

1 *Resubmission to Nature Climate Change (Perspective)*

2 **Climate change challenges for central banks and financial regulators**

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5 **[Abstract]**

6 The academic and policy debate regarding the role of central banks and financial regulators in addressing
7 climate-related financial risks has rapidly expanded in recent years. This Perspective presents the key
8 controversies and discusses potential research and policy avenues for the future. Developing a comprehensive
9 analytical framework to assess the potential impact of climate change and the low-carbon transition on
10 financial stability appears to be the first crucial challenge. These enhanced risk measures could then be
11 incorporated in setting financial regulations and implementing central banks' policies.

12 **[Main text]**

13 Achieving the objectives of the Paris Agreement will require a large-scale shift towards low-carbon
14 technologies. However, socio-technological transitions often involve disruptive adjustments, even when they
15 are ultimately beneficial to human welfare.^{1,2} This process of 'creative destruction' is likely to take place also
16 during the low-carbon transition, with potentially significant repercussions on economic dynamics and
17 financial stability.^{3,4} Societies thus face the challenging task of achieving a rapid structural shift to a low-
18 carbon economy, while concurrently avoiding excessive economic losses and safeguarding the stability of the
19 financial system (see Table 1).

20 [TABLE 1 ABOUT HERE]

21 Central banks and financial regulators have started examining the implications of climate change and the
22 low-carbon transition in recent years. In 2015, Mark Carney, the Governor of the Bank of England and
23 Chairman of the Financial Stability Board, first discussed the 'tragedy of the horizon' embedded in the
24 different time spans that characterize monetary and financial stability policies (2-3 years and up to a decade,
25 respectively) and the much longer-term perspective required to deal with climate-related risks.⁵ This was
26 followed by related speeches by other central bankers and regulators.⁶⁻¹² More recently, a group of eight central
27 banks and financial regulators from both high-income and emerging economies have formed a 'Network for
28 Greening the Financial System'.¹³ Researchers in academia, international institutions, and civil society
29 organizations are also investigating the dynamic links between central banks, financial systems and the low-
30 carbon transition.¹⁴⁻²⁰

31 This *Perspective* critically discusses the main features of the debate, and identifies avenues for future
32 research and policy implementation. First, we present the rationale for central banks and financial regulators to
33 be interested in climate and the low-carbon transition. Second, we analyze their potential role in promoting a
34 better understanding of climate-related financial risks. Third, we discuss the appropriate scope of their role in

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35 mitigating these risks. Options range from supporting voluntary risk disclosure by private companies and
36 investors to mitigating climate-related risks, or even actively promoting low-carbon investments. Finally, we
37 discuss how these activities would fit into their current mandates, and present open questions for further
38 research.

39 **Central banks and climate change**

40 Central banks are public institutions with specific objectives determined by their national governments or
41 legislators. They are typically responsible for monetary policy, which influences the supply and the demand of
42 money and credit in the economy. Monetary policy is often aimed at achieving price stability, defined in terms
43 of an explicit inflation rate target. In addition, several central banks also have a mandate to maintain the
44 stability of the financial system and to regulate and supervise individual financial institutions. Additional
45 objectives of central banks may include exchange rate stability, employment creation and economic growth.¹⁸

46 Some central banks have started studying the implications of climate change and the low-carbon transition
47 for the financial sector, primarily due to their responsibility for financial regulation and supervision. Recent
48 research suggests that, in addition to large physical and economic losses, unmitigated climatic change could
49 also affect the stability of the financial system.²¹⁻²³ For instance, the increase in climate-induced *physical risks*
50 (e.g. heat waves, floods and storm surges) could have a direct effect on the insurers that cover them. If these
51 risks are uninsured, the deterioration of the affected households' and corporates' balance sheets could lead to
52 losses for their lender banks.

53 To avoid physical damages and the associated financial instability, a transition to a carbon-free economy is
54 ultimately necessary. However, the transition itself might increase the risks of economic dislocation and
55 'stranded' assets (*transition risks*). For instance, meeting the 2°C temperature threshold will probably require a
56 large portion of existing reserves of oil, gas and coal to remain in the ground^{24,25}, and thus be written off from
57 the balance sheets of the companies that own them. Other physical assets that could lose value include part of
58 the electricity generation capacity, real estate, transportation infrastructure and carbon-intensive industrial
59 technology.²⁶⁻²⁸ Such asset stranding could not only lead to economic losses and unemployment, but could also
60 affect the market valuation of the companies that own these assets, thus negatively impacting their investors,
61 and potentially triggering cascade effects throughout the interconnected financial system.^{4,29}

62 While some disruption at the sectoral level is inevitable, the transition as a whole could represent an
63 opportunity for sustainable and inclusive economic prosperity.^{30,31} However, this is likely to be possible only in
64 the presence of a comprehensive and harmonized set of policies aimed at supporting the low-carbon transition
65 and managing its complex dynamics.

66 The primary responsibility for strategic planning rests with governments, which have a variety of policy
67 options at their disposal. For instance, they can introduce environmental regulations (e.g. standards on fuel
68 efficiency); implement climate-friendly infrastructure investment programs (e.g. smart electrical grids); and
69 design market-based policies to shift the preferences of households and companies towards low-carbon
70 activities. The main proposed policy instrument has been carbon pricing, which could be implemented either
71 through the introduction of a tax on the carbon content of goods and services, or the creation of a cap-and-trade
72 system of emission allowances.^{32,33} Other market-based instruments, such as the introduction of subsidies for
73 clean technologies and a phasing-out of fossil fuel subsidies, also follow a similar logic.

74 Whether a well-designed set of fiscal and environmental policies by the government will prove sufficient to
75 meet Paris climate objectives is subject to debate. Certain market failures existing in financial systems might
76 not be properly addressed by pricing mechanisms, thus providing inadequate incentives to mobilize low-carbon
77 investments at the scale and pace required.¹⁴ More importantly, government climate policies might not by
78 themselves prevent financial instability during the transition; in fact, they might exacerbate transition risks, if
79 implemented too abruptly and without the necessary precautions. Finally, the perception that carbon pricing
80 could damage businesses and consumers often makes it a politically unpalatable choice for governments
81 constrained by the electoral cycle, thus leading them not to act with the strength that would be required to
82 ensure a smooth transition.

83 The complexity of the transition has led researchers to start investigating what central banks and financial
84 regulators could do to support a rapid and orderly transition. The rest of this *Perspective* will critically evaluate
85 the debate over the appropriate scope of their interventions. Four broad types of interventions have been either
86 adopted by, or suggested for, financial regulators and central banks in dealing with climate-related risks. First,
87 they can develop methodologies and tools that would promote a better understanding of these risks and their
88 economic and financial implications. Second, investors can be encouraged or required to disclose their
89 exposure to climate-related risks. Third, these risks can be explicitly taken into account in setting financial
90 regulations. Fourth, central banks can take into account climate-related risks in their policy toolkit (e.g.
91 monetary policy). Table 2 gives an overview of these potential actions.

92 [TABLE 2 ABOUT HERE]

93 **Assessing climate-related financial risks**

94 Some central banks have started assessing the exposure of their domestic financial system to climate-related
95 risks. For instance, De Nederlandsche Bank (DNB) has recently conducted two studies of the Dutch financial
96 system showing that, while the exposure to fossil fuel producers is relatively small, the broader exposure to
97 carbon-intensive sectors is large enough to pose potential systemic risks, and that some of these risks are
98 already materializing.^{26,34} Insurers and banks could also experience significant losses as a result of severe
99 climate-related events. The Bank of England reviewed the exposures of the UK insurance sector to climate-
100 related financial risks in 2015, and is conducting a similar review of the banking sector.³⁵ Other institutions that
101 have examined the potential impact of climate change or the low-carbon transition on financial stability include
102 the European Systemic Risk Board, Sweden’s Finansinspektionen and Banque de France.^{29,36,37} Researchers
103 have also started developing ‘climate stress-testing’ methods, highlighting how exposures among investors can
104 exacerbate the impact of the low-carbon transition on the financial system.^{4,38}

