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Stranded Assets and Central Banks: from Lenders of Last Resort to 'Green' Balance Sheet Policies in Support of Decarbonization

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Stranded Assets and Central Banks: from Lenders of Last Resort to 'Green' Balance Sheet Policies in Support of Decarbonization

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Abstract

This article analyses the role that central banks could play in dealing with stranded 'brown' assets as a result of the ecological transition. The latter could transform monetary authorities – the central banks – into 'liquidators of last resort' for stranded fossil assets markets. In practice, this role would consist of central banks purchasing stranded fossil assets in order to close these markets. This central bank balance sheet policy would allow the decarbonization of the balance sheets of the financial sector, thereby facilitating the 'greening' of their balance sheets and, more broadly, the ecological transition and its speed.

To assess the practical feasibility of this central bank balance sheet policy, we are building a database that compiles estimates of the amounts of stranded assets for five geographical areas (the whole world, the USA, the European Union including the Eurozone, the United Kingdom and Japan), drawing on 29 publications over the period 2011-2022, which provide a total of 253 valuations. These estimates suggest that central banks, as 'liquidators of last resort' of stranded asset markets, would inject volumes of liquidity comparable to those they injected to deal with previous crises (the 2007-2009 global financial crisis and then Covid), at least in the high-income countries in our database. We then discuss the implications of our estimation for the credibility of central bank balance sheet policy and its implications for the speed of the ecological transition. Finally, we analyse the risks associated with this 'green' balance sheet policy by central banks and propose strategies to limit these risks. We also offer theoretical foundations for our proposal of a liquidator of last resort, ideas according to the Minsky's theory of endogenous financial instability which involves preventive action by the central bank tailored to the changing sources of instability.

Keywords: "market liquidator of last resort;" central bank balance sheet policy; brown and fossil stranded assets; decarbonization; ecological transition; Minsky

JEL classification: E58; G28; G18; Q54; Q58

Key policy insights

- With the ecological transition, 'brown' fossil assets will become 'stranded assets', losing their value: this is a 'transition risk' slowing down the speed of the ecological transition.
- The central bank would buy these stranded assets, assuming the role of 'liquidator of last resort' by closing these asset markets.
- This involves a central bank balance sheet policy aimed at decarbonizing balance sheets, or "quantitative decarbonization", comparable in some ways to quantitative easing.
- We are building a database of the various estimates of the amount of these stranded assets available according to the empirical literature on the subject.
- Compared with the amounts of securities purchased by the G4 central banks during the financial and health crises, the amounts of stranded asset purchases appear to be of the same order, at least for the G4 countries.
- This result suggests that the transition risk would be manageable through a decarbonization balance sheet policy by the central bank.
- This central bank's balance sheet policy would relax the constraint represented by the prospect of stranded assets on the balance sheet of the financial sector, so that one of its main benefits would be the possibility of accelerating the ecological transition.
- But in a cost-benefit balance, this central bank's decarbonization balance sheet policy, and the accompanying liquidation of brown assets, could also entail risks, notably moral hazard. The article also proposes measures to limit these risks.

1. Introduction

The notion of stranded assets (Caldecott et al., 2013) has become key to the climate policy debate. These stranded assets are 'brown' assets, as opposed to 'green' assets, because they are linked to the fossil fuel sectors (oil, gas and coal), which emit greenhouse gases and cause pollution. They could lead to losses, or even a systemic risk for the financial sector, known as 'transition risk' (Carney, 2015). By being stranded on the balance sheets of commercial banks after having lost all value, these assets could lead to a major ecological financial crisis of a 'green swan' type.[1]

Faced with these risks to finance and the economy, the literature is beginning to stress the need for central banks to expand their lender-of-last-resort (LLR) function, which should be made 'greener' (IPCC, 2018, p. 379; Bolton et al., 2020 and 2021; Hansen, L., 2022; Scialom, 2022). The global financial crisis of 2007-2009 and the Covid pandemic in 2020-21 have already changed the function of the LLR: central banks have not only lent over longer time horizons, they have also become (large-scale) 'asset buyers of last resort' to avoid market collapse (Acharya et al. 2021). In the case of the US Federal Reserve (Fed), these massive purchases of securities are commonly referred to as 'large-scale asset purchases' (LSAPs).

From now on, in the face of the ecological crisis, this is above all a question of buying up stranded 'brown' assets on a large scale: central banks will no longer just be evolving from being the 'lender of last resort' to being the 'buyer of last resort', but to a function of 'buyer of last resort of stranded assets' (Carré et al., 2022). Decarbonizing financial sector balance sheets is difficult to envisage without central banks helping to close fossil fuel asset markets. Without this, market players will at best sell their brown assets to buy other brown assets, and the

[1] According to the literature (Bolton et al., 2020; Pereira da Silva, 2020), a 'green swan' crisis can take different forms. It may be linked to a climatic event, and therefore correspond to the 'physical risk' described by Carney (2015). It can also be linked to the ecological transition, and therefore to what Carney (2015) calls a 'transition risk'.

transition will not progress. Unlike the asset purchases made during the financial and health crises, this would not be a matter of the central bank restoring the price of a troubled asset class, but of liquidating the markets for assets that have been rendered obsolete by the ecological transition, by being very heavily devalued, and therefore stranded. So, whereas in the face of the financial crisis, the central bank's action was that of a 'market maker of last resort' (Buiter, 2008), trying to shore up a market in difficulty, in the face of the ecological crisis, it must become instead a 'market closer or liquidator in last resort'. Such action would be different from that of a traditional LLR in several respects. Firstly, it would be less temporary and cyclical than structural, since it would be part of the process of ecological transformation. Secondly, unlike the emergency action forced by the crisis in the standard LLR, the 'market liquidator in last resort' function is conceived of as not just involving emergency crisis management but as a kind of prudential policy implemented early and in advance, aimed at preventing *ex ante* the 'green swan' ecological crisis. Indeed, there are specific ecological reasons for adopting a preventive policy in advance of the ecological crisis, notably to avoid reaching levels of ecological degradation leading to 'tipping points', points of no return or thresholds triggering non-linearities (Lenton et al., 2008; IPCC, 2021, p. 21). This is also a question of limiting irreversible ecological losses and avoiding irreversible changes in the climate system (Toniazzo et al., 2004; IPPC, 2023). The ecological crisis appears to be of a different nature to the traditional financial crises, and therefore calls for a different policy on the part of central banks. We develop the idea that such preventive action can find theoretical foundations in the works of Minsky.

Combining loans with purchases of 'brown' securities, this specific monetary policy for the ecological transition could ultimately be defined as a 'green central bank's balance sheet policy', in reference to the term 'central bank balance sheet policy' commonly used in the literature (Borio and Dysiatat, 2010; Boeckx et al., 2017; van den End and Pattipeilohy, 2017;

Horvath et al., 2018; Magill et al., 2020). More specifically, this central bank balance sheet policy for the ecological transition would consist of last-resort[2] liquidation purchases of stranded 'brown' assets by the central bank, to decarbonize the balance sheets of financial institutions.

