climate change models and inflation in its *2021 Global Economic Outlook*.[39]

Complete Reports

Concurrently, there is a growing trend of reports fully dedicated to climate change risks and effects, or broader sustainability issues. For instance, the Central Bank of the Philippines detailed the impacts of climate change in the country in its *2022 Sustainability Report*, outlining the bank's actions and future plans.[40] Similarly, the Central Bank of Brazil annually assesses environmental, social, and governance (ESG) related risks and opportunities.[41] These reports

37. This group includes the central banks of the Czech Republic, Fiji, Gambia, Georgia, Hungary, Iraq, Malaysia, Nepal, Philippines, Russia, Singapore, South Africa, Tanzania, Ukraine, Zimbabwe, and the Central Bank of West African States.

38. Box in the 2019 Annual Report available at the Central Bank of Malaysia's website.

39. See Motl and others (2021).

40. The report is available at the Central Bank of Philippines' website.

41. *2022 Report on Social, Environmental and Climate-related Risks and Opportunities* available at the Central Bank of Brazil's website.

typically focus on green finance, sustainability, or country-specific climate change exposure.

Guidelines

Central banks are also playing a pivotal role in mitigating financial stability risks by formulating guidelines for key stakeholders, particularly in banking and insurance. These guidelines aim to bolster resilience against environmental risks and provide best practices for risk management. Several banks, including those in Zimbabwe, Tanzania, Nepal, South Africa, and Singapore, have been instrumental in developing these guidelines.[42]

Climate Disclosure

Lastly, central banks are beginning to evaluate their own exposure to climate risks by publishing climate disclosure reports. Prominent examples include the central banks of Germany, Denmark, and England, which have taken significant strides in this area.[43]

D.1.2 Events

Central banks play a pivotal role in fostering research and dialogue through organizing a wide range of events, from internal seminars within research teams to large-scale international conferences. These gatherings provide a platform for central banks to convene diverse stakeholders, including academics, think tanks, private sector representatives, international institutions, and peers from other central banks.

In these events, discussions on climate change have been gaining prominence since 2015, reflecting a heightened consciousness and concern about its implications on financial stability and the broader financial system. The increased focus on these topics demonstrates the evolving role of central banks in addressing the intersection of climate change and financial dynamics.

Internal Seminars and Workshops

Central banks have engaged in the organization of internal seminars and workshops, focusing on the assessment of the risks

42. The reports are available at the websites of the central banks of Zimbabwe, Tanzania, Nepal, South Africa, and Singapore.

43. The climate disclosure reports are available at the websites of the central banks of Germany, Denmark and England.

induced by climate change on a variety of topics. While the format and the scope differ across banks, we observe that the frequency of these workshops is increasing. We notice that some thematic annual workshops can cover climate change for a specific year, as illustrated by the 4th International Capital Flows and Financial Policies Workshop, a joint event of the banks of England, France, Italy, the OECD, and the IMF, which focused on climate change in 2023. On the other hand, some workshops have been created especially to tackle climate change issues. This is the case for workshops organized by the Central Bank of Chile, the Bank of Japan, or the De Nederlandsche Bank (DNB), for example.[44]

Conferences

In the same vein, international conferences follow a similar pattern. With a larger scope and a more diverse audience than for workshops, the conferences gather various researchers, central bankers, and policymakers over specific topics. Again, climate change topics are increasingly represented, and in some cases, lead to the establishment of the conference. Examples include the ESG conference of the Bank of Italy in 2023 or the 2022 Caribbean Economic Forum on Climate Change by the Central Bank of Barbados. Interestingly, climate change topics are selected for being the theme of annual conferences of multiple central banks. This is the case for the De Nederlandsche Bank in 2021 or for the Central Bank of Chile in 2023.[45]

D.1.3 Other material

In addition to formal research outputs, some central banks also produce insightful and educational materials to engage with a broader audience. These resources vary in form. For instance, the ECB produces podcasts aimed at the general public to clarify its role and initiatives. Concerning climate change, the ECB offers a

44. Respectively, the Workshop on "Macroeconomic and Financial Implications of Climate Change" in 2021 by the Central Bank of Chile, the International Research Workshop on "Climate-related Financial Risks: Interactions of Climate Change and the Financial System" in 2021 by the Bank of Japan, and the Workshop on "Central Banking and Green Finance" in 2017 by the De Nederlandsche Bank (DNB).

45. The annual conference of the De Nederlandsche Bank in 2021 was entitled "The Economy in Transition: Efficient and Sustainable Policies to Support Business Dynamism" and the one of the Banco de Chile in 2023 was entitled "Implications of Climate Change and Ecosystem Services Degradation for Macroeconomic and Financial Stability."

podcast discussing climate risks[46] and introducing *climate disclosures*. Similarly, the Bank of England has developed an educational series called *Explainers*, which includes explanations on various economic topics such as climate impacts.[47]

Moreover, some central banks have dedicated specific sections on their websites to the topic of climate change. These sections usually provide an accessible overview of climate-related issues, followed by an outline of the actions undertaken by the banks. Notable examples include the central banks of France, England, Italy, and Greece.[48]

Collaboration with External Actors

Central bank research also promotes cooperation with external actors. Of the papers we analyzed, almost half were co-authored by individuals affiliated with institutions other than the central banks. These collaborations often involve academics, but also include researchers from international institutions like the IMF and the World Bank, as well as other central banks. For instance, Colacito and others (2019), a well-cited paper, is a collaborative work between the Federal Reserve Bank of Richmond, the University of North Carolina at Chapel Hill, and the Inter-American Development Bank.[49] Significantly, collaboration extends to experts from fields outside economics, as seen in papers like Svartzman and others (2021) and Anvari and others (2022), which include co-authors from diverse scientific disciplines.

46. The podcast titled *Being Transparent about Climate Risks* is available at ECB Podcast.

47. Two articles on climate change, *How is the Bank of England Responding to Climate Change?* (Bank of England Explainer) and *Climate Change: What are the Risks to Financial Stability?* (Bank of England Explainer), are available.

48. See the respective webpages of the central banks of France, England, Italy, and Greece.

49. See also Ferrari and Landi (2023), initially published as part of the ECB Working Paper Series (No. 2500), with contributions from the ECB, Harvard Kennedy School of Government, and the Bank of Italy.