105 However, the assessment of the climate-related financial risks faces various challenges. First, the data
106 required to perform a comprehensive climate stress test are often absent or insufficiently granular, and hard to
107 access for researchers outside financial regulatory bodies. Second, an integrated evaluation of climate-related
108 financial risks cannot rely only on static snapshots: it requires the modelling of the dynamic interactions
109 between the macroeconomy, the financial system, climate change and environmental policies.

110 This is not a trivial task. Integrated Assessment Models (IAMs), traditionally used to study economy-climate
111 interactions, typically lack a representation of the financial system. Despite some exceptions, Dynamic
112 Stochastic General Equilibrium (DSGE) models, often used by central banks in macroeconomic and monetary
113 policy analysis, normally abstract from climate change and environmental policies.³⁹ Moreover, benchmark
114 DSGE models featuring representative agents, rational expectations, and a rapid reversal to equilibrium in
115 response to shocks are not appropriate for assessing the complex and dynamic implications of a large-scale
116 structural change. Analyzing these effects will require a framework which features an accurate description of
117 real and financial interactions between heterogeneous agents, and incorporates the role of fundamental
118 uncertainty in their decision-making process. Stock-Flow Consistent (SFC) and Agent-Based Models (ABM)
119 might provide valuable alternatives.^{40–43} These models analyze the macroeconomy as a complex adaptive
120 system, in which non-linearities and disequilibrium phenomena play a key role. They can also incorporate
121 network effects that stem from the interactions between agents, and are able to represent the process of
122 endogenous money creation by commercial banks through bank loans.⁴⁴ Some central banks have started
123 developing such models, although without an environmental focus.^{45,46} However, these are relatively new
124 methodological approaches and the techniques for estimating and calibrating them are still in development.
125 Establishing a framework, or a plurality of frameworks, for assessing and quantifying the macro-financial
126 impacts of climate change and the low-carbon transition thus remains an area that requires further research.

127 **The push for risk disclosure**

128 A key obstacle to the achievement of a smooth low-carbon transition is the low awareness of companies and
129 investors about their exposure to climate-related financial risks. The majority of companies are not used to

130 assessing how these risks impact their business models, while most investors are unaware of how exposed their
131 portfolios are. The recent international effort has thus primarily focused on improving information flows by
132 supporting the disclosure of climate-related risks by private actors. For example, the Financial Stability Board
133 established a Task Force for Climate-related Financial Disclosures. Its final report makes sector-specific
134 recommendations on how companies could *voluntarily* disclose climate-related financial risks, in order to better
135 inform their investors, lenders and insurance underwriters.⁴⁷ The French Energy Transition law goes further
136 and *requires* listed companies to disclose information on their exposures to climate-related risks and the
137 measures adopted to reduce them, and requests banks to conduct climate-related stress testing on their portfolio
138 of loans and disclose the results.⁴⁸ Several industry- or academia-led initiatives aimed at improving climate-
139 related information available to financial investors also exist.⁴⁹ However, while central banks have been
140 supportive of disclosure of climate-related risks by private firms, to date they have not disclosed the exposure
141 of their own asset portfolios.

142 The support for the development of voluntary disclosure standards is in line with the wider strategy of
143 encouraging the financial industry to appropriately price climate-related risks, while respecting the freedom of
144 enterprise and market dynamics. However, it is still uncertain what the effects of voluntary disclosure will be.
145 Many large investors appear reluctant to request companies to assess and disclose how they would be affected
146 by a 2°C-compliant scenario.⁵⁰ Despite recent progress, climate-related risk disclosures by firms may not
147 become sufficiently comprehensive, meaningful and comparable in the near term. Investors may also fail to pay
148 attention to the disclosed information if they are not available in formats that are easy to understand and
149 comparable across firms.

150 Thus, further research is needed in refining methodologies for assessing and disclosing climate-related
151 financial risks facing individual firms.⁴⁷ Over time, this could lead to more standardized, comparable disclosure
152 which allows investors to take these risks into account in allocating their capital. Such research is also likely to
153 contribute to better classification schemes for ‘green’ assets, and more informative labelling of such assets for
154 investors.⁵¹ Concurrently, the development of spatially-detailed integrated databases of physical assets could
155 improve risk assessment, even in the absence of disclosure.⁵²

156 However, existing research suggests that a combination of behavioral biases and misaligned professional
157 incentives may lead financial markets to be excessively focused on short-term returns and thus not to fully
158 price climate-related risks, even when information about these is available.^{53–55} Therefore, risk disclosure and
159 asset-level data might be made more effective by measures that promote the use of longer-term horizons in
160 investment decisions.⁵⁶

161 **Climate-aligned financial regulation**

162 It is in principle possible to go further and adapt financial regulations to take into account climate-related
163 risks. Macro- and micro-prudential policies (e.g. the Basel III regulatory framework designed in the aftermath
164 of the financial crisis) encompass a range of regulatory instruments aimed at limiting systemic financial risk, or
165 specific financial risks facing individual financial institutions. The tools at their disposal vary across
166 jurisdictions, and could include reserve, liquidity, and capital requirements, caps on loan-to-value ratios and
167 ceilings on credit growth, in some cases aimed at specific sectors.^{57,58} In some cases institutions holding riskier
168 assets are required to satisfy more stringent regulatory requirements, e.g. to fund their assets with more equity
169 than otherwise. Recent research suggests that this might have negatively affected the willingness of banks to
170 lend to low-carbon projects, because of their higher perceived risk, low liquidity and long tenor.⁵⁹ However,
171 current prudential regulation does not explicitly account for climate-related risks. Implementing a more
172 comprehensive assessment of risk could instead lead to a higher capital requirement on carbon-intensive assets,
173 in consideration of their higher transition risks.^{60,61} If this in turn leads to an increase in the cost of financing
174 high-carbon activities, it could also have the effect of re-directing lending towards low-carbon activities.

175 Some emerging market central banks have used prudential policies to mitigate environment-related risks or
176 encourage lending to low-carbon activities.⁶² For example, *Banque Du Liban* differentiates reserve requirement
177 ratios - i.e. the required ratio of central bank reserves held by private banks to their stock of deposits –

178 according to the amount of bank lending flowing to renewable energy and energy efficiency projects.⁶³ *Banco*
179 *Central do Brasil* requires commercial banks to incorporate environmental risk factors into their governance
180 framework and demonstrate how these risks are evaluated when calculating their capital needs.⁶⁴ The People's
181 Bank of China is in the process of incorporating green financing into its 'Macro-Prudential Assessment' (MPA)
182 framework.⁶⁵

183 The idea that financial regulations could take into account climate-related risks more explicitly appears to be
184 gaining political traction also in high-income countries. The EU High-Level Expert Group on Sustainable
185 Finance has recently suggested to explore the option of introducing 'brown-penalizing' or 'green-supporting'
186 factors on capital requirements depending on the sustainability risks carried by the borrowing sectors.^{56,66} The
187 European Commission has proposed that the European Supervisory Agencies integrate environmental, societal
188 and governance (ESG) criteria into their work, in order to enable them to monitor how financial institutions
189 identify, report and address the risks that such factors may pose to financial stability.⁶⁷

190 There are still several areas of concern over the effectiveness of such measures. First, there is the danger that
191 reducing capital requirements on bank loans to low-carbon investments could jeopardize prudential policy
192 objectives. More in general, the role of capital requirements is to mitigate risks; their design should thus remain
193 risk-based. Second, climate-aligned prudential policy could be too blunt a tool if applied to banks' exposures to
194 entire productive sectors or companies, as it would not be able to discriminate within carbon-intensive sectors
195 (e.g. utilities) those companies that engage in low-carbon investments. However, estimating banks' capital
196 requirements based on the 'greenness' of specific investment projects might overburden banks with assessment
197 exercises they are not familiar with. Third, high-carbon companies could bypass the tightening of prudential
198 policy in one jurisdiction by raising funds on the international financial markets, unless such policies are
199 implemented across all major jurisdictions.

200 Given the concerns above, financial regulators in high-income countries may not consider reflecting climate-
201 related financial risks in the calibration of prudential policy tools unless there is compelling evidence that the
202 exposure of the financial sector to these risks is sufficiently large. This calls for further innovative research in
203 the field of climate stress-testing and macroeconomic modelling aimed at quantifying climate-related financial
204 risks.

205 **A 'green' Quantitative Easing?**

206 It has also been proposed that central banks might wish to consider aligning their monetary policy tools to
207 environmental sustainability goals.⁶⁸ Prior to the 2007-8 global financial crisis, major central banks operated
208 monetary policy primarily through adjustments of the reference interest rate. In the aftermath of the crisis,
209 many central banks have also initiated 'unconventional' Quantitative Easing (QE) measures in the form of
210 large-scale purchase of financial assets, such as government and corporate bonds, in order to provide additional
211 stimulus to the economy.

212 Central banks' QE programs are intended to be temporary cyclical tools. As such, they have been designed
213 to avoid 'distorting' the market, while concurrently ensuring that assets being purchased meet high credit
214 standards. The European Central Bank (ECB), for instance, buys sovereign bonds respecting the current
215 maturity distribution, and allocates purchases of corporate bonds across sectors according to the current bond
216 market sectoral weights.^{69,70} However, recent research suggests that the 'market-neutral' corporate bond
217 purchases have inadvertently favored large carbon-intensive companies, reflecting their relatively strong credit
218 ratings and the fact that many low-carbon firms are too small to issue corporate bonds.⁷¹ When central banks
219 buy a type of asset in large quantities, market participants might assess this asset category more liquid and less
220 risky than others. This raises a concern that central banks' asset purchases, even if temporary, could have the
221 unintended consequence of perpetuating the current 'carbon lock-in' of the economic system, thus undermining
222 their own effort of encouraging financial markets to better account for climate-related risks.

223 To mitigate this undesired effect, it has been suggested that central banks could recalibrate QE purchases so
224 to exclude carbon-intensive financial assets and favor bonds issued to fund low-carbon projects.^{16,72,73}
225 Alternatively, central banks could keep their current QE programs unchanged and run a parallel independent

226 program focused on purchasing additional low-carbon financial assets. This ‘green’ QE would have the benefit
227 of providing large amounts of additional liquidity to companies interested in shifting to clean forms of
228 production. The overall purchases by the ECB during 2017, for instance, amounted to around €730 billion,
229 while the total additional annual investment required to achieve EU energy and climate targets are estimated at
230 €170 billion.^{55,63} Central banks could expand the proportion of purchases in ‘green’ bonds, which represent a
231 niche but rapidly expanding market, estimated at €221 billion globally in 2016.⁷⁵ These bonds can be issued by
232 companies, development banks, local authorities or, more recently, governments.

233 Among the proposals discussed here, this is probably the one that has raised greatest controversy. This is
234 primarily due to the fact that central banks view QE as a cyclical policy instrument aimed at providing
235 temporary stimulus to the economy. Using it to engineer a low-carbon structural change might overburden
236 central banks with additional responsibilities and potentially compromise their effectiveness in maintaining
237 price stability. Moreover, low-carbon assets often do not meet the existing financial risk standards to be
238 included into the list of eligible assets for central bank purchase, which mainly consist of investment grade
239 bonds – i.e. bonds with low default risk. Purchasing riskier green assets could raise concerns regarding the
240 quality of central banks’ portfolio, particularly when central banks do not have the capacity to evaluate the
241 relative merits of new technologies in times of disruptive change. Finally, introducing strict low-carbon
242 requirements for central bank asset purchase might reduce the universe of purchasable assets. For these and
243 other reasons, the idea of explicitly supporting the low-carbon transition via a ‘green QE’ has been repeatedly
244 rejected by central bankers.⁹

245 It should be noted, however, that an indirect form of green QE might already be happening through the
246 purchase of bonds issued by public sector entities that finance low-carbon activities. For example, the ECB
247 allocates around 10% of its Public Sector Purchase Programme to bonds issued by ‘supranational institutions’,
248 which include several regional and national development banks.⁷⁴ Development banks have been at the
249 forefront of climate mitigation financing in recent years.^{76,77} For instance, the European Investment Bank (EIB)
250 dedicates a minimum of 25% of its lending to climate action projects.⁷⁸ Thus, the ECB might already be
251 indirectly supporting low-carbon investments, although to a limited extent, through the inclusion of EIB-issued
252 bonds in its QE program.

253 **Central bank mandates**

254 Ultimately, what central banks and financial regulators will do to support a smooth low-carbon transition
255 will depend on what their mandate allows, how this is interpreted, and their willingness to act. The mandates
256 and policy tools at the disposal of central banks significantly differ across countries. In particular, a distinction
257 can be drawn between the central banks of high-income regions and the central banks of developing
258 economies.

259 Most central banks in high-income countries have relatively narrow mandates primarily focused on price
260 stability and, in some cases, financial stability and regulation of individual financial institutions. They are
261 typically granted operational independence in order to achieve specific objectives within their mandate. Thus,
262 they normally avoid interfering either with market dynamics or government policies, unless it is necessary to
263 achieve their objectives. Consequently, they have thus far mainly sought to enhance the resilience of the
264 financial system to climate-related risks by developing and promoting the use of better information and
265 portfolio assessment tools (e.g. climate stress tests). Other measures taken include international collaboration
266 for nurturing green financial markets, including through the Green Finance Study Group of the G20, the
267 Sustainable Insurance Forum, and the Network for Greening the Financial system (NGFS).^{13,79,80}

268 By contrast, central banks in emerging and developing countries have used a wider set of tools to target
269 sectors linked to environmental sustainability, reflecting their mandates that are both broader and more strongly
270 linked to governments’ development objectives. For instance, the Reserve Bank of India requires that
271 commercial banks allocate a certain proportion of lending to a list of ‘priority sectors’, which now include
272 renewable energy.⁸¹ The Bangladesh Bank has introduced a minimum credit quota that financial institutions
273 have to allocate to green sectors, currently set at 5%, and offers refinancing lines to commercial banks at
274 preferential terms for their green loans.⁸² While not in an emerging economy, the Bank of Japan’s Loan

275 Support Program also offers loans at below market rate to financial institutions in order to support several
276 ‘lending priority sectors’, including ‘environment businesses’.⁸³

277 A key question is whether central banking institutions in high-income countries are likely to modify their
278 mandates in order to start using their policy tools to explicitly support the financing of low-carbon activities.
279 Changes in central bank mandates are far from unprecedented. The first central banks were established to
280 enhance the financial power of the sovereign during military conflicts.⁸⁴ Over time, the responsibilities of
281 central banks have transformed in response to economic events and changing monetary practices. For the
282 majority of the 20th century central banks had a larger range of objectives than today, including high or full
283 employment, exchange rate stability, management of government deficits and support to strategic industrial
284 sectors (in particular in the post-World War II period⁸⁵). With the consent of national governments, they have
285 also often implemented policies supporting or repressing specific sectors of the economy, sometimes stretching
286 beyond their usual boundaries of operation.⁸⁶

287 However, despite this historical experience, it seems unlikely that central bank mandates in high-income
288 countries will be modified to include wider societal goals, such as supporting a low-carbon transition.
289 Moreover, the question of whether this would be appropriate requires further examination. On the one hand,
290 there is an increasing recognition that climate change and the low-carbon transition might pose system-wide
291 risks to the macroeconomic and financial system, which may justify more proactive interventions by a wider
292 set of public institutions, including central banks and financial regulators. On the other hand, widening their
293 mandate – for example to support credit to low-carbon investment projects – could risk overburdening central
294 banks with excessive responsibilities, which could take up management capacity to the detriment of their
295 primary objectives of maintaining monetary and financial stability. Moreover, as unelected institutions, it may
296 be undesirable to confer central banks additional powers and responsibilities over a broad range of social and
297 environmental issues for which credible accountability frameworks are difficult to design.

298 **Incorporating climate-related risks**

299 While a change in mandate seems unlikely, this may not be necessary in order for central banks in high-
300 income countries to support the transition to a low-carbon economy. In case climate-related financial risks are
301 found to be material to the stability of the financial system, this could ultimately justify the implementation of
302 measures aimed at mitigating them across all central banking operations.

303 Central banks could incorporate climate-related criteria in assessing whether an asset should be eligible for
304 central banks’ asset purchase as part of their standard portfolio management. The DNB already applies ESG
305 criteria and purchases green bonds for own-account investments.⁸⁷ The Swiss National Bank has its own
306 ethical criteria to exclude a certain set of companies from its foreign equity purchase.⁸⁸ The Norges Bank has
307 ESG criteria for the government’s pension fund that it manages, and explicitly excludes companies involved in
308 coal-based energy production or responsible for severe environmental damage.⁸⁹ Central banks could consider
309 applying these criteria to cyclical policy measures, such as the current QE programs. The objective would not
310 be to support financing of low-carbon investments, but to prevent the purchase of assets that do not satisfy
311 financial risk standards, where risk is assessed using more comprehensive methodologies that include climate-
312 related criteria.

313 The same principle could be applied to central banks’ collateral frameworks. The collateral framework
314 defines assets that financial institutions can pledge in order to borrow from the central bank, as well as the
315 amount that they can borrow against those assets. The criteria used by central banks to establish the eligibility
316 of an asset as collateral and the ‘haircut’ imposed could have deep impact on the desirability - and thus price -
317 of the asset.⁹⁰ Being included in the collateral framework gives an incentive to issue such financial instruments
318 in larger quantities, which could in turn have an impact on the economy.^{91,92} Central banks could therefore
319 consider incorporating climate-related risks explicitly in determining the list of eligible collateral and the size
320 of the haircut.

321 **Conclusions and future avenues of research**

322 The primary responsibility for managing the transition to a low-carbon economy rests with the elected
323 governments. However, if it is true that climate change is indeed ‘the greatest and widest-ranging market
324 failure ever seen’,⁹³ the effort for a smooth low-carbon transition will require the implementation of a
325 comprehensive set of policies, some of which might require the collaboration of central banks and financial
326 regulators.

327 This cooperation will not require a modification of central banks’ mandate. Supporting the development of
328 more comprehensive measures of financial risk to include climate physical and transition risks is well within
329 their present mandate of ensuring effective functioning of financial markets. These more comprehensive
330 measures can then be applied to test and disclose the climate-related exposure of both the financial system as a
331 whole and individual financial institutions. If these risks are evaluated to be material to the stability of the
332 financial system, central banks and financial regulators should consider reflecting them in their regulatory and
333 asset eligibility assessment frameworks.

334 Several open questions and research gaps remain. First, despite the recent growth of work on the topic,⁹⁴
335 further progress is needed in developing robust methodologies and collecting comprehensive data for
336 evaluating climate-related risks which companies and investors are exposed to. The push for risk disclosure, the
337 development of asset-level databases and the refinement of climate stress-test techniques will all contribute in
338 filling this gap. Progress in this direction will help firms to disclose climate-related risks in a comparable
339 manner, and support central banks and financial regulators to better assess the exposure of both individual
340 financial institutions and the financial system as a whole. Further research in these areas will also help central
341 banks to evaluate climate-related risks in their own asset portfolios. It will also contribute to developing a
342 definition of green or sustainable investment, which is both widely accepted and used by investors. Having a
343 clear and widely accepted methodology and taxonomy could also help central banks in considering the case for
344 disclosing climate-related risks in their own asset portfolios.

345 Second, there is the need to develop models that enable a forward-looking assessment of climate-related
346 risks and their social and macroeconomic repercussions. This is particularly relevant for the evaluation of the
347 potential effects of the policies discussed in this article on growth, employment, distribution and financial
348 stability. The analysis of these effects is challenging since policies are likely to involve time-dependent trade-
349 offs and might have undesirable or unexpected implications (e.g. rebound effects). This will require combining
350 dynamic macroeconomic modelling (possibly using a plurality of methodological approaches: IAMs, ABMs,
351 DSGE and SFC models), financial data and modelling, climate scenarios, historical analysis and political
352 economy considerations. Central banks can be instrumental in supporting such efforts and facilitating the
353 exchange of best practices across modelling communities.

354 Making progress in the directions outlined above is urgently needed in order to sustain the momentum
355 in ”greening” the financial system, which will require collaboration across the research community, financial
356 market participants, financial regulators and central banks. Researchers can best contribute in this process by
357 developing practically and immediately useful methodologies for evaluating climate-related risks and their
358 wider economic impact, and refine these over time.

359 *[End]*

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544

545 **Author contributions**

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Table 1 The low-carbon transition trade-off

	No transition	'Rapid and orderly' transition	Abrupt transition
Short term	No stranded assets	Limited stranding of assets	Stranded physical assets (e.g. fossil reserves and carbon-intensive capital) ^{25,27} Stranded financial assets (loss in market valuation and cascade effects) ⁴
Long term	Large-scale climate damages to productive assets ⁹⁵ Climate-induced financial losses ²³	Limited climate damages to physical and financial assets	Limited climate damages to physical and financial assets Potential long-term economic repercussions resulting from asset stranding

Table 2 Environment-friendly interventions by central banks and financial regulators

		Concept	Selected current applications
Research	Assessment of climate-related financial risks	Develop and apply methodologies to identify and measure climate-related risks to financial institutions	De Nederlandsche Bank ³⁴ , Bank of England ³⁵
	Macroeconomic modelling of low-carbon transition	Develop modelling tools to assess the wider impact of climate risks and the transition	Only outside of central banks and regulators (private sector and academia)
Policy	Support to international activities on green finance	Enhance knowledge, cooperation and diffusion of good practices	G20 Green Finance Study Group ⁷⁹ , Sustainable Insurance Forum ⁸⁰ , Network for Greening the Financial System (NGFS) ¹³
	Disclosure of climate-related financial risks	Enforce or encourage voluntary disclosure of climate-related financial risks by firms	FSB Task Force on Climate-related Financial Disclosures ⁴⁷ , French Energy Transition Law ⁴⁸
	Environmentally-aligned prudential regulation policy	Incorporate environmental considerations into prudential regulation	Banque du Liban ⁶³ , Banco Central do Brasil ⁶⁴
	Green central bank financing	Provide additional/subsidized liquidity to banks lending to environment-friendly activities	Bangladesh Bank ⁸² , Bank of Japan ⁸³
	Lending quotas	Impose a minimum proportion of bank lending to flow to environment-friendly sectors	Reserve Bank of India ⁸¹ , Bangladesh Bank ⁸²
	ESG factors in asset eligibility criteria	Include ESG criteria in the evaluation of the overall risk of an asset purchased or accepted as collateral	Only for own purchase, e.g. De Nederlandsche Bank ⁸⁷ , Norges Bank ⁸⁹
	Green Quantitative Easing	Purchase 'green' assets as part of Quantitative Easing programs	Assets purchased only if they meet the central bank's eligibility criteria, e.g. EIB bonds ⁷⁴