Our article deals with this central bank balance sheet policy dedicated to stranded brown assets, thus contributing to the more general literature linking central banks and climate policies. However, the article adds a complementary perspective of analysis to the issues addressed so far. The most common proposal in the literature is that of 'green' quantitative easing (QE), which consists of buying risk-free green assets (Dafermos et al., 2018; Diluiso et al., 2021; Svartzman et al., 2021; Brown et al., 2023). The policy proposed in our article differs from this 'green' QE in several respects: the QE we envisage to decarbonize banks' balance sheets targets not green assets, but 'brown' stranded ones. It is a form of 'brown asset' QE, though it does not necessarily rule out green QE. Secondly, QE generally aims to restore a financial market, whereas we propose to liquidate it. Our proposal can be understood as 'quantitative decarbonization' or 'quantitative liquidation'. Finally, as this policy targets ecological transformation, it extends beyond simple crisis periods, and can also include loans. Therefore, the broader term 'balance sheet QE' seems more appropriate to us than the more restrictive 'quantitative easing'.

From the point of view of the systemic financial crisis that stranded assets could cause by remaining on banks' balance sheets, their purchase by central banks seems credible, given the QE experiments carried out during the financial crisis that began in 2007, and then during the Covid crisis, which led central banks to buy risky financial assets, and not just risk-free assets. During the 2007 crisis, the Fed bought MBS securities derived from subprime loans, while the European Central Bank (ECB) bought Greek government debt. In this respect, the comparison

[2] This is an action of 'last resort' in the classic sense of Baring (1797) and Thornton (1802), for which the other 'resorts' (markets, States) are unable or unwilling to carry out these liquidation purchases.

between stranded 'brown' assets and risky financial assets seems relevant because, in both cases, the central bank seeks to halt the panic in distressed financial markets, notably through its asset purchases. During the 'subprime' crisis, the central bank's role as LLR and buyer of risky assets was challenged. Some central bankers saw it as excessive risk-taking on the central bank's balance sheet, as an unsustainable increase in the size of that balance sheet, or as a source of inflation and financial bubbles in the future (Carré and Leloup, 2020). Politicians also questioned it, notably because they perceived these actions as a bailout of the financial sector, even though the latter was partly responsible for the crisis; in other words, a bailout that did not respect the 'polluter-pays' principle.

These questions, which arose during the global financial crisis, could come up again if central banks decided to buy stranded fossil assets. Our article therefore looks at these issues from the perspective, this time, of a financial crisis that would be caused by keeping stranded assets on banks' balance sheets. But more broadly, we envisage these asset purchases in the more structural context of the ecological transition, and the central bank's decarbonization balance sheet policy that goes with it. From the specific perspective of the ecological transition, the trade-off facing the central bank differs significantly from that of a conventional financial crisis. Outside the ecological transition, the trade-off concerning the integration of financial stability into the conduct of monetary policy has been well summarised in the 'clean *versus* lean' debate (Mishkin, 2011). Given with this trade-off, central banks may to choose between: i) a 'clean' strategy, which consists of not trying to deflate the asset bubble *ex ante*, and therefore allowing a bubble – supposedly favourable to economic growth – which, even if it were to burst, would cause damage that the LLR would be able to clean up *ex post*; and ii) a 'lean' strategy, in which the central bank attempts to burst the bubble by taking *ex ante* a preemptive action, to spare the economy the costs of a financial crisis, at the risk, however, of precipitating the crisis or, alternatively, fighting a bubble that is not really a bubble.

In the case of the ecological transition, the dilemma identified in the literature, particularly following Carney (2015), takes the form of a trade-off between 'transition risk' and 'physical risk' (TCFD, 2017; Campiglio et al., 2018; Chenet et al., 2021). One interpretation of this trade-off suggests that a too-rapid ecological transition would reduce physical risks, but would quickly strand fossil assets and thus raise the 'transition risk' for the financial sector, ultimately generating systemic risk. Conversely, a transition that is too slow would reduce the 'transition risk' for the fossil assets in the financial markets, but would increase the 'physical risks' for nature and therefore for humanity. By buying 'brown' assets to reduce the physical risk, the central bank could be accused of sending a signal to the financial markets that it is devaluing these assets, thereby increasing the transition risk and hastening the stranding of the 'brown' assets: hence the interest in looking at estimates of the cost of this stranding of brown assets, as proposed in this article. If this 'preventive' stranding represents a reasonable amount in terms of central bank balance sheets, then the climate inaction that consists of reducing the transition risk by increasing the physical risk is all the less defensible. The strong climate action represented by the central bank's decarbonization balance sheet policy, based on purchases of 'brown' securities, aims to reduce the transition risk by organising an orderly stranding of brown assets, thus avoiding the maintenance of a carbon asset bubble and avoiding the radical uncertainty that would generate the bursting of this 'carbon' bubble.

The central question posed in our article is therefore to estimate whether, in view of the amounts involved, central banks would have to create more or less monetary base to stabilise a 'green swan' type crisis, or to liquidate the stranded asset markets, by buying up the 'brown' polluting stranded assets than to deal with the financial and health crises of the last two decades. In theory, the central bank has no limit to its money creation, as long as it remains credible in its ability to preserve the value of money. *A priori*, therefore, the policy of buying stranded assets would not face a budgetary constraint. But, in practice, the central bank may face constraints: constraints linked to its primary objectives (price stability and financial stability), constraints of accountability to politicians, constraints of credibility with the public, or internal constraints of admissibility within the monetary policy committee (Dikau and Volz, 2021). From this point of view, the balance sheet policy of decarbonization through purchases of stranded brown securities would be all the more credible if it did not require excessive increases in the size of the balance sheet compared with previous balance sheet policies conducted by central banks.

To provide an answer to this question of the credibility of a policy of purchasing stranded 'brown' assets, we propose, as suggested by Hansen, T (2022) in particular, to compare the estimates of stranded assets that central banks should acquire with the amounts of securities purchased as part of their balance sheet policies during recent financial crises. From the financial crisis of 2007 until the tightening of monetary policy that began in 2022, central banks significantly increased the size of their balance sheets, in particular through asset purchases, some of which, as we have already seen, were deemed to be 'toxic'. Would the stranded assets to be purchased increase central bank balance sheets by the same amount?

In order to carry out this comparison, a database of estimates of the value of stranded assets is constructed. This database gathers estimates of the amount for the entire world and four other geographical zones (the USA, the European Union including the Eurozone, the United Kingdom (UK) and Japan). These estimates are then compared with the maximum amounts on the balance sheets of the G4 central banks (USA, Eurozone, UK and Japan) – the latter being commonly studied in the literature due to their key role in managing financial crises (Fawley and Neely, 2013; Goodhart et al., 2016; Bordo and Siklos, 2017).

Of course, analogies are not perfect, and the results of this comparison should be treated with caution. That said, the results tend to suggest that, in the light of a number of assessments, a buyer of last resort for stranded assets would be 'credible' in the sense that its 'environmental' balance sheet policy would not mobilise more central bank money than during the recent financial crises, at least in the case of the G4. Indeed, the increases in central bank balance sheets due to these recent crises appear to be compatible with the estimates of stranded assets. This is all the more so as these stranded assets would be acquired at low prices, given their loss of value and the haircuts that would have to be applied to them.

The rest of the article is organised as follows. In Section 2, we present the database of available estimates of stranded assets, as well as data on central banks' balance sheets. In Section 3, we analyse the results of the comparison of the two types of amounts collected previously (stranded assets and central bank balance sheet assets). Finally, in Section 4, following Semieniuk et al. (2022), we discuss the implications of these results not only for the conduct of central bank balance sheet policy for decarbonization, but also in terms of (systemic) 'transition risks' and the speed of ecological transition. The risks associated with the policy of purchasing 'brown' securities are also discussed; in particular, the moral hazard that this balance sheet policy could generate for the financial sector, which would come to take this 'green' safety net for granted. Beyond that, we develop the idea that Minsky's work provides a theoretical foundation for our idea of preventive action by a market liquidator of last resort to contribute to the ecological transition. We conclude (Section 5) by suggesting avenues for future research on stranded assets, in particular by refining our database to include other fossil fuel-producing countries (whether industrialised countries outside the G4, or emerging or developing countries), and by suggesting the need for an 'international market liquidator of last resort' to take charge of their 'brown' stranded assets.

2. Data

We first explain the construction of the database on stranded assets (sub-section 2.1), and then the collection of data on central bank balance sheets (sub-section 2.2).

2.1. Estimates of stranded assets

The literature offers a limited number of articles providing a quantitative summary of the potential amounts of stranded assets across the globe (Jewell et al., 2016; IRENA, 2017; Curtin et al., 2019; Saygin et al., 2019; Hansen, T., 2022). The most complete calculation is that of Fisch-Romito et al. (2021), which includes 14 articles proposing values of stranded assets over the period 2011-2020. Our database extends and completes this database over the period 2011-2022. It includes 29 articles, leading to 253 estimates of the amount of stranded assets, details of which are given in the online supplementary material. We integrate the estimates found in the corpus of the articles into the database, and we also integrate the additional estimates provided in the online appendices of these articles.

To compare these amounts of stranded assets with the balance sheet sizes of central banks, we collect data on stranded assets for specific geographic areas corresponding to jurisdictions of central banks; namely the amounts of stranded assets for the USA, the Eurozone, the UK and Japan which are compared respectively to the balance sheets of the Fed, the ECB, the Bank of England (BoE) and the Bank of Japan (BoJ). Not all stranded asset estimates have this geographic granularity. Sometimes, estimates for the Eurozone are not provided for all member countries, but only for the main ones. In this case, we aggregate the estimates for these main countries to form the estimate for the Eurozone. Sometimes, estimates of stranded assets are presented not for the Eurozone, but for the European Union (EU). In this case, for comparison with the balance sheet size of central banks, we make an approximation by aggregating the balance sheets of the ECB and BoE. This approximation, which does not take into account several EU countries outside the Eurozone, must be taken with caution.[3] The use of the EU geographical area is also limiting, as it does not include one of Europe's largest fossil fuel-producing countries, namely Norway. Finally, the database contains the amount of stranded assets for the entire world. To compare these global estimates with the balance sheets of central banks, we aggregate the balance sheets of the four G4 central banks (the Fed, ECB, BoE and BoJ). The idea here is not to present an approximation of the total balance sheets of central banks across the world, because this would require adding several central banks, notably the People's Bank of China and the Reserve Bank of Australia. Instead, the aim is to get an approximation of the stabilization capacity of the central banks of the developed countries, which played a key role in regulating the financial crisis of 2007, and therefore, which could play a role in dealing with the ecological transition or handling a 'green swan' crisis. Descriptive statistics from the stranded asset estimates database are provided in the online supplementary material.

The construction of this database on the evaluations of the amounts of stranded assets has limitations. Firstly, the database does not cover all geographical areas. It therefore does not include estimates of stranded assets specific to low/middle income countries or to fossil fuel producing countries, which could be among the most heavily affected (the Middle East, Russia, China, Australia, etc.). Moreover, the values for different time periods are lumped together, ranging from 1 year (Caldecott and McDaniels, 2014) to 100 years (Linquiti and Cogswell, 2016). An alternative would have been to calculate average losses per year. But this measurement would also have been imperfect because the losses vary over time. The second limit concerns the losses of different types which can be aggregated; for example, losses on different energies (oil, coal and gas), mitigation costs, capital expenditure (capex), or value at

[3] Furthermore, Brexit took place on January 31, 2020, so the UK was not part of the EU in 2022, when the BoE's balance sheet size peaked. However, as a simplifying assumption, we proceed to aggregate the ECB and the BoE within the EU.

risk. Third, the studies do not use constant dollars. Furthermore, these studies do not all use the same assumptions for a certain number of parameters, such as the discount rate, the climate scenario (1.5, 1.8 or 2°C of warming, and 450 or 550 ppm of CO_2 concentration), or even the carbon price projections. Finally, another limit stems from the fact that the estimates collected restrict the scope of stranded assets to losses of assets held in the fossil sectors. Other ecological losses could have been taken into account, such as those linked to biodiversity and 'physical risks' (hurricanes, floods, fires and droughts, etc.). Due to these limitations, our database gives orders of magnitude that are certainly approximate, but nevertheless useful.

After presenting the data on stranded assets, we describe the data on the balance sheets of central banks, with which a comparison is made.

2.2. The data on central bank balance sheets

Concerning the data on central bank balance sheets, we collect it directly from the websites of each central bank. The details of the series collected are explained in the online supplementary material.

For each central bank, we collect two types of data: Category 1 data for the total size of the balance sheet (total assets), and Category 2 data for the aggregate amount of the asset purchase programs. Category 1 serves as our proxy for central bank balance sheet policy. Academics and central bankers, as highlighted by Horvath et al. (2018), commonly use total balance sheet assets as a baseline metric to study a central bank's balance sheet policy (Gambacorta et al., 2014; Benigno and Nistico, 2017; Boeckx et al., 2017; van den End and Pattipeilohy, 2017; Smith and Valcarcel, 2023). A limitation of this Category 1 measure, however, is that the central bank's balance sheet includes elements other than purchased securities or loans. Nevertheless, the entire balance sheet remains a satisfactory approximation of these purchases and loans programs which represent the majority of the total assets of central banks. In addition, the total size of the balance sheet gives a maximum estimate of the balance sheet policy capacity of central banks in practice. We supplement this measure with other approximations of central bank balance sheet policy to ensure the robustness of the results.

Category 2 is more restrictive than Category 1 because it is limited to asset purchases. It therefore excludes, in particular, loans from the central bank, and necessarily results in an amount lower than the balance sheet total of the central bank (Category 1). The decarbonization balance sheet policy we propose could be broader than just these purchases, and also involve loans in the form of central bank loans against 'green' collateral, or central bank loans conditional on the use of this liquidity lent for ecological purposes. If these loans have medium to long-term maturities, then they will have a lasting impact on the size and composition of the central bank's balance sheet, and therefore will also fall under the central bank's balance sheet policy, as highlighted by the definition of balance sheet policy by Borio and Dysiatat (2010). We could also have taken as a series the aggregation of securities purchases and loans, which would *prima facie* be a more precise approximation of balance sheet policy. But it is sometimes difficult to distinguish central bank loans which fall under conventional monetary policy from those which fall under unconventional balance sheet policy. The balance sheet policy must be demarcated; otherwise, the conventional monetary policy of loans classically considered for 'normal' times disappears completely. For example, at what maturity does a classic central bank loan become a balance sheet policy? This difficulty in determining whether or not a central bank loan falls within its balance sheet policy could explain why most studies defining balance sheet policy as an aggregate of central bank purchases and loans remain focused on the sole case of the Eurosystem to have a homogeneous and comparable whole (Horvath et al., 2018; Arce et al., 2020; Darracq-Pariès and Papadopoulou, 2020; De Fiore et al., 2022; Avalos and Mamatzakis, 2023). Our study stands out by focusing not on the ECB alone, but on the G4 central banks, which implies a comparable measurement of balance sheet policy for these four central banks and would not be possible by integrating central bank loans.

The advantage of taking into consideration Category 2 of the amount of securities purchases by central banks is firstly that it is of a lower amount than the total amount of Category 1, and allows testing the robustness of the results by making a comparison with a lower limit. Furthermore, Category 2 is more closely comparable to stranded brown asset QE during a 'green swan' financial crisis. Indeed, Category 2 corresponds to the unconventional monetary policies of asset purchases carried out during the 'black swan' crisis of 2007 (known at the Fed as LSAP, and corresponding to the ECB's numerous programs for purchasing securities, both public and private (SMP, CBPP, PSPP, etc.)). Secondly, Category 2 corresponds to the definition of balance sheet policies in several articles which restrict this policy to purchases of securities (Chadha et al., 2012; Reis, 2017; Benigno and Nisticò, 2020; Magill et al., 2020; Dedola et al., 2021; Iovino and Sergeyev, 2023).

We select the maximum amount of the balance sheet total as a reference figure for Category 1. We proceed in the same way for Category 2 for securities purchases. This choice of reference values makes it possible to have an approximation of the maximum amount of the credible decarbonization balance sheet policy, in view of the past experiences of central banks. This data is weekly, so we choose the maximum amount for a given week.

Estimates of stranded assets are all expressed in dollars. We therefore converted the balance sheet amounts of the ECB, BoE and BoJ into dollars. For this, we used the dollar exchange rate on the day of the maximum values of Categories 1 and 2 of the balance sheets. The exchange rate used is that provided by the FRED database of the Federal Reserve Bank of St. Louis.

The following section presents the result of the comparison between the estimates of the amounts of stranded assets on the one hand, and the maximum amounts on the balance sheets of central banks on the other.

3. Results

In Figure 1, three data points are used for each geographical area to estimate the amount of stranded assets: i) the maximum, ii) the median and iii) the mean.[4] The maximum is a truly maximum approximation because it is unlikely that the central bank will buy carbon assets at their full price. Indeed, during periods of crisis, financial assets are generally depreciated. The decarbonization balance sheet policy would act before a crisis, but the price of 'brown' assets will not necessarily be high, because the balance sheet policy aims to close these brown asset markets and so considers them as stranded, as if they no longer had a market price. More precisely, balance sheet policy could, through a signaling effect, lower the price of brown assets. But, at the same time, past experience with QE shows that these programs tend to raise asset prices. However, such rises in asset prices come from the fact that the LLR intends to restore a failing market. Conversely, our decarbonization balance sheet policy intends to close 'brown' markets, so that it should not result in an increase in prices. Logically, the effect of falling asset prices should outweigh the effect of increasing the price of 'brown' assets, so ultimately, the scenario would be that of a decrease in their price following the announcement of the decarbonization balance sheet policy program. In addition, it is the central bank and not the market which would set the 'acquisition-liquidation' price of these stranded assets. We analyze this issue of the liquidation price of stranded assets in more detail in the next section.

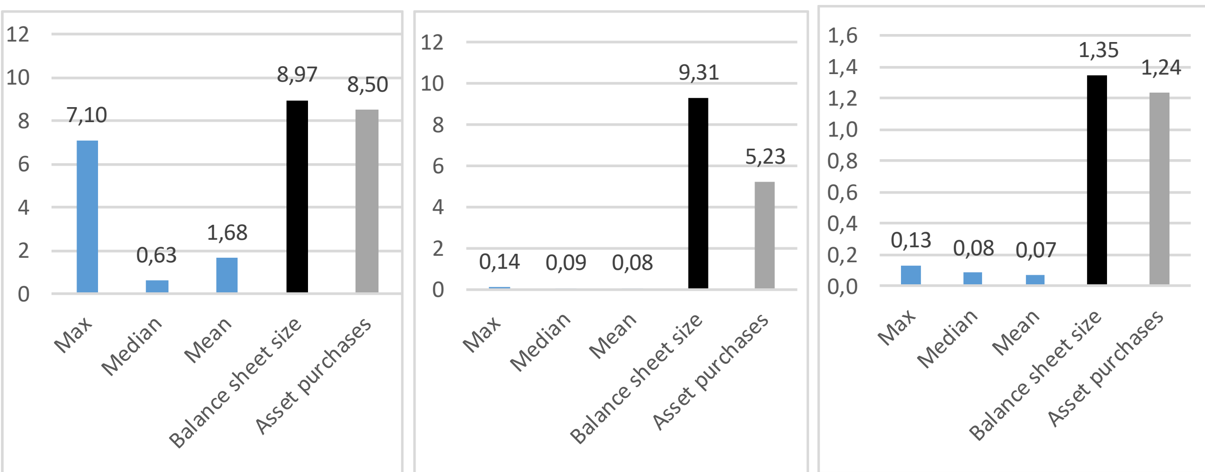
Three categories of results are observable. The first relates to areas where the amount of central bank balance sheets clearly exceeds estimates of the amount of stranded assets in the Eurozone and the UK (Figures 1-b and 1-c). The second category is that of countries where the size of central bank balance sheets exceeds the amount of estimated stranded assets, but less

[4] Jewell et al. (2016) rely on the median.

significantly so: the USA, the EU and Japan. In these two cases, the decarbonization balance sheet policy is fully justified since the amount of purchases required would increase the size of the central bank's balance sheet in proportions lower than those recorded during the recent subprime and Covid crises. Finally, for the whole world (Figure 1-f), we observe the opposite result: the amount of estimates of stranded assets largely exceeds the sum of the balance sheets of the G4 central banks. This result was expected as the sum of central banks does not include several fossil fuel-producing countries. This result highlights the difficulties G4 central banks would face if they had to manage stranded assets alone. At the global level, stranded assets would be so high that it would require international cooperation from central banks, either an 'international LLR' to use the classic term, or a global balance sheet policy scenario for central banks.

To test the robustness of the results, balance sheet policy action is measured more strictly by taking not the size of the central bank's balance sheet as a whole, but more strictly the total amount of securities purchase programs by central banks (see Figure 1, Asset purchases). This robustness test confirms the previous results.

a. USA b. Eurozone c. United Kingdom



d. Japan e. European Union f. World

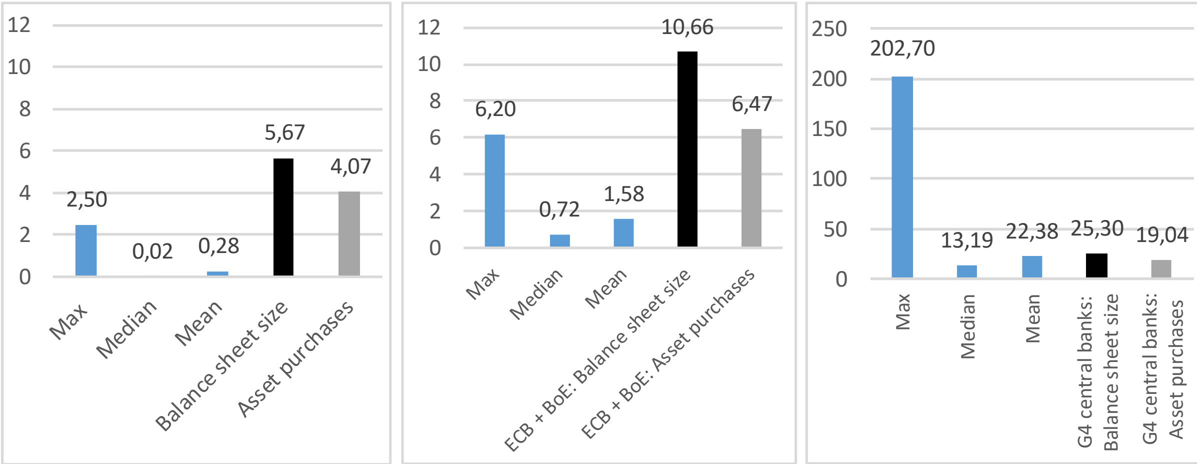


Figure 1. Stranded assets estimates and central banks' balance sheet data ($ trillions). Max: maximum estimates of stranded assets. Median: the median of the estimates of stranded assets. Mean: the mean of the estimates of stranded assets. Balance sheet size: the maximum size of the central bank's balance sheet. Asset purchases: maximum amount of the central bank's asset purchase programs. G4 central banks: Fed, ECB, BoE and BoJ.

To pursue the analysis further, we examine in detail the implications of these results for climate policy, as well as for the LLR and the decarbonization balance sheet policy of central banks.

4. Policy implications: the drawbacks and advantages of a decarbonization balance sheet policy by central banks

According to a cost-benefit analysis, the balance sheet policy of central banks would theoretically present risks in terms of moral hazard, in particular (sub-section 4.1). These analytical limits to the balance sheet policy, however, appear questionable, especially from an ecological economics perspective (sub-section 4.2). Consequently, the risk-benefit balance of this decarbonization policy would lean in the direction of its implementation. The fact remains, however, that obstacles to the balance sheet policy, particularly those of moral hazard, could arise during its deployment. We make operational proposals to deal with this complication (sub-section 4.3).

4.1. Limits of the central bank's decarbonization balance sheet policy

According to the 'cleaning up afterwards' strategy, the first risk of a balance sheet policy would be that it would attempt to pop a form of financial 'bubble' formed by 'brown' assets. However, according to the efficient markets hypothesis, such deflation of the bubble is not totally justified insofar as the financial markets provide a price for such brown assets, which therefore do not need to be liquidated. On the contrary, there would be a danger that the central bank's announcement of liquidation would cause panic in the financial markets and precipitate the stranding of brown assets, possibly generating a 'green swan' financial crisis. According to the 'clean' strategy, any deliberate *ex ante* bursting of the 'brown' asset bubble would be risky. A related argument is that, because of this panic and the crisis that a precipitous bursting of the bubble could generate, the cost of such preventive action would be (too) high, particularly in cases where the amount of stranded assets is sometimes significant (Figure 1). According to this 'clean' strategy, the risk of this balance sheet policy for the central bank would be not only its cost in terms of the amount of 'brown' assets purchased, but also the resulting losses on the central bank's balance sheet, or even the risk of the central bank going bankrupt (Boneva et al., 2022). Fear of this bankruptcy risk led some central bankers to be critical of policies to purchase risky securities during the 2007 financial crisis.

A second risk associated with central bank purchases of 'brown' securities is moral hazard (Bolton et al., 2020; 2021; Semieniuk et al., 2022). This risk, highlighted in the debate between clean *versus* lean strategies, arises from the fact that if industrial sectors (fossil fuels and finance) know that there is a safety net for their ‘brown’ assets, then there will be no constructive ambiguity regarding the central bank’s decarbonization action: polluters will be assured of its intervention. In this case, the incentive for the financial sector to get rid of its polluting assets quickly will be reduced. This risk of moral hazard can go even further: knowing in advance that the central bank will intervene in any case, the financial sector would not only be encouraged to keep its current polluting assets, but could continue to buy and issue them. Brown financing in the form of loans to carbon-intensive companies or purchases of securities issued by them could even continue once the central bank’s decarbonization action of last resort is underway, if it is not accompanied by sufficiently strong conditionalities forcing the banks benefiting from the liquidation of stranded assets to turn away from ‘brown’ financing and towards ‘green’ financing. This would be similar to the securitisation of loans before 2007, when the banking sector issued subprime loans, knowing that it could quickly dispose of them by securitising them. The underlying idea is that if commercial banks that continue to finance carbon-intensive activities in the expectation that the central bank will unconditionally buy their ‘brown’ assets, they will not fear being exposed to losses by continuing to hold new fossil assets (Sen and von Schickfus, 2020). Finally, moral hazard would arise because these purchases by the central bank are akin to a bail-out (and not a bail-in) of polluting sectors. It would therefore be a public bailout of private assets, in breach of the polluter-pays principle.

The limits of the central bank’s decarbonisation balance sheet policy are also highlighted by a risk-based analysis of the ecological transition, à la Carney (2015). Within the central banking community, it is common to distinguish several scenarios for the speed of the ecological transition (NGFS, 2022). In particular, it is common in this literature to consider that the speed of transition cannot be maximal because of the ‘transition risks’ that this would cause for the financial sector and fossil industries. Consequently, because of the alleged trade-off between physical risk and transition risk, the central bank should not announce a rapid decarbonisation program. Faced with these risks of losses that the balance sheet policy would produce in the rapid ecological transition scenario, the financial sector and the fossil fuel sector could try to capture the regulators and the central bank to avoid this precipitous scenario. The financial industry would defend its interests by arguing that the purchases to be made by the central bank are on such a scale (Figure 1), and therefore, the potential losses on such a scale too, that the central bank's credibility with the financial markets would be undermined. This attempt at capture would express the willingness of the sectors concerned to resist change (Hansen, T., 2022). This would delay the decarbonisation efforts of central banks. If the banking sector were unable to prevent the central bank's decarbonisation balance sheet policy, it could use the alleged trade-off between 'transition risk' and 'physical risk' to demand compensation in exchange for the faster liquidation of brown assets. Indeed, this trade-off could be interpreted by the fossil fuel industries as recommending a reduction in transition risk (at the cost of an increase in physical risk), and not an increase, as the central bank's balance sheet policy is supposed to do by precipitating transition risk. The financial and fossil fuel industries would then demand a subsidy in the form of relatively high purchase prices for their brown stranded assets, thus constituting a form of low haircut on these assets.

These difficulties with the central bank's decarbonisation balance sheet policy are not without theoretical justification, and could be considerable in practice. However, they are debatable in theory and would probably be surmountable in practice. The benefits of the balance sheet policy would outweigh its costs, so it could be implemented. We first present the theoretical foundations and then the operational elements of the central bank's decarbonisation balance sheet policy in practice. These developments provide both theoretical and practical answers to the questions raised above.

4.2. Theoretical arguments in favour of a central bank decarbonisation balance sheet policy

The previous arguments against the central bank's decarbonisation balance sheet policy can be questioned. By nuancing these criticisms, we emphasise the theoretical foundations of the central bank's policy of liquidating 'brown' assets.

With regard to the first criticism concerning the costs and losses of a balance sheet policy that bursts the brown asset bubble, the opposite reasoning can be applied. The first and most questionable limitation from a theoretical point of view is that concerning losses on the central bank's balance sheet. The balance sheet of the monetary institution is difficult to compare with that of a commercial bank or, *a fortiori*, that of a private firm. A central bank can operate with negative capital, as the Bank for International Settlements has pointed out (BIS, 2013; Bell et al., 2023). For the credibility of the central bank, losses are less important than the legitimacy of their cause. As long as the losses incurred are necessary for the fulfilment of the mandate entrusted to the central bank by the community, then they are legitimate and acceptable to the community.

There remains the question of the costs of the *ex ante* action or 'leaning against the wind' strategy against 'brown' assets, which would be higher than the costs of the *ex post* 'clean' strategy. This conclusion on the relative costs of the two strategies is open to question: on the contrary, delayed action against a possible brown asset bubble, or *ex post* LLR action following the bursting of that bubble, could be costly. By pursuing a 'clean' strategy, the central bank would run the risk of doing 'too little, too late', to use Goodhart's term (1995, p. 226), in the face of the 'green swan' crisis caused by the bursting of the brown asset bubble. The *ex post* emergency action of the LLR to deal with the crisis would then entail the risk of an even greater financial panic than that of the *ex ante* decarbonisation policy. We could then have a scenario where 'brown' assets fail more strongly and more quickly than in the case of the announcement of the decarbonisation policy. In this 'clean' strategy scenario, central bankers would be forced to buy even larger amounts of assets to calm the panic. The consequence would be that the size of the central bank's balance sheet policy would be such that the institution would fear for its credibility, making it difficult to gain political and public support for emergency LLR action. The expectations of various agents would work against the central bank. Moreover, in this scenario, the central bank would ultimately take the risk of even higher losses on its balance sheet.

On the other hand, there are many reasons in favour of the *ex ante* 'lean' strategy: decarbonisation action by the central bank would benefit from being *ex ante*, before the stranded assets crisis, and no longer an *ex post* LLR action once the 'brown' assets have failed. The first reason is that the brown asset bubble is less a theoretical possibility than an empirical reality. Studies show that there is currently a 'carbon bubble' resulting from the overvaluation of 'brown' assets (Leaton, 2011; Battiston et al., 2017; Mercure et al., 2018). Consequently, the 'liquidator of last resort' of brown assets would make it possible to deflate this bubble. This deflation would reduce not only the scale of, but also the uncertainty about the 'green swan' crisis that would follow the bursting of this 'carbon' bubble. If this decarbonisation policy action by central banks is *ex ante*, rapid and on a large scale, financial market expectations could be reversed, thus putting a quicker end to the panic and doubts about decarbonisation (Sen and von Schickfus, 2020; Dunz et al., 20221; Campiglio et al., 2023). Furthermore, estimates of the value of stranded assets (Figure 1) suggest that this deflation of the carbon bubble would be sustainable and credible in the light of central banks' past balance sheet policies. There would be a connection between, on the one hand, a rapid ecological transition and, on the other hand, as a corollary, a decarbonisation balance sheet policy acting preventively (before the crisis and the bursting of the bubble) and rapidly. Such rapid action by the central bank would maximise the chances that the cost of the balance sheet policy in terms of the amount of purchases of stranded 'brown' assets would not saturate the size constraint of the central bank's balance sheet. In other words, rapid *ex ante* decarbonisation would require a smaller increase in the central bank's balance sheet. In particular, preventive decarbonisation action in the G4 high-income countries in the database would limit the contagion of a carbon bubble crisis from these countries to fossil energy producers operating in low/middle-income countries. Decarbonisation and the ecological transition thus once again raise the question of an international LLR (Aglietta and Espagne, 2022); not only because the Earth (and its climate) is a global public good, but also because the results show the mismatch between the amount of stranded assets at global level and the size of the G4 central banks' balance sheets (see Figure 1-f). This raises the question of who will play the role of international LLR in the event of a 'green swan' starting in the G4 countries. The question also arises as to which institutions could take on the role of international LLR in the event of a 'green swan' crisis arising outside the G4: i.e. a crisis emerging either in developed fossil fuel-producing countries (say Australia or Norway), or in other types of countries that are also fossil fuel producers (Russia, China and the Middle East, etc.).

Another challenge to central banks' decarbonisation policy is based on the trade-off between transition risk and physical risk. The theoretical elements of ecological economics lead us to question the validity of this argument.

The basic argument against a balance sheet policy was the trade-off between physical risk and transition risk. The standard choice, which protects the short-term interests of the financial sector, is that we should choose to reduce the transition risk, at the cost of an increased physical risk. A first interpretation of this trade-off is that transition risk must be reduced. One reason would be that the cost of this transition risk for the financial sector, a sort of 'green swan', would be too great to bear. This argument from the financial fossil sector strongly resembles a form of moral hazard commonly called 'too big to fail'. However, the data on stranded assets (Figure 1) suggest that, on the contrary, this transition risk (the stranding of brown assets) is sustainable for some central banks. Following this view of the trade-off between transition risk and physical risk, the balance sheet policy of liquidating stranded assets is not advisable, as it would accelerate the speed of failure of 'brown' assets, and therefore increase transition risks. This arbitrage thesis biases the debate in favour of reducing financial 'transition risk'. The problem is that this bias gives a perverse incentive to the financial sector: the increase in transition (financial) risk, and hence the reduction in 'brown' assets, is presented as an 'abnormal', sub-optimal situation that must be compensated for by the central bank. Yet this subsidy is contrary to the polluter-pays principle. Secondly, this trade-off raises questions because, by being biased in favour of reducing the risk of transition, it implies a relatively slow speed of transition, with only moderate concern for eliminating fossil assets. The consequence of this relative inaction on climate change is that the carbon bubble is allowed to expand. Above all, this strategy has a negative impact by increasing the physical risks to reduce the transition risk. However, the increase in physical risk that this would cause could be much greater than expected. Such a trade-off is based on the questionable assumption that the physical risk increases in a continuous and linear manner, in particular as the transition risk decreases. However, the studies put forward the hypothesis of non-linearity, with critical thresholds of physical risk when tipping points, bifurcations, or regime changes occur (Lenton et al., 2008; Lenton, 2013; Lenton et al., 2019; Kedward et al., 2022). The other problem with the rise in physical risks is that it could lead to points of no return, with 'sunk costs' generated by irreversible destruction or disappearance (Toniazzo et al., 2004; Solomon et al., 2009; Stern, 2013; Chenet et al., 2021; Scialom, 2022). In view of these dangers of non-linearity and irreversibility, the idea of managing the trade-off by swapping a reduction in transition risk for an increase in physical risk seems sub-optimal. To put it another way, the strategy of reducing the speed of ecological transition in order to reduce transition risk appears harmful in view of the physical risks it entails. It follows that the trade-off between transition risk and physical risk is therefore rather ill-founded. The conclusion is that a faster path of ecological transition is desirable, and achievable thanks to a decarbonisation balance sheet policy by central banks.

Beyond the previous cost-benefit analysis, our proposal for a market liquidator of last resort (MLLR) has theoretical foundations in Minsky's theses. Our proposal for an MLLR is largely based on Minsky's extension of LLR theory. Minsky developed an evolutionary theory of the LLR: "Institutions are both legislated and the result of evolutionary processes. Once legislated, institutions take on a life of their own and evolve in response to market processes" (Minsky, 1986 (2008, p. 7)). Our MLLR proposal is consistent with Minsky's evolutionary theory.

Firstly, in his LLR theory, Minsky proposes, as we do, *ex ante*, preventive, structural, last resort action by the central bank to preserve financial stability: "The lender of last resort functions of the central bank must be so organised that they can respond to changes in financial markets. In particular, this function has preventive as well as rescue aspects" (Minsky, 1959, p. 4). For this preventive approach of last resort, Minsky (1970, p. 79; 1982a, p. 156) specifies: "Maintaining orderly conditions in a key asset market is an extension of the lender-of-last-resort functions in that it [the central bank] is a preventive lender of last resort". In this regard, Minsky considers that the traditional LLR, which consists instead of *ex post* intervention of last resort, for curative purposes and on a temporary basis only during periods of crisis, is insufficient: "One view of the central banks' money-market responsibilities limits them to the maintenance of the liquidity of the banking system and orderly conditions in the government bond market. A central bank with such a view of its money-market responsibilities would not stabilise the new assets either by purchasing or discounting them" (Minsky, 1982 (2016, p. 179)). The reason is that Minsky assigns central bank interventions not only an emergency mission in the face of crisis, but also the mission of preventing *ex ante* the systemic uncertainty inherent in finance, since, according to him, this generates crises endogenously: this is Minsky's famous "Financial Instability Hypothesis" (FIH). This is why the central bank must also intervene outside of crisis periods to regulate finance: “Because the Federal Reserve has the responsibility, so to speak, to pick up the pieces when things go wrong, it must be concerned with and guide the growth and evolution of financial practices in periods of tranquillity as well as when circumstances force it to intervene” (Minsky, 1986 (2008, p. 45)). Thus, according to Minsky, this *ex ante* preventive action by the central bank must prevent the sources of financial crises, such as bubbles in financial assets. More generally, it is a question of regulating financial activities by encouraging those that promote financial stability, and discouraging those that, on the contrary, lead to financial instability: “It is also a responsibility of the central bank to guide the evolution of the financial system, either by legislation or by its operations, so that the actual and potential weights of speculative and Ponzi finance are constrained” (Minsky, 1982b, pp. 35-36). This justifies the role of our MLLR, which would discourage the current bubble in “brown” fossil assets, and reduce the exposure of bank balance sheets to climate risks.

Secondly, Minsky’s theory of “preventive” action of last resort by the central bank to preserve financial stability underpins our idea of an MLLR, which is designed to be a long run policy, and therefore takes a long-term view, unlike traditional short-term LLR action once a financial crisis has begun. Minsky emphasises the long-term horizon of the central bank’s financial regulation action: “The major thrust of the argument that follows is that the Federal Reserve should use its monetary powers to guide the evolution of financial markets in directions that are compatible with financial stability in the longer run rather than improvise controls that put out fires but which allow the underlying market situation to remain unchanged” (Minsky, 1982 (2016, p. 187)). Ecological planning is typically a long-term policy with long-term financing needs. This contrasts with the generally short-term horizon of finance (Chenet *et al.,* 2021), with Minsky’s hypothesis of disaster myopia (Guttentag and Herring, 1984, p. 1359). Consequently, following Minsky’s approach, our MLLR proposal is part of a “last resort” logic in the sense that, in the first instance, market players would not be able to do it themselves:

either because of their time horizon (Minsky's disaster myopia), or because of their intrinsic instability according to Minsky (FIH). Our MLLR proposal follows Minsky's idea that the central bank must evolve to adapt to the new long-term reality of ecological planning.

Furthermore, Minsky provides a theoretical basis for the necessary evolution of the central bank: the classic LLR has evolved into the "market maker of last resort", then into the "buyer of last resort", and now into the "market liquidator of last resort" in the ecological transition. This evolution is the result of the central bank's necessary adaptation to the sources of financial instability endogenous to the economic and financial system, which are themselves constantly evolving, in accordance with Minsky's theory of endogenous financial instability. Thus, following Minsky's perspective, the central bank's action of last resort can take various forms that are not necessarily those of being a "lender", but can also evolve towards being a "liquidator" of last resort.

Finally, Minsky recommends that the central bank should not be subject to financial developments, but should guide them: "The evolution and development of central banking has not been solely a reaction to an independently evolving financial structure, but has also been a determinant of this evolution" (Minsky, 1982 (2016, p. 186)). Our MLLR proposal is fully in line with this approach. In the context of the ecological transition, the central bank cannot limit its action to that of an LLR that would intervene after the carbon asset bubble bursts. In fact, such action would not be optimal because it would be too late: the ecological crisis is fundamentally different from a financial crisis in that it is irreversible, so it can only be limited upstream through preventive action. By contrast, downstream or after-the-event intervention, according to the standard LLR logic, would be to take the risk of doing "too little, too late". In this sense, the central bank must participate in ecological planning policy aimed at decarbonising bank balance sheets, which justifies the evolution of its action from LLR to MLLR.

For Minsky, central bank action must evolve with the evolution of the forms of uncertainty generated by finance. However, fossil assets bring radical uncertainty with the ecological crises of the 'Capitalocene' with the current geological and ecological era as shaped primarily by capitalism (Malm and Hornborg, 2014; Haraway, 2015; Malm, 2016; Moore, 2016). Faced with this radical uncertainty for life on earth, the central bank must shift its action towards MLLR for fossil assets.

With the previous cost-benefit analysis associated with Minsky's theoretical foundations, the preceding developments temper the criticisms of balance sheet policy and, in fact, highlight its benefits. A detailed discussion is still needed on how to mitigate the moral hazard problems arising from balance sheet policy. This would involve adapting the implementation of the balance sheet policy in order to minimise its perverse moral hazard effects.

4.3. Operational implementation of the decarbonisation balance sheet policy

The limitations of the balance sheet policy raised from the moral hazard approach relate in particular to the incentives and expectations of actors in relation to stranded assets. The aim is therefore to suggest ways of reducing these problems through the practical implementation of balance sheet policies, in particular by means of pre-announcements and conditionalities. The perverse moral hazard incentives of the policy of purchasing 'brown' securities, which lead to a slow reduction, or even the preservation or expansion of brown assets, would be reduced in particular by the central bank's transparency regarding this policy by announcing its operational procedures in advance. This transparency would modify agents' incentives and expectations. By announcing the rules and conditions in advance, the central bank would limit uncertainty about the terms and conditions of its intervention. This transparency would enhance the credibility of the decarbonisation policy and enable it to anchor agents' expectations. This anchoring of market expectations could facilitate the ecological transition, reduce the volatility of brown assets (the transition risk), and therefore facilitate and accelerate the central bank's decarbonisation action (Dunz et al., 2021; Campiglio et al., 2023).

A first solution to moral hazard would be for the central bank to announce in advance that it would only buy polluting assets that have already been issued. In this way, any 'brown' assets issued after the start of the liquidation process would not be purchased. Only brown assets issued before the liquidator of last resort's action would be purchased by the central bank. Another, more drastic, operational solution would be for the central bank to pre-announce that the aim of its action is not to safeguard the markets in polluting assets but to liquidate them. The balance sheet policy of buying brown securities would then become an action of 'liquidator of last resort'. In this case, the central bank would not be searching to restore the market value (price) for stranded fossil assets, but instead to close these markets. This pre-announcement would imply a sharp anticipated depreciation in the value of fossil fuel assets, providing an incentive for the financial sector to stop trading them in the knowledge that these assets may no longer have a market price. A final possible solution to the moral hazard problem would relate to the central bank's brown asset purchase price policy, in particular, because the liquidation value set by the central bank would constitute one of the variables determining the possible level of central bank losses during the decarbonisation balance sheet policy.[5] In order to reduce moral hazard, a radical proposal in terms of pricing would be for the central bank to announce in advance that it will buy stranded fossil assets at a negative price. The literature on negative pricing has a long history in the field of energy and ecology (Wright and Williams, 1989; Baumgärtner and Winkler, 2003), and is currently growing rapidly (Ahonen et al., 2022; Biber et al., 2022; Frondel et al., 2022; Lin and Zhang, 2022; Prokhorov and Dreisbach, 2022),

[5] From a theoretical point of view, it could be argued that these questions of price and losses are not the most crucial insofar as the central bank is an institution that can operate outside of the market logic and its price mechanism. Moreover, it has been pointed out that the central bank is an institution that serves in part to incur losses in order to preserve the economy, and is therefore resilient to losses.

particularly following the Dasgupta report (2021). In line with the polluter-pays principle, the liquidation of stranded assets at a negative price would mean that commercial banks would pay for the central bank (in the collective interest) to get rid of their polluting assets (waste). This negative price would be a form of haircut or Pigouvian tax that would give banks an incentive to hold fewer brown assets.[6] A negative purchase price would limit the cost to the central bank of purchasing 'brown' assets. By limiting the increase in the size of the central bank's balance sheet, the decarbonisation balance sheet policy would be facilitated because it would become more consensual in the community of central bankers, potentially reducing the limitations placed on it by the most conservative central bankers.

Nonetheless, given the radical uncertainty involved in liquidating brown asset markets from an ecological transition perspective, it seems difficult to set a liquidation price for 'brown' stranded assets. The level of the haircut, discount or tax on these stranded assets will *a priori* be complex for the central bank to determine. This is not the classic action of an LLR looking for an asset restoration price to relaunch a market. It is a question of closing a market, so the more appropriate term is liquidation value, which could be very different from restoration or recovery value. Even a negative price for these stranded assets is part of a market logic that is *a priori* ill-suited to liquidating a market: an optimal and efficient market price is ill-suited to the uncertainty and complexity of this environment. This specificity means that the concept of assets transferred to a 'bad bank' scheme also seems to apply imperfectly. Indeed, a 'market liquidator of last resort' differs from a bad bank structure not only because it does not buy brown assets at market value, but also because, unlike a bad bank structure, it does not seek to resell the assets purchased. In addition, the central bank has to set the liquidation price on the basis of the contradictory considerations of Pigouvian taxation on the one hand, and the desire for subsidies or compensation for liquidation that the financial sector would need on the other.

[6] On haircuts, see McConnell et al. (2022).

Brown assets are thus analysed as non-valuable wastes, and the polluter must pay for their removal by the central bank. At the same time, they are presented by the financial sector as valuable assets, so that the central bank must pay and compensate the financial sector for having taken away a valuable asset from its wealth.

The policy of announcement of the liquidation of brown assets would be supplemented by strong conditionality: for example, the financial sector would be prohibited from buying new carbon assets (based on a carbon rating scale). In addition, as the ultimate objective of central banks' decarbonisation policy is to 'green' financial actors' balance sheets, another condition for purchases of brown securities by the central bank would be the obligation to improve the ratio (and volume) of 'green' assets on the balance sheet of the institution benefiting from the central bank's purchases of its 'brown' securities.

5. Conclusion

Our database on stranded asset estimates shows that for some countries, notably the USA and Japan, the estimated amount of stranded assets appears to be of a magnitude that fully justifies large-scale asset purchase (LSAP) programs of 'brown' securities and central bank balance sheet policies. The data also highlight that, at least in the G4 countries, the size of central banks' balance sheets puts them in a position to buy the stranded assets. These purchases would be no larger than those made in response to the global financial crisis (2007-2009) and Covid pandemic (2020-2021).

Given this assessment, which concerns high-income countries, it can be concluded that the speed of the ecological transition and the 'greening' of financial regulation could be accelerated. In a cost-benefit analysis, this acceleration could bring clear benefits, including: the reduction of physical risk, the preservation of the environment, and better targeting of banks' financing to the needs of ecological transformation. Thus, at first glance, the data seem to indicate that the counter-argument that the amount of stranded assets would be so large as to prevent central banks from managing these assets in the form of purchase programs has little empirical basis. On the contrary, the data suggest that central banks would be able to manage the transition risk through balance sheet policy. In other words, central banks would not be forced to increase physical risk to deal with a supposedly insurmountable transition risk.

Admittedly, the ambition of the balance sheet policy we are proposing is modest, as it concerns the decarbonisation of balance sheets rather than the direct 'ecologisation' of banks' balance sheets. But it seems that decarbonisation is a prerequisite, a necessary step for the subsequent ecologisation of balance sheets. The amount of brown assets currently seems to be a constraint for achieving a rapid ecological transition, in the name of reducing 'transition risk', and thus the speed of the transition is being slowed down in the name of losses on fossil assets. Brown assets appear to be not only a bubble, but also a source of climate inaction, of path dependency holding back socio-ecological transformation.

However, the central bank's decarbonisation policy we develop also raises several questions, particularly for the financial sector. We suggest ways to mitigate the potential risks of central bank decarbonisation policies.

Obviously, our developments do not claim to exhaust all the issues raised, so questions remain open for future research. First, unfortunately, our database only covers the balance sheets of central banks in a limited number of high-income countries. However, the issue of stranded assets and their purchase by central banks could also be acute for other high-income fossil fuel-producing countries (notably Australia, Saudi Arabia and Norway) or other upper-middle and lower-middle income countries that also produce fossil fuels (Russia, China and Iran). The research and database could therefore be extended to these countries. If it turns out that the central banks of these countries are not in a position to buy the stranded fossil assets, then the question of international LLR arises. The ecological transition is very likely to renew the classic theme of the international LLR. Indeed, the data collected suggests that the amount of stranded assets at the global level could far exceed the balance sheet sizes of the G4 central banks, so that the latter would have difficulty forming the global financial LLR in the event of a 'green swan' crisis at the global level. Second, the database analysed covers only one dimension of the socio-ecological transformation from fossil fuels. The database should be broader, including estimates of the human costs (linked, for example, to the fate of climate refugees) of global warming, the physical risks (hurricanes, floods, fires, droughts, etc.), and the sunk costs of biodiversity loss and the destruction of nature in general. Central banks could be led to integrate these vital ecological issues into their objectives, which are at the very least a major source of economic, monetary and financial destabilisation, and therefore are at the heart of their mandates.

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