Macrofinancial causes and risks of deforestation, land conversion and water stress

Analysing the role of central banks and financial supervisors through a stock-flow double materiality lens

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Macrofinancial causes and risks of deforestation, land conversion and water stress: analysing the role of central banks and financial supervisors through a stock-flow double materiality lens

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Executive summary

The financial system has contributed to the global environmental crisis, and central banks and financial supervisors have a critical role to play in aligning this system with environmental sustainability. Based on the concept of double materiality, central banks and financial supervisors should not just try to protect the financial system from the financial risks of the environmental crisis (financial materiality). They should also take actions aimed at reducing the environmental materiality of the financial system by incorporating environmental criteria into monetary and financial policies. From a systemic perspective, the more central banks and financial supervisors help reduce the adverse environmental effects of economic activities, the lower the risks posed to the financial system.

So far, central banks and financial supervisors have mostly focused on certain climate aspects of double materiality. However, the interactions between the ecosystem and the financial system have several non-climate aspects, which include land conversion, in particular deforestation and conversion of other non-forest natural ecosystems (such as natural grasslands and savannahs), as well as unsustainable water use. It is now urgent that central banks and financial supervisors pay specific attention to these non-climate aspects as well.

In this report, we argue that central banks and financial supervisors can use stock-flow consistent approaches to analyse the double materiality of the financial system related to climate change, land conversion and water stress. These approaches pay particular attention to the dynamic interactions between monetary stocks and flows (such as debt, credit flows and consumption spending) and physical stocks and flows (such as available water stocks, deforestation flows and cropland areas).

From an environmental materiality perspective, stock-flow consistent approaches can analyse how the provision of credit by the financial system contributes to the generation of physical flows that harm the ecosystem, leading, for instance, to land conversion and water stress. This contribution of financiers can be either direct, when they finance those that generate these flows, or indirect, when they finance those who are in the supply chains of the companies that directly harm the ecosystem.

From a financial materiality perspective, stock-flow consistent approaches can dynamically analyse physical and transition risks related to the environmental crisis. Physical risks are the result of various ecosystem stocks having become either too high (e.g. high atmospheric carbon stocks that lead to climate change) or too low (e.g. low forest coverage that has adverse implications for climate and hydrological cycles, or low water stocks that result in water stress). Transition risks are primarily linked to policies that can be implemented to address environmental problems, such as regulations limiting deforestation or water pollution. Physical and transition risks can increase the cost of production, reduce resource availability and trigger knock-on effects, such as inflation. These can lead to rapid asset price changes, rising interest rates, debt defaults and consequently macrofinancial instability. Stock-flow consistent approaches are well-equipped to capture such non-linear and path-dependent macrofinancial feedback loops.

The report also argues that central banks and financial supervisors should introduce environmental materiality into their monetary and financial policy tools as soon as possible. To do so they need to collaborate with other public authorities to co-design environmental policy mixes and develop metrics that capture the environmental materiality of finance. These metrics should mostly focus on the activities undertaken by companies and the environmental impact of these companies in terms of physical flows. Physical flow-based metrics should capture both the past environmental performance (backward-looking metrics) and the targets of companies to reduce their environmental footprint with a specific emphasis on transition plans (forward-looking metrics). They should also reflect both direct and indirect environmental impacts (for example through supply chains) and be reported both in net and gross terms (i.e. with and without environmental offsets) to reduce the risk of greenwashing.

Due to data challenges, central banks and financial supervisors might need to use a gradual approach to the development and use of environmental materiality metrics. They can first develop some imperfect metrics based on existing data (e.g. metrics that mostly rely on activities) and design environment-adjusted monetary and financial tools based on these. They can then gradually improve the metrics and the tools, as more data is becoming available. Irrespective of the exact approach that each central bank and financial supervisor will adopt, it is important for them to do whatever it takes to stop being part of the problem and take action to discourage the financing of always environmentally harmful activities as soon as possible.

At the same time, central banks and financial supervisors should carefully monitor the financial materiality of the environmental crisis. They can capture transition risks by using environmental materiality metrics as proxies and they can approximate physical risks by using environmental dependency metrics. However, proxies might provide an inaccurate depiction of environment-related financial risks. For this to be addressed, central banks and financial supervisors should translate environmental impacts and dependencies into specific financial effects using scenarios about how climate change, land conversion and water stress might evolve in the coming years, depending on transition policies. Stock-flow consistent approaches can be used in this direction.

The actions of central banks and financial supervisors should be consistent with global environmental justice. Climate change, land conversion and water stress have historically been associated with the consumption and production of Global North countries. Therefore, central banks and financial supervisors in the Global North have a responsibility to act decisively on reducing the financing of environmentally harmful activities in a way that respects human rights and social justice in the Global South. Global North countries should also support the environmental efforts of central banks and financial supervisors in the Global South in a way that fits the differentiated needs of Global South countries.

1. Introduction

Over the past few decades, human activity across the globe has led to an environmental crisis, which is reflected in the acceleration of global warming, the unprecedented depletion of natural resources, the rapid conversion and degradation of natural ecosystems and the loss of biodiversity. To address this environmental crisis, it is necessary to fundamentally transform how we produce and consume in a way that is consistent with social justice. This transformation can be facilitated through the implementation of fiscal, industrial, regulatory, financial, monetary and social policies. But despite increasing calls for action, policy interventions around the globe fall substantially short of what is required to achieve ambitious decarbonisation targets, stop the depletion of natural resources, protect ecosystems from further degradation and restore such systems where this is possible.

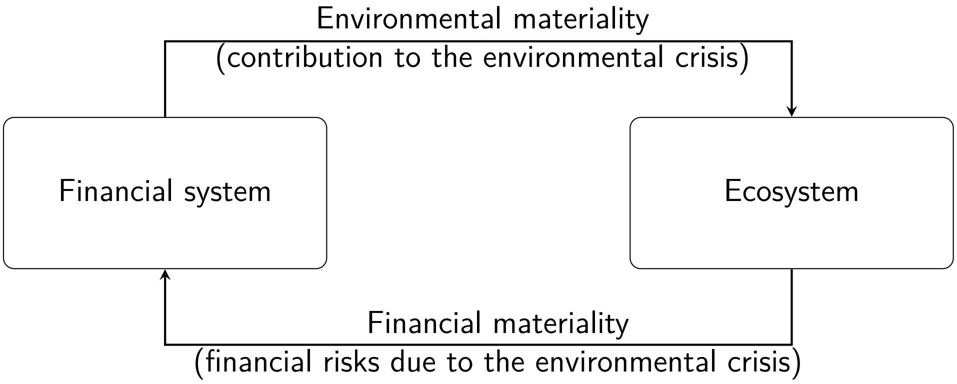
The financial system has contributed to the global environmental crisis and central banks and financial supervisors have a crucial role to play in aligning this system with environmental sustainability. The concept of double materiality – which captures the interactions between the financial system and the ecosystem – is particularly important in understanding how central banks and financial supervisors should react to the growing challenges associated with the environmental crisis (Figure 1). Double materiality suggests that there are two forms of materiality that are relevant for the financial system: environmental materiality and financial materiality.[1] On the one hand, *environmental materiality* captures the fact that the financial system, which includes financial markets as well as private and public financial institutions, contributes to the environmental crisis. Through credit provision, the financial system supports activities that are conducive to deforestation, the conversion of other non-forest natural ecosystems (such as natural grasslands and savannahs), unsustainable water use, water pollution, as well as to the generation of greenhouse gas (GHG) emissions and hazardous waste. On the other hand, *financial materiality* refers to the physical and transition risks that arise due to the environmental crisis – and attempts to address it. These risks, which materialise both at the micro and the macro level, can lead to debt defaults, asset price deflation and higher risk premia, causing macrofinancial instability.

Based on the concept of double materiality, central banks and financial supervisors should not just try to protect the financial system from the financial materiality of the environmental crisis. They should also take actions aimed at reducing the environmental materiality of the financial system, by incorporating environmental criteria into monetary and financial policy tools. From a systemic perspective, the more central banks and financial supervisors reduce the adverse environmental effects of the financial system, the lower the risks related to financial materiality.[2]

[1] For the concept of double materiality, see Adams et al. (2021), Oman and Svartzman (2021) and Täger (2021). See also NGFS (2021) and WWF (2021a), for an analysis of the importance of double materiality for central banks in the case of biodiversity.

[2] See also WWF (2022d) where it is highlighted that today's negative environmental impacts are tomorrow's financial risks.

Figure 1: The double materiality of the financial system



Source: Authors' depiction drawing on NGFS (2021) and Oman and Svartzman (2021).

So far, central banks and financial supervisors have mostly focused on certain climate aspects of double materiality. However, the interactions between the ecosystem and the financial system have several non-climate aspects, which are most notably related to deforestation, conversion of other non-forest natural ecosystems and unsustainable water use. Central banks and financial supervisors should pay specific attention to these non-climate aspects as well.[3]

First, from an environmental materiality perspective, the financial system supports many activities that lead directly or indirectly to land conversion (including deforestation) and unsustainable water use. Agricultural activities, such as cattle ranching and farming, as well as mining activities are direct drivers of land conversion and water use since land and water are essential components of these activities.[4] Activities in other sectors, such as food manufacturing and electricity generation, are indirect drivers of ecosystem degradation through their supply chains.

Second, from a financial materiality perspective, the smooth function of the financial system is highly dependent on forests and non-forest natural ecosystems, biodiversity and freshwater. This is so because companies in the agriculture, mining and other sectors that depend on land, water and biodiversity for their everyday activities might fail to meet financial commitments as a result of ecosystem degradation and policies that try to address this degradation.

There are many examples that illustrate the double materiality of finance from the perspective of land conversion and water use. For instance, it is well-documented that many financial institutions around the world contribute to deforestation via the activities that they finance, being at the same time exposed to transition risks. Forest500 has identified 150 financial institutions that have provided financing to 350 companies that have a high contribution to tropical deforestation via beef and leather,

[3] A few central banks have recently started paying attention to environmental issues that move beyond climate (see for example the speeches by Breeden, 2022 and Elderson, 2022, as well as the ECB's 2024-25 climate and nature plan; ECB, 2024). However, they have done so mostly from a financial materiality perspective, relegating the environmental materiality of finance to the sidelines. Moreover, the growing awareness of the ecosystems-finance nexus has not been translated into any concrete decisions or actions.

[4] For the impact of agriculture and mining on deforestation, see Pacheco et al. (2021).

soy, palm oil, timber, pulp and paper supply chains.[5] Apart from their negative environmental impact, these companies and their financiers seem to be significantly exposed to the recent EU regulation on deforestation-free products which does not allow companies to place specific deforestation-related products in the EU market (or export from this market).[6]

The impact that the financial system has on deforestation is also exemplified by the favourable effects of rural credit policy on deforestation in Brazil. In 2008, the Central Bank of Brazil introduced a policy that made the concession of subsidised rural credit conditional on the compliance of borrowers with legal titling requirements and environmental regulation. This policy helped to reduce deforestation by restricting access to rural credit in municipalities where cattle ranching is the key economic activity.[7] This illustrates that credit conditions have an impact on the environment and green financial policies can reduce the environmental materiality of finance.

Importantly, the double materiality of the financial system with respect to deforestation, land conversion and unsustainable water use should not be understood within a static context. Instead, a dynamic systems-based analysis is necessary. In the case of environmental materiality, the effects of the financial system's support for unsustainable activities typically take time to materialise. For example, the conversion of natural forests to other types of land use threatens biodiversity and the climate system once it has led to a substantial reduction of forest stocks. Similarly, unsustainable water use leads to water stress once water resource stocks have been substantially depleted or polluted so that local water demand exceeds local supply.[8]

Financial materiality should be analysed in a dynamic manner as well. As is well-known, financial crises are often caused by growing credit flows that lead to the accumulation of too much private debt. However, it might take time until a sufficiently high stock of debt has been accumulated and households and firms are unable to repay it, leading to macrofinancial instability. In the analysis of environment-related financial risks, time is important for several reasons. First, the transition to an environmentally sustainable economy might require a substantial level of debt-financed investment. However, after some time, the growing flow of credit towards environmentally sustainable projects could lead to unsustainable levels of private debt, creating green credit bubbles. Second, although transition policies might create a financial burden for companies as they are implemented, they can reduce physical risks in the long run. For example, the EU regulation on deforestation-free products or higher capital requirements for activities conducive to deforestation can create instability in the agricultural industry in the short run, but can help to stabilise ecosystems in the long run. Third, physical risks can start causing big financial crises

[5] For more details, see Thomson (2022).

[6] See Marriner (2023).

[7] See Assunção et al. (2020).

[8] Throughout the report, the term 'water stress' is used to capture both quantitative and qualitative aspects. This implies that water stress refers to cases where too much water is consumed or when too much water is released in a polluted form – in both cases water becomes unavailable for use in other sectors. Therefore, our definition of water stress is broader than other definitions that capture only quantity aspects, for example, by referrring to water withdrawals relative to available renewable water supplies (see e.g. Hofste et al., 2019).

once specific environmental thresholds related to physical stocks have been passed. For instance, large decreases in the population of pollinators driven by deforestation and reduced natural ecosystems areas might take time until they generate substantial irreversible losses in crop yields. Moreover, deforestation is likely to steeply reduce rainfall (and thus agricultural productivity) only once a specific threshold of forest loss has been passed.[9]

The importance of dynamic analysis for understanding the links between the environmental crisis and finance has been recognised in the central banking and financial supervision community. As a result, scenario analysis with the use of long time horizons has become a prominent tool for analysing climate-related financial risks.[10] However, central banks and financial supervisors have not sufficiently recognised the implications of double materiality, and more specifically that their decisions have an impact on the environmental crisis. This is reflected in climate stress testing exercises where environmental materiality is typically ignored since the environmental risks are treated as exogenous to the actions of central banks and financial supervisors. On top of it, the models used by central banks do not typically include an integrated approach to the interactions between physical and monetary stocks and flows which, as we will explain in more detail below, is important for a comprehensive analysis of how macrofinancial systems and ecosystems interact through time.

In this report, we provide a stock-flow double materiality lens to the interactions between finance and the ecosystem, paying particular attention to land conversion (with an emphasis on deforestation) and water stress. We also make recommendations on how central banks and financial supervisors should respond to the environmental crisis. The report is organised as follows. In Section 2, we explain what monetary and physical stocks and flows are and why they are important for understanding the interactions between the macrofinancial system and the ecosystem. In Section 3, we analyse the channels through which the financial system affects the environment (environmental materiality). We focus again on issues related to climate change, land conversion and water stress. Section 4 zooms in on the channels associated with the financial materiality of the environmental crisis. Our aim is to provide an in-depth understanding of the transmission channels through which climate change, land conversion and water stress can cause financial risks. In Section 5, we explain how central banks and financial supervisors can develop metrics and approaches that allow them to calibrate monetary and financial tools to address climate, land conversion and water stress through a double materiality perspective. Finally, we provide a summary of our recommendations.

[9] For an analysis of the effects of deforestation on rainfall, see Leite-Filho et al. (2021).
[10] See, for example, the NGFS (2023a).

2. Understanding monetary and physical stocks and flows

The concepts of stocks and flows have been extensively used both in the environmental science and the economics literature. Stocks refer to the accumulation or storage of a particular quantity or value at a given point in time, while flows refer to the rate at which that quantity or value changes over time. Monetary stocks and flows capture the dynamic evolution of the macrofinancial system, while physical stocks and flows capture key changes taking place in ecosystems. Monetary stocks and flows are measured in monetary units, such as dollars or pesos, while physical stocks and flows are measured in physical units; for example, carbon dioxide is measured in tonnes, forest area stocks are measured in hectares and water stocks are measured in km^3.

2.1 The role of monetary stocks and flows

Our economies and financial systems are characterised by continuous changes in monetary stocks and flows. Let us consider the monetary interactions of carbon-intensive companies with households and banks to illustrate that. When households buy goods from carbon-intensive companies, they typically use their bank deposits as a source of funds. These bank deposits are transferred to the carbon-intensive firms that sell these goods. This is shown in Table 1, where plus signs indicate sources of funds (inflows) while negative signs indicate uses of funds (outflows). For example, the consumption of households (C) is a use of funds for them, so we denote it by a negative sign, while it is a source of funds for companies and this is why we use a plus sign in Table 1.[11]

ΔD_C captures the deposit flows related to the consumption spending of households. When households pay for the goods that they buy, there is an outflow of deposits from the banking sector. This is accompanied by an inflow of deposits into the banking sector as companies receive money into their deposit account. Therefore, the overall deposits of the banking sector remain unchanged.

When banks provide loans to companies, the latter receive a monetary inflow ($+\Delta L$) which corresponds to a monetary outflow for banks (-ΔL). In order for banks to fund these they create deposits ($+\Delta D_L$). Deposits are an asset for companies and a liability for banks, while loans are a liability for companies and an asset for banks. Assets and liabilities represent monetary stocks, while changes in assets and liabilities represent monetary flows.

These changes in stocks and flows create specific commitments that can sometimes lead to financial fragility. For instance, if in our example carbon-intensive companies accumulate too much debt, they might be more vulnerable to climate policies aimed

[11] For more details, see Godley and Lavoie (2012).

Table 1: Monetary flows between households, carbon-intensive companies and banks: illustrative example

	Households	**Carbon-intensive companies**		**Banks**	**Sum**
		Current	**Capital**	**Capital**	
Consumption	-C	+C			0
Change in households' deposits due to consumption spending	+ΔD_C			-ΔD_C	0
Sales		-S	+S		0
Change in companies' deposits due to consumption spending			-ΔD_C	+ΔD_C	0
Change in deposits due to new loans			-ΔD_L	+ΔD_L	0
Change in loans			+ΔL	-ΔL	0
Sum	0	0	0	0	0

Source: Authors' depiction
Note: Δ denotes change. A positive sign is associated with the use of funds, while a minus sign captures use of funds. The current account refers to payments made or received. The capital account captures how investment in real and financial assets is funded.

at reducing carbon emissions, such as carbon pricing. These policies might reduce their revenues and increase their spending, which in turn might reduce their ability to repay their debt. In a similar way, the banks that have provided loans to these companies might experience financial losses as well.

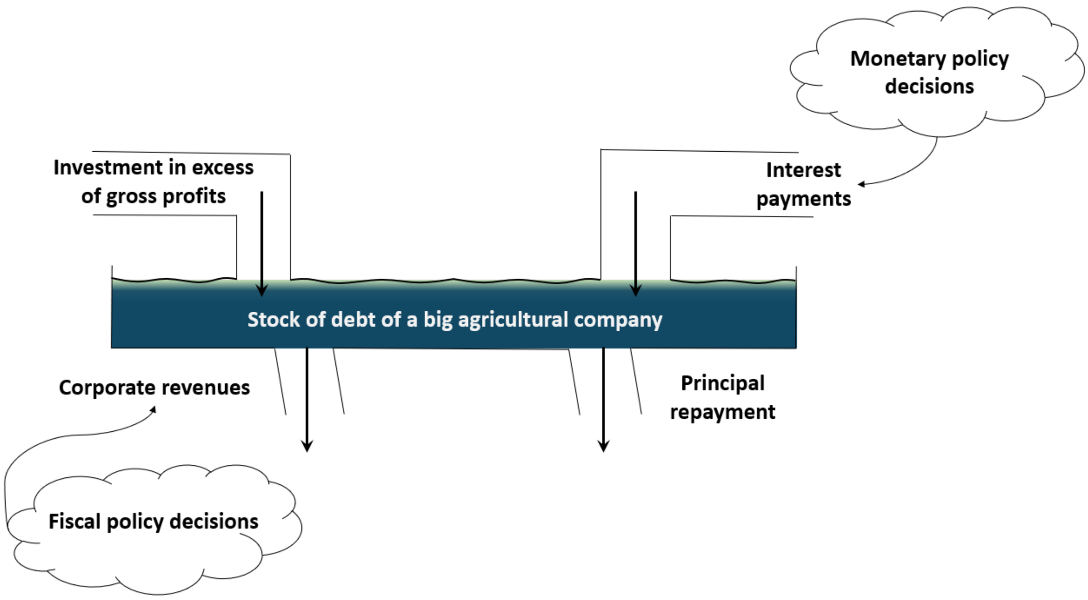
By tracking changes in monetary stocks and flows across different sectors, it is possible to monitor sources of macrofinancial instability and evaluate the performance of macroeconomic and financial systems. This is typically done through stock-flow consistent models. These models capture in detail the assets and liabilities of the institutional sectors of an economy through balance sheet matrices. They also track the monetary flows between these sectors through transaction flow matrices, which are more comprehensive versions of that matrix depicted in Table 1.[12]

Stock-flow consistency can therefore provide a systems-based perspective to the dynamics of macrofinancial systems. To illustrate that further, let us use the debt of a big agricultural company as an example (Figure 2). The debt of this company tends to increase when banks provide new loans to it, for example, because this company wishes to invest in new machines (this is an outflow for the company). As the company repays this debt, the stock of debt declines. For given investment needs, the lower the gross profits of the company (an inflow) and the higher the interest payments (an outflow), the higher the need to take out new loans and increase its debt. The accumulation of a high stock of private debt can result in default.

But the accumulation of private debt and the ability of this agricultural company to repay its debt are not only affected by these monetary stock-flow interactions at the micro level. Broader macroeconomic developments have a crucial impact as well. For

[12] For a detailed analysis of the stock-flow consistent modelling methodology, see Godley and Lavoie (2012). For the use of the Stock-Flow Consistent (SFC) modelling approach for analysing the macroeconomic performance of specific countries, see e.g. Zezza (2009) for the US, Papadimitriou et al. (2013) for Greece, Burgess et al. (2016) for the UK, and Zezza and Zezza (2022) for Italy. See also Nikiforos and Zezza (2017) for an overview of country-specific SFC models.

Figure 2: Monetary stock-flow interactions: the case of an agricultural company's debt



Source: Authors' depiction

instance, if central banks increase interest rates, the outflows of the company related to interest payments can gradually increase: a higher policy interest rate will sooner or later translate into a higher cost of borrowing. This can deteriorate the financial position of the company. Similarly, if the government reduces its subsidies to the agricultural sector, the revenues of the company can also decline. The same can happen if the government reduces social transfers to households, since part of these transfers might be used to buy food associated with the activities of the agricultural company. And if many agricultural and other companies relying on agricultural inputs default at the same time (for instance because of a collapse of agricultural productivity), both the government and the central bank might need to step in to provide liquidity to banks and take measures to ensure their insolvency.

These examples illustrate why it is important for central banks and financial supervisors to collect data that allows them to track stocks and flows in an integrated way. Without monitoring monetary stocks and flows and their interactions, sources of systemic macrofinancial instability might not be appropriately understood. This is particularly important in the context of the financial materiality of the environmental crisis as the transmission channels of environmental risks, and their compounded effects, are still poorly understood and quantified.

2.2 The role of physical stocks and flows

Stock-flow consistent models have not only been used to capture dynamic interactions in macrofinancial systems. More recently, these models have also been used to analyse interactions between physical stocks and flows. The DEFINE (Dynamic Ecosystem-FINance-Economy) modelling framework is one of the most prominent ecological stock-flow consistent framework that has been developed to simultaneously analyse monetary and physical stocks and flows. DEFINE has been used to generate several global scenarios about the macrofinancial system and its interaction with specific parts of the ecosystem [13] under different environmental policies.[14]

A key advantage of the ecological stock-flow consistent models is that they do not need to monetise the different components of the ecosystems (such as water, material reserves and forests) in order to analyse how they interact with macroeconomic and financial systems. Instead, the components of the ecosystems are expressed in physical units which makes it easy to identify how human activity might lead to the exceeding of planetary boundaries and what this implies for social and macrofinancial stability. Although these models are not in a position to assess the complex intrinsic value of ecosystems, they are well–suited to evaluate how policies and other interventions affect ecological systems and what trade-offs might be generated under different scenarios about the implementation of these policies and interventions.[15]

Let us use some examples to illustrate the importance of physical stocks and flows and their interactions. A typical example is related to carbon dioxide, the main contributor to rising atmospheric temperatures and climate change. Every year the carbon dioxide that is concentrated in the atmosphere tends to increase because of the carbon emissions that our economies generate. Although some carbon is absorbed by the biosphere and the oceans, the reduction in the stock of carbon in the atmosphere is not sufficient to offset the increase caused by the new flows of emissions. This leads to climate change.

Another example is the physical stock-flow interactions associated with land conversion, most notably deforestation. Figure 3 presents a simplified version of these interactions.[16] Depending on the level of economic activity, every year natural (regenerated and non-regenerated) forests are converted into (i) pastureland areas due to cattle ranching, (ii) cropland areas that are used for the production of food, feed or fuel, (iii) built-up areas, i.e. areas where houses, roads, mines and quarries and other buildings and facilities are located, and (iv) planted forests. This land conversion is captured by the deforestation flows in Figure 3.[17]

[13] These so far include material and energy resources, carbon and waste.

[14] See Dafermos et al. (2017, 2018); Dafermos and Nikolaidi (2019, 2021, 2022a). The website of the DEFINE modelling framework is available here. For other ecological stock-flow consistent models, see e.g. Jackson and Victor (2020) and Dunz et al. (2021).

[15] Although other macroeconomic models (such as the Dynamic Stochastic General Equilibrium models) can analyse environmental variables in physical units as well, (i) they lack the holistic perspective provided by stock-flow consistent models (where the dynamic evolution of stocks and flows is depicted through accounting matrices), (ii) they typically restrict their attention to the analysis around equilibria making it difficult to analyse path-dependencies, non-linearities and instabilities in contrast to the case in stock-flow consistent models and (iii) they depict the financial system as more passive compared to what is the case in stock-flow consistent models. For more discussion on these issues, see Battiston et al. (2021) and the references therein.

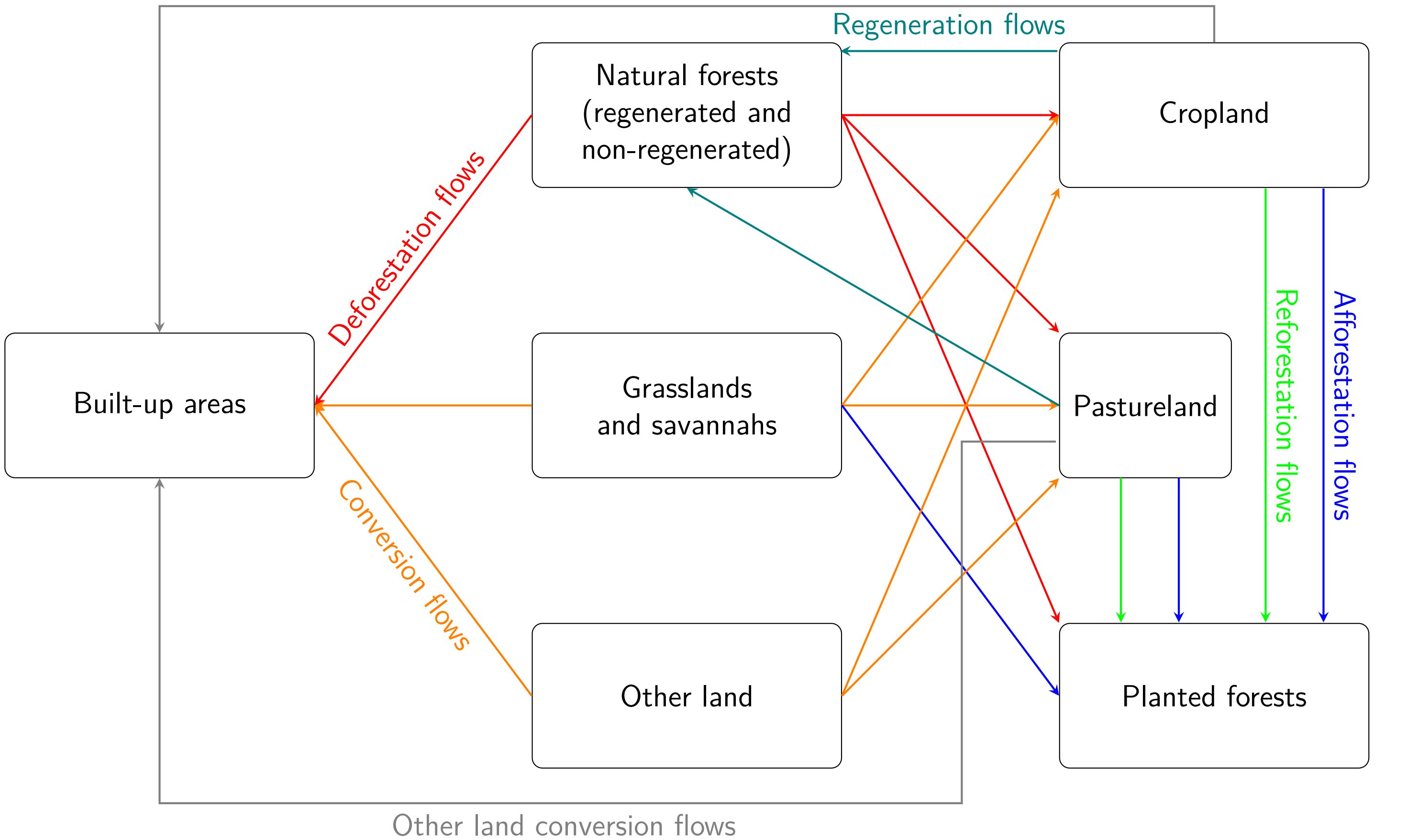
[16] The figure draws on the definitions of land use that can be found in FAO (2021), FAO (2023) and SBTN (2023). See also the Glossary of environmental terms at the end of this report.

[17] Deforestation is not only caused by economic activity in the agriculture and forestry sector. Additional causes of deforestation include hydropower expansion, oil and gas exploration, transport infrastructure and mining (see, e.g. WWF, 2016 and Pacheco et al., 2021.) In Fig 3 these causes are partly captured by the deforestation flows that go to built-up areas. However, large scale agricultural production is widely known as the single most important driver of deforestation in the tropics; see Curtis et al. (2018), Shukla et al. (2019) and Dummett et al. (2021).

Natural forests can be regenerated through passive natural restoration of vegetation in land that was used for pasture/cropping in the past, or through active planting of diverse native tree species as part of management practices for ecosystem restoration which can gradually be transformed into regenerated natural forests. Forest cover can also grow through the increase in planted forests, composed of trees established through planting and/or deliberate seeding, some of which consist of planted forests of a few commercial species that are intensively managed. Regeneration and plantation are reflected in the regeneration and reforestation flows in Figure 3, respectively. Forest stocks can also increase due to afforestation, which consists of the conversion of pastureland and cropland areas (that were not forests in the past) to planted forests. Eventually, regenerated and planted forests may end up in other uses due to further processes of land conversion.

Moreover, the production of a few globally traded commodities such as beef, palm oil, soybean, timber, coffee, and cacao is estimated to be responsible for the majority of tropical deforestation; see Henders et al. (2015), Pendrill et al. (2019) and Weisse and Goldman (2021).

Figure 3: Physical stock-flow interactions: the case of deforestation and land conversion (simplified illustration)



Source: Authors' depiction.
Notes: Deforestation flows: conversion of forests into other land use types irrespective of whether human-induced or not; conversion flows: conversion of grasslands, savannahs and other ecosystems into other land use types irrespective of whether human-induced or not; reforestation flows: re-establishment of forests through planting and/or deliberate seeding on land classified as forest; afforestation flows: establishment of forest through planting and/or deliberate seeding on land that, until then, was under a different land use. For the definition of the land are types shown in the figure, see the Glossary of environmental terms.

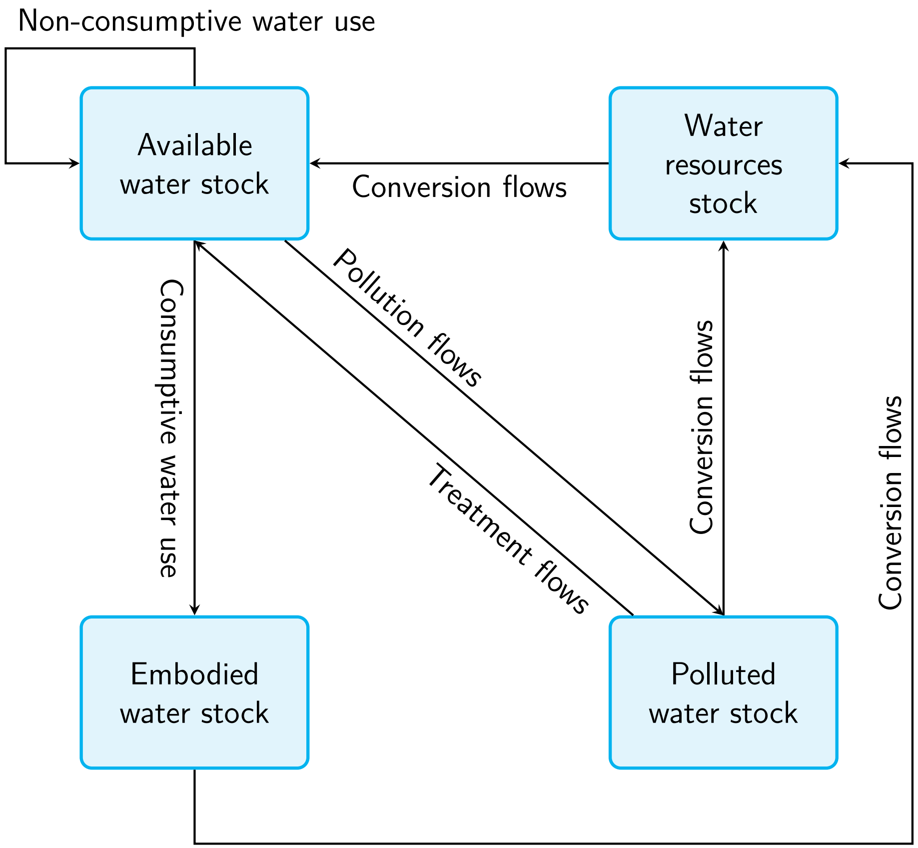
Currently, at the global level, the increase in planted forest areas is insufficient to offset the reduction in natural forests due to the high rates of deforestation. This means that we urgently need to stop deforestation in order to prevent a further decline in forest areas. However, halting deforestation may shift pressures on other types of land conversion: in many cases, policies that stop deforestation lead to the conversion of other natural ecosystems, such as grasslands and savannahs, into cropland or pastureland to satisfy agricultural needs or needs for the expansion of built-up areas. This is captured by the conversion flows in Figure 3. For example, it is well-documented that policies that reduced deforestation in the Amazon led to the conversion of a significant part of the Cerrado to soy production to fulfil a growing market demand.[18]

Crucially, forests are not only affected by land conversion that leads to deforestation. They are also affected by forest degradation whereby land is still classified as forest but the chemical, biological and/or physical structure of the forest has been damaged. There are multiple causes of forest degradation. Climate change is one of them, since it increases the severity and frequency of wildfires, results in edge effects and fragmentation, and facilitates insect outbreaks that adversely affect the functions of forest ecosystems. Harvesting, which satisfies demands for the generation of bioenergy and industrial timber, is another contributor to forest degradation. In general, timber products can be generated in four ways:[19] (1) they can come from forest plantations whereby the harvested area is replanted or left regrown; (2) timber can be provided from selected harvest in natural forests where the harvested area is usually left regrown (selective logging); (3) the conversion of forests into agricultural land can provide a source of timber through the trees that are cut down (a by-product of agriculture-driven deforestation); (4) timber can come from trees that are cut down in forests without being replaced (clear-cutting logging). (1) and (2) can contribute to forest degradation while (4) counts as timber-driven deforestation. (1) can also lead to deforestation when plantations expand to the detriment of natural forests.

As a third example of physical stock-flow interactions, we consider those interactions associated with freshwater. A simplified depiction of these interactions is provided in Figure 4. Water resources are converted into available water stock (e.g. through a well) following demand for water from socio-economic systems. The available water stock can be used in a non-consumptive way. Non-consumptive water use refers to water that is withdrawn but then returned to the water stock. This includes, for example, groundwater used for irrigation that infiltrates back into the ground (i.e. is not embodied in the crop) or water used for the cooling of power plants and released back to its source, when temperature and quality are not too altered compared to the initial state. When water is used in that way, the available water stock generally does not decline.

[18]See e.g. WWF (2020) and WWF (2022b).
[19]See, for example, Damette and Delacote (2011).

Figure 4: Physical stock-flow interactions: the case of freshwater (simplified illustration)



Source: Authors' depiction.
Note: For simplicity, the circular flow of non-consumptive water use back into the available water stock does not consider that some water flows that are generally counted and appear in data sources as 'non-consumptive water use' are also lost to evaporation.

There are three ways via which available water stock can be reduced. First, water can be used in a consumptive way, in which case the available water stock is reduced by the volume embodied in crops and animals and the volume that evaporates into the atmosphere, increasing the stock of embodied water and water vapour (see Figure 4). Second, water can be polluted, for example by being mixed with fertilisers or chemicals.[20] In that case, available water stock becomes polluted water stock (see Figure 4). Third, the available water stock can be reduced due to global warming that increases the amount of water vapour stored in the atmosphere. Soil erosion and saturation reduce the infiltration rate of green water and the groundwater stock may not replenish as quickly as in the absence of global warming. For simplicity, this is not shown in Figure 4.

Over time, a proportion of the embodied and evaporated water stock can be converted into water resources stock through recharge flows. This happens, for instance, through precipitation reaching the groundwater or decaying plant material. In addition, the polluted water stock can be converted into available water through treatment activities, adding back to the available water stock. Polluted water may also be cleaned by natural filtration, adding to the water resources stock.[21]

2.3 Physical stock-flow interactions between land conversion, climate change and water

The above examples illustrate that tracking climate-, land- and water-related physical stocks and flows is essential for monitoring ecosystem changes. However, it would be misleading to analyse the dynamics of land conversion, climate change and water separately. There are a number of important feedback loops between water stress and land conversion. Climate change adds another layer of complexity, as both forest ecosystems and hydrological systems are directly impacted by climatic conditions. Figure 5 illustrates these interactions.

Effects of land conversion on water stress

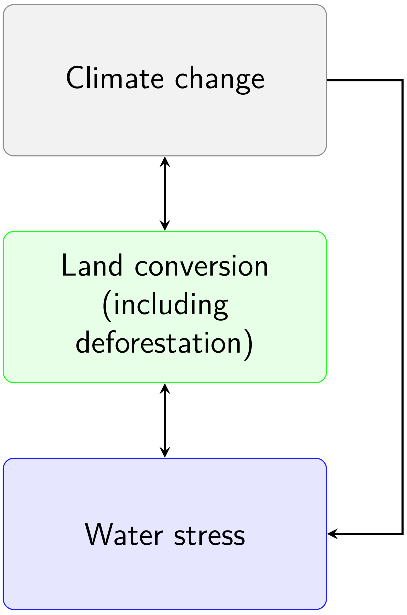
Land conversion can lead to water pollution and can alter the hydrological cycle, influencing the distribution of the available water stock.[22] First, land conversion can affect the amount of water lost through evapotranspiration. This is so because different types of land covers have different evapotranspiration rates, which change the amount of water vapour in the surrounding atmosphere and thus precipitation patterns. Inter-regional interdependencies can play a key role in this process. For instance, downwind areas' precipitation depend on green water flows generated by other natural ecosystems.

[20] The GCAM model provides an example of the water-economy system; see Calvin et al. (2019).

[21] Note that only certain metals, pesticides, sediments and overabundant nutrients can be filtered by natural organisms, while other pollutants quasi-permanently pollute water bodies. See, for example, Knox et al. (2008) and Haarstad et al. (2012) for the role of natural wetlands in filtrating pollutants.

[22] For the impact of land conversion on water see, for instance, Sliva and Williams (2001), Tong and Chen (2002), Ichii et al. (2003), Neary et al. (2009), Liu et al. (2015), Bosmans et al. (2017), Camara et al. (2019), Kupiec et al. (2021), Zhang et al. (2021) and Zhang and Wei (2021).

Figure 5: Interactions between climate change, water stress and land conversion (including deforestation)



Source: Authors' depiction.

Second, land conversion can affect the surface runoff (i.e. water that does not infiltrate and runs across the surface into the nearest body of water unchanneled) and interflow (i.e. water that infiltrates the soil but does not reach the groundwater, before discharging into other water bodies). This can affect regional rainfall distribution and the amount of water reaching the groundwater.

Third, land conversion can contribute to the pollution of the available water stock by influencing the local ecological balance and overall health of aquatic ecosystems (for the link between available and polluted water stocks, see Figure 4). For example, when natural ecosystems are converted into built-up areas, the surrounding waterways become vulnerable to pollutants: increased runoff from roads and buildings transports contaminants like heavy metals, fertilisers, pesticides and sediment directly into water bodies. Additionally, deforestation of natural forests and the conversion of wetlands disrupt the natural filtration and nutrient retention processes, further degrading water quality. This degradation can result in reduced biodiversity, harmful algal blooms, eutrophication, and a decline in fish and other aquatic species.

The impact of water stress on land conversion

Looking at the relationship of water and land use from the opposite direction, water stress can impede land conversion efforts. Water stress reduces soil fertility and restricts the potential use cases of land. For example, the stock of available water underpins consumptive water use by the agriculture & forestry sector and sufficient soil moisture is essential for soil structure improvement and nutrient cycling during land restoration projects. Moreover, when land that was used for agriculture, mining or buildings is reforested, or when degraded lands, such as arid or eroded areas, are restored, an adequate and reliable supply of water is required.[23]

Interactions between climate and land conversion and water ecosystems

As the planet's climate heats up, water evaporation from land, rivers, lakes and oceans accelerates. This intensified evaporation disrupts hydrological cycles, leading to changes in rainfall distribution. Prolonged droughts as well as intense precipitation events become more frequent. In turn, prolonged and more frequently recurring drought periods lead to soil erosion. The latter reduces soil's ability to absorb water when it falls in the form of extreme rainfall, further declining soil's infiltration capacity.[24] Global warming is also conducive to a reduction in rivers' runoff.[25] All these changes increase the proportion of available water stocks that becomes water vapour stock (see Figure 4).

Climate change also has adverse effects on water pollution. For example, increased precipitation may result in amplified sediment, nutrient, pathogen, and other matter runoff into water sources.[26] Augmented nutrient overflow, coupled with elevated water temperatures, may also induce the emergence of detrimental algal blooms. Rising sea levels and heightened periods of drought can facilitate the encroachment of saline water further upstream and inland, impacting estuaries, wetlands and groundwater. Increased salinity has the potential to taint the available water stock and inflict harm upon aquatic flora and fauna.[27]

In tandem with the water crisis, global warming has negative effects on forests, which face heightened vulnerability to devastating wildfires and insect outbreaks.[28] The elevated atmospheric temperatures create ideal conditions for pests, such as bark beetles, to proliferate and decimate trees.[29] The resulting dead and dying trees provide ample fuel for wildfires to spread rapidly, consuming hectares of forestland and releasing copious amounts of carbon back into the atmosphere, further increasing global warming.[30]

It is in the aftermath of extreme weather events that the relationship between climate change and forests becomes most apparent. Extreme weather events influence the capacity of forests to deliver vital functions like carbon sequestration, evapotranspiration, and air purification. For instance, the growing frequency and intensity of flooding events pose a significant threat to the stability of forest ecosystems, since floodwaters might lead to the erosion of forest soils. Soil erosion in turn destabilises trees, impeding their ability to absorb carbon dioxide.[31] Similarly,

[23] Gleick (1994) and Dubovyk et al. (2016).

[24] See Gimbel et al. (2016).

[25] For instance, Zhang et al. (2012) find that climate change is responsible for the decrease of observed runoff in Huifa River, Northern China.

[26] Rehana and Mujumdar (2011) and Tornevi et al. (2014).

[27] Brock et al. (2005), Gholami et al. (2010) and Flower et al. (2017).

[28] For instance, Westerling (2016) shows that wildfires in the US are strongly associated with warming and earlier spring snowmelt.

[29] Berner et al. (2017), Netherer et al. (2019) and Pureswaran et al. (2018).

[30] Nepstad et al. (1999) and Chen et al. (2013).

[31] Rozas and García-González (2012), Myster (2015), and Mason-Romo et al. (2018).

the increase in the number and intensity of wildfires and storms can lead to the degradation of forest ecosystems.[32] Since these ecosystems contribute to carbon sequestration, the deterioration in their health can amplify climate change. At the same time, the deterioration in the health of these ecosystems reduces the hedge that they provide against further escalation of climate-induced extreme weather events.[33]

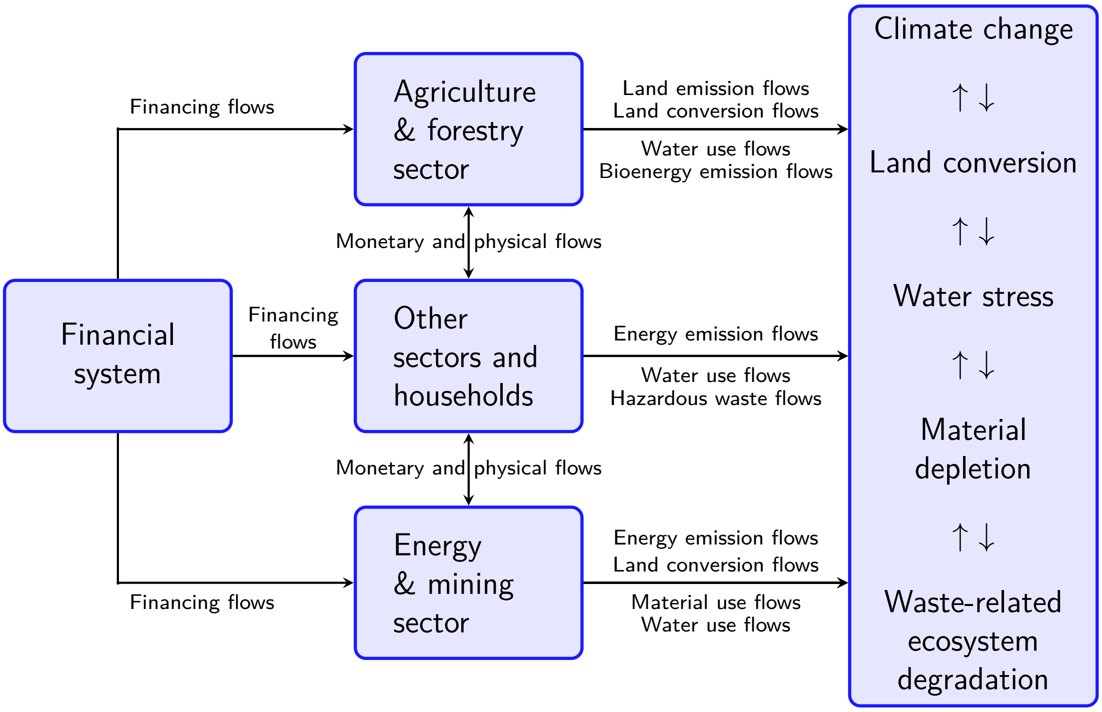
All the above examples illustrate the importance of understanding stock-flow interactions within ecosystems. However, from a stock-flow perspective, what is equally important is that physical stock-flow dynamics should not be treated independently of monetary stock-flow dynamics. In the next sections, we explain this interdependence with reference to environmental and financial materiality.

[32] Lindroth et al. (2009), Miller et al. (2009), Kemp et al. (2016), Liang et al. (2017) and Armenteras et al. (2021).
[33] See, for instance, Vári et al. (2022) for the role of ecosystems in 'flood regulation'.

3. The environmental materiality of the financial system

Figure 6 shows the main channels through which the financial system can affect the depletion of natural resources and the degradation of ecosystems. To simplify our analysis, we make a distinction between (i) the agriculture & forestry sector, (ii) the energy & mining sector and (iii) the rest of non-financial corporate sectors as well as the household sector. All these sectors receive financing flows from the financial system, most typically in the form of bank loans, bonds or stocks.

Figure 6: The environmental materiality of the financial system: examples of transmission channels



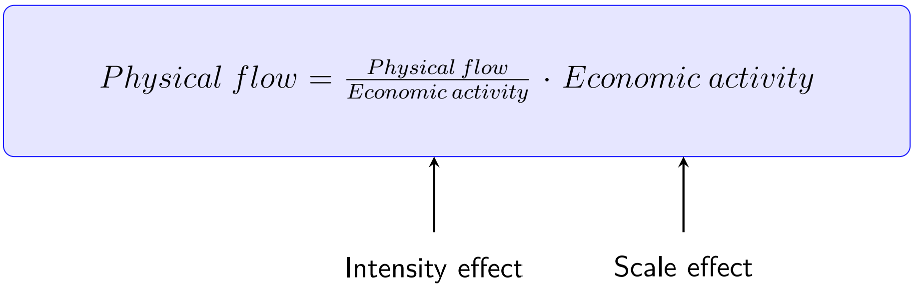
Source: Authors' depiction.
Note: The right-hand side depiction of the environmental pressures that follow from the materiality of the financial system (left-hand side) only lists examples that are directly related to the purposes of this report. There are many other environmental pressures, such as hazardous waste from the energy and mining sector and bioenergy emission flows from the agricultural sector, that have not been included in the figure for simplicity.

3.1 Scale effect of environmental materiality

At the aggregate level, the higher the amount of financing flows and the more favourable the conditions for the provision of these flows, the higher the level of economic activity in the different sectors of the economy. With everything else given, higher economic activity leads to higher environmental pressures. We call this the *scale effect*.

As illustrated in Figure 7, with everything else given, higher economic activity in the agriculture & forestry sector leads to an increase in land conversion, including

Figure 7: The combined impact of the scale and the intensity effect on physical flows



Note: Physical flows include, for instance, carbon emissions measured in tonnes, water use measured in cubic metres and land conversion (for example, extent of deforestation and conversion) measured in hectares. Economic activity can be captured by using an income or an expenditure perspective and is measured in currencies, such as dollars, pesos or euros.

deforestation and the conversion of other natural ecosystems to other land uses, such as cropland and pastureland (as depicted in Figure 3). Similarly, higher economic activity in the energy & mining sector leads to higher extraction of materials (minerals and metals), higher (consumptive) use of water, as well as higher emissions associated with the burning of fossil fuels. This suggests that there is a clear link between financing flows and physical stocks and flows: financing flows generate physical flows, such as land conversion, water use and emissions, which adversely affect physical stocks, such as atmospheric carbon concentration, the available water stock and forest stocks.

Crucially, higher economic activity both in the agriculture & forestry sector and the energy & mining sector is driven by the demand from the rest of the sectors as well as household consumption.[34] Therefore, in terms of the environmental materiality of finance, it would be misleading to attribute responsibility for the physical flows that are generated from the agriculture & forestry sector and the energy & mining sector only to those financing flows that support economic activity in these sectors. Financing flows to other sectors that require inputs from the agriculture & forestry and energy & mining sectors (supply chain and consumption effects) also matter from an environmental materiality perspective. For example, when banks provide credit to households and firms that use these flows to buy energy-intensive and material-intensive goods (such as cars, trucks and machines), they indirectly support the activities of the energy & mining sector that generate physical flows that harm the environment. The same holds when banks provide credit to food processing and food service industries that rely on palm oil production which contributes to deforestation.

But on top of it, the economic activity of other sectors and households also leads by itself to higher emissions (e.g. because of the heating, transport and infrastructure needs), higher generation of hazardous waste and higher water use.[35] Furthermore,

[34] If demand from sectors using inputs produced in the agriculture & forestry sector or in the energy & mining sector increases, the production in those sectors is expected to increase as well in order for supply to meet demand.

[35] Apart from agriculture & forestry and mining & energy, other sectors that use significant amounts of water include

this activity generates additional income that can increase spending further, having second-round effects on physical flows.

This overall has an important implication for the actions of central banks and financial supervisors: when they evaluate the environmental performance of borrowers they need to consider both the direct physical flows that these borrowers generate and the indirect physical flows that are associated with their supply chains and consumption. For example, to substantially reduce finance that supports deforestation and conversion of other natural ecosystems it would not be sufficient to consider only the land that is converted as a direct consequence of the credit received by the agriculture & forestry sector. Central banks and financial supervisors should also take into account that the demands of, e.g., the food industry (and the finance that this industry receives) ultimately drive the scale effect in the agriculture & forestry sector and consequently lead to more land conversion.

3.2 Intensity effect of environmental materiality and its combination with the scale effect

For a given level of financing provided to households and firms, the environmental pressures associated with their activities can be higher or lower. We call this the *intensity effect*. If firms receive credit on favourable terms on the condition of meeting an environmental target, the sector's overall environmental intensity can be reduced. For example, if a policy is introduced that implies that utility companies will pay lower interest on a loan if they reduce the water use per unit of energy, these companies have an incentive to reduce the environmental intensity of their activities and, as a result, their overall environmental pressure.

The combined implications of the scale and intensity effects are captured by the equation shown in Figure 7. Whenever finance is provided to support an economic activity, the scale effect always leads to the generation of physical flows that harm the environment (for a given intensity effect). However, for the majority of economic activities, harmful physical flows can be reduced if financing is provided under the condition of a sufficiently low intensity effect.

As will be explained in Section 5, the distinction between the intensity effect and the scale effect can help the development of environmental materiality metrics that central banks and financial supervisors can use to incorporate environmental issues into their monetary and financial policy tools. Box 1 provides an example of the scale and intensity effects of financing flows related to palm oil.

Box 1

Scale and intensity effect of financing flows related to palm oil

Palm oil plantations are a significant contributor to deforestation and

textiles, chemicals & chemical products, cement & cement products and beverage & tobacco; see WWF (2019b).

land conversion around the world. Recent research has shown that, during the period between January 2016 and June 2021, the total financing flows provided for palm oil activities by financial institutions in the form of loans, underwriting services, bonds and stocks was approximately USD 48 billion.[a] These flows have been used for financing expansion plans and working capital for day-to-day operations.

From an environmental materiality perspective, a key physical flow that is associated with palm oil activities is land conversion measured, for instance, in hectares. The activities that lead to land conversion can be measured in monetary terms by the revenues or spending in USD millions of palm oil companies or companies that rely on palm oil through their supply chains (manufacturers, retailers as well as food service and hospitality companies).

Take a food manufacturing company that produces biscuits, butter, cakes, chocolate and other processed foods that rely on palm oil. Suppose that the land conversion that is attributable to the palm oil that this company uses is 2000 hectares and that the revenue of this company is USD 50 million. This means that the land conversion intensity of this company is equal to 2000 hectares/USD 50 million=40 hectares/USD million.

We therefore have the following:

Land conversion (2000 hectares)

=[Land conversion intensity (40 hectares/USD million)]x[Revenues (USD 50 million)]

There are two ways for the land conversion of this company to be reduced, let's say from 2000 to 1000 hectares. First, the scale effect could become less strong by reducing the sales of this company from palm oil-based products. If the sales declined to USD 25 million, the new land conversion would be 1000 hectares. Second, the intensity effect could be weakened if the company was to increase the proportion of palm oil that is produced in a more sustainable way, for instance by ensuring that palm oil is free of land conversion. If the land conversion intensity was reduced to 20 hectares/USD million as a result of this, the new land conversion would be 1000 hectares.

Suppose now that this company receives loans from a bank that wishes to reduce its environmental footprint either voluntarily or because of some environmental financial regulation. From a scale perspective, the bank can reduce its environmental footprint by shrinking the loans that it provides to the food manufacturing company, or by increasing the interest rate at which these loans are provided. If many other financial institutions follow a similar approach, the food manufacturing company will have less access to finance. This can gradually reduce its palm oil-related revenues and, therefore, land conversion. Alternatively, from an intensity perspective, the bank and other financial institutions could make the provision of new loans conditional on the reduction of the land conversion intensity of the company (or the land conversion in hectares in absolute terms). In that case, the company would be incentivised to make its palm oil supply chains deforestation- and conversion-free.

[a] See WWF (2023).

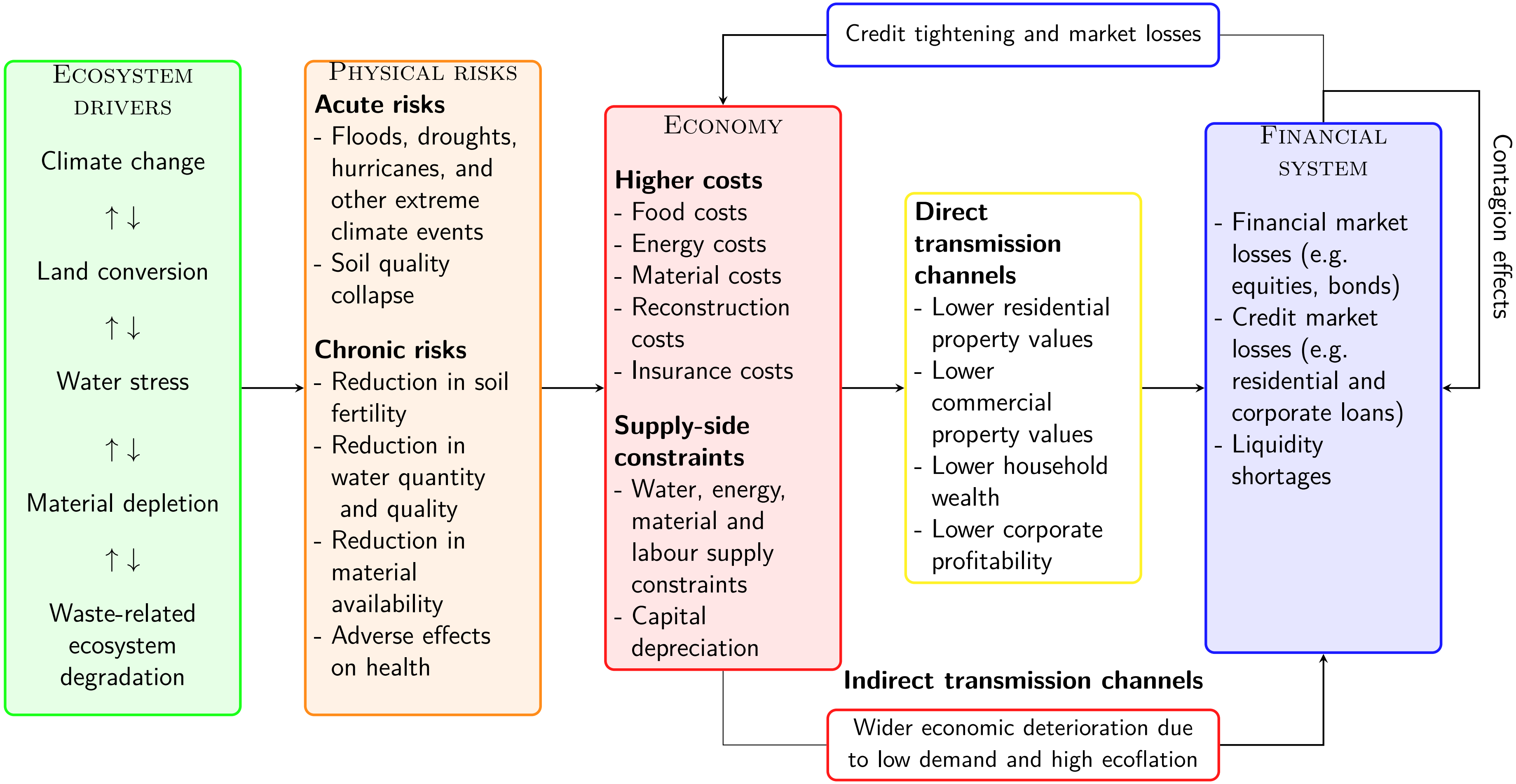
4. The financial materiality of the environmental crisis

There are numerous channