

1 *Resubmission to Nature Climate Change (Perspective)*

2 **Finance and climate change: what role for central banks and financial**  
3 **regulators?**

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6 *[Abstract]*

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

14 *[Main text]*

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

22 [TABLE 1 ABOUT HERE]

23 Central banks and financial regulators have started examining the implications of climate change and  
24 the low-carbon transition in recent years. In 2015, Mark Carney, the Governor of the Bank of England  
25 and Chairman of the Financial Stability Board, first discussed the 'tragedy of the horizon' embedded in

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26 the different time spans that characterize monetary and financial stability policies (2-3 years and up to  
27 a decade, respectively) and the much longer-term perspective required to deal with climate-related  
28 risks.<sup>5</sup> This was followed by related speeches by other central bankers and regulators.<sup>6-12</sup> More recently,  
29 a group of eight central banks and financial regulators from both high-income and emerging economies  
30 have formed a ‘Network for Greening the Financial System’.<sup>13</sup> Researchers in academia, international  
31 institutions, and civil society organizations are also investigating the dynamic links between central  
32 banks, financial systems and the low-carbon transition.<sup>14-20</sup>

33 This *Perspective* critically discusses the main features of the debate, and identifies avenues for future  
34 research and policy implementation. First, we present the rationale for central banks and financial  
35 regulators to be interested in climate and the low-carbon transition. Second, we analyze their potential  
36 role in promoting a better understanding of climate-related financial risks. Third, we discuss the  
37 appropriate scope of their role in mitigating these risks. Options range from supporting voluntary risk  
38 disclosure by private companies and investors to mitigating climate-related risks, or even actively  
39 promoting low-carbon investments. Finally, we discuss how these activities would fit into their current  
40 mandates, and present open questions for further research.

#### 41 **Central banks and climate change**

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

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

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

66 While some disruption at the sectoral level is inevitable, the transition as a whole could represent an  
67 opportunity for sustainable and inclusive economic prosperity.<sup>30,31</sup> However, this is likely to be possible  
68 only in the presence of a comprehensive and harmonized set of policies aimed at supporting the low-  
69 carbon transition and managing its complex dynamics.

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

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

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

98 [TABLE 2 ABOUT HERE]

### 99 **Assessing climate-related financial risks**

100 Some central banks have started assessing the exposure of their domestic financial system to climate-  
101 related risks. For instance, De Nederlandsche Bank (DNB) has recently conducted two studies of the  
102 Dutch financial system showing that, while the exposure to fossil fuel producers is relatively small, the  
103 broader exposure to carbon-intensive sectors is large enough to pose potential systemic risks, and that

104 some of these risks are already materializing.<sup>26,34</sup> Insurers and banks could also experience significant  
105 losses as a result of severe climate-related events. The Bank of England reviewed the exposures of the  
106 UK insurance sector to climate-related financial risks in 2015, and is conducting a similar review of the  
107 banking sector.<sup>35</sup> Other institutions that have examined the potential impact of climate change or the  
108 low-carbon transition on financial stability include the European Systemic Risk Board, Sweden’s  
109 Finansinspektionen and Banque de France.<sup>29,36,37</sup> Researchers have also started developing ‘climate  
110 stress-testing’ methods, highlighting how exposures among investors can exacerbate the impact of the  
111 low-carbon transition on the financial system.<sup>4,38</sup>

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

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

### 137 **The push for risk disclosure**

138 A key obstacle to the achievement of a smooth low-carbon transition is the low awareness of  
139 companies and investors about their exposure to climate-related financial risks. The majority of  
140 companies are not used to assessing how these risks impact their business models, while most investors  
141 are unaware of how exposed their portfolios are. The recent international effort has thus primarily  
142 focused on improving information flows by supporting the disclosure of climate-related risks by private  
143 actors. For example, the Financial Stability Board established a Task Force for Climate-related

144 Financial Disclosures. Its final report makes sector-specific recommendations on how companies could  
145 *voluntarily* disclose climate-related financial risks, in order to better inform their investors, lenders and  
146 insurance underwriters.<sup>47</sup> The French Energy Transition law goes further and *requires* listed companies  
147 to disclose information on their exposures to climate-related risks and the measures adopted to reduce  
148 them, and requests banks to conduct climate-related stress testing on their portfolio of loans and  
149 disclose the results.<sup>48</sup> Several industry- or academia-led initiatives aimed at improving climate-related  
150 information available to financial investors also exist.<sup>49</sup> However, while central banks have been  
151 supportive of disclosure of climate-related risks by private firms, to date they have not disclosed the  
152 exposure of their own asset portfolios.

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

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

168 However, existing research suggests that a combination of behavioral biases and misaligned  
169 professional incentives may lead financial markets to be excessively focused on short-term returns and  
170 thus not to fully price climate-related risks, even when information about these is available.<sup>53–55</sup>  
171 Therefore, risk disclosure and asset-level data might be made more effective by measures that promote  
172 the use of longer-term horizons in investment decisions.<sup>56</sup>

### 173 **Climate-aligned financial regulation**

174 It is in principle possible to go further and adapt financial regulations to take into account climate-  
175 related risks. Macro- and micro-prudential policies (e.g. the Basel III regulatory framework designed in  
176 the aftermath of the financial crisis) encompass a range of regulatory instruments aimed at limiting  
177 systemic financial risk, or specific financial risks facing individual financial institutions. The tools at  
178 their disposal vary across jurisdictions, and could include reserve, liquidity, and capital requirements,  
179 caps on loan-to-value ratios and ceilings on credit growth, in some cases aimed at specific sectors.<sup>57,58</sup> In  
180 some cases institutions holding riskier assets are required to satisfy more stringent regulatory  
181 requirements, e.g. to fund their assets with more equity than otherwise. Recent research suggests that  
182 this might have negatively affected the willingness of banks to lend to low-carbon projects, because of

183 their higher perceived risk, low liquidity and long tenor.<sup>59</sup> However, current prudential regulation does  
184 not explicitly account for climate-related risks. Implementing a more comprehensive assessment of risk  
185 could instead lead to a higher capital requirement on carbon-intensive assets, in consideration of their  
186 higher transition risks.<sup>60,61</sup> If this in turn leads to an increase in the cost of financing high-carbon  
187 activities, it could also have the effect of re-directing lending towards low-carbon activities.

188 Some emerging market central banks have used prudential policies to mitigate environment-related  
189 risks or encourage lending to low-carbon activities.<sup>62</sup> For example, *Banque Du Liban* differentiates  
190 reserve requirement ratios - i.e. the required ratio of central bank reserves held by private banks to  
191 their stock of deposits - according to the amount of bank lending flowing to renewable energy and  
192 energy efficiency projects.<sup>63</sup> *Banco Central do Brasil* requires commercial banks to incorporate  
193 environmental risk factors into their governance framework and demonstrate how these risks are  
194 evaluated when calculating their capital needs.<sup>64</sup> The People's Bank of China is in the process of  
195 incorporating green financing into its 'Macro-Prudential Assessment' (MPA) framework.<sup>65</sup>

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

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

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

220 **A 'green' Quantitative Easing?**

221 It has also been proposed that central banks might wish to consider aligning their monetary policy  
222 tools to environmental sustainability goals.<sup>68</sup> Prior to the 2007-8 global financial crisis, major central  
223 banks operated monetary policy primarily through adjustments of the reference interest rate. In the  
224 aftermath of the crisis, many central banks have also initiated ‘unconventional’ Quantitative Easing  
225 (QE) measures in the form of large-scale purchase of financial assets, such as government and corporate  
226 bonds, in order to provide additional stimulus to the economy.

227 Central banks’ QE programs are intended to be temporary cyclical tools. As such, they have been  
228 designed to avoid ‘distorting’ the market, while concurrently ensuring that assets being purchased meet  
229 high credit standards. The European Central Bank (ECB), for instance, buys sovereign bonds  
230 respecting the current maturity distribution, and allocates purchases of corporate bonds across sectors  
231 according to the current bond market sectoral weights.<sup>69,70</sup> However, recent research suggests that the  
232 ‘market-neutral’ corporate bond purchases have inadvertently favored large carbon-intensive companies,  
233 reflecting their relatively strong credit ratings and the fact that many low-carbon firms are too small to  
234 issue corporate bonds.<sup>71</sup> When central banks buy a type of asset in large quantities, market participants  
235 might assess this asset category more liquid and less risky than others. This raises a concern that  
236 central banks’ asset purchases, even if temporary, could have the unintended consequence of  
237 perpetuating the current ‘carbon lock-in’ of the economic system, thus undermining their own effort of  
238 encouraging financial markets to better account for climate-related risks.

239 To mitigate this undesired effect, it has been suggested that central banks could recalibrate QE  
240 purchases so to exclude carbon-intensive financial assets and favor bonds issued to fund low-carbon  
241 projects.<sup>16,72,73</sup> Alternatively, central banks could keep their current QE programs unchanged and run a  
242 parallel independent program focused on purchasing additional low-carbon financial assets. This ‘green’  
243 QE would have the benefit of providing large amounts of additional liquidity to companies interested in  
244 shifting to clean forms of production. The overall purchases by the ECB during 2017, for instance,  
245 amounted to around €730 billion, while the total additional annual investment required to achieve EU  
246 energy and climate targets are estimated at €170 billion.<sup>55,63</sup> Central banks could expand the proportion  
247 of purchases in ‘green’ bonds, which represent a niche but rapidly expanding market, estimated at €221  
248 billion globally in 2016.<sup>75</sup> These bonds can be issued by companies, development banks, local authorities  
249 or, more recently, governments.

250 Among the proposals discussed here, this is probably the one that has raised greatest controversy.  
251 This is primarily due to the fact that central banks view QE as a cyclical policy instrument aimed at  
252 providing temporary stimulus to the economy. Using it to engineer a low-carbon structural change  
253 might overburden central banks with additional responsibilities and potentially compromise their  
254 effectiveness in maintaining price stability. Moreover, low-carbon assets often do not meet the existing  
255 financial risk standards to be included into the list of eligible assets for central bank purchase, which  
256 mainly consist of investment grade bonds – i.e. bonds with low default risk. Purchasing riskier green  
257 assets could raise concerns regarding the quality of central banks’ portfolio, particularly when central  
258 banks do not have the capacity to evaluate the relative merits of new technologies in times of  
259 disruptive change. Finally, introducing strict low-carbon requirements for central bank asset purchase

260 might reduce the universe of purchasable assets. For these and other reasons, the idea of explicitly  
261 supporting the low-carbon transition via a ‘green QE’ has been repeatedly rejected by central bankers.<sup>9</sup>

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

### 270 **Central bank mandates**

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

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

286 By contrast, central banks in emerging and developing countries have used a wider set of tools to  
287 target sectors linked to environmental sustainability, reflecting their mandates that are both broader  
288 and more strongly linked to governments’ development objectives. For instance, the Reserve Bank of  
289 India requires that commercial banks allocate a certain proportion of lending to a list of ‘priority  
290 sectors’, which now include renewable energy.<sup>81</sup> The Bangladesh Bank has introduced a minimum credit  
291 quota that financial institutions have to allocate to green sectors, currently set at 5%, and offers  
292 refinancing lines to commercial banks at preferential terms for their green loans.<sup>82</sup> While not in an  
293 emerging economy, the Bank of Japan’s Loan Support Program also offers loans at below market rate  
294 to financial institutions in order to support several ‘lending priority sectors’, including ‘environment  
295 businesses’.<sup>83</sup>

296 A key question is whether central banking institutions in high-income countries are likely to modify  
297 their mandates in order to start using their policy tools to explicitly support the financing of low-  
298 carbon activities. Changes in central bank mandates are far from unprecedented. The first central



299 banks were established to enhance the financial power of the sovereign during military conflicts.<sup>84</sup> Over  
300 time, the responsibilities of central banks have transformed in response to economic events and  
301 changing monetary practices. For the majority of the 20th century central banks had a larger range of  
302 objectives than today, including high or full employment, exchange rate stability, management of  
303 government deficits and support to strategic industrial sectors (in particular in the post-World War II  
304 period<sup>85</sup>). With the consent of national governments, they have also often implemented policies  
305 supporting or repressing specific sectors of the economy, sometimes stretching beyond their usual  
306 boundaries of operation.<sup>86</sup>

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

### 319 **Incorporating climate-related risks**

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

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

334 The same principle could be applied to central banks' collateral frameworks. The collateral  
335 framework defines assets that financial institutions can pledge in order to borrow from the central  
336 bank, as well as the amount that they can borrow against those assets. The criteria used by central  
337 banks to establish the eligibility of an asset as collateral and the 'haircut' imposed could have deep  
338 impact on the desirability - and thus price - of the asset.<sup>90</sup> Being included in the collateral framework

339 gives an incentive to issue such financial instruments in larger quantities, which could in turn have an  
340 impact on the economy.<sup>91,92</sup> Central banks could therefore consider incorporating climate-related risks  
341 explicitly in determining the list of eligible collateral and the size of the haircut.

## 342 **Conclusions and future avenues of research**

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

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

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

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

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

383 *[End]*

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## 580 **Author contributions**

581 All authors contributed to the writing of the manuscript, under the coordination of E.C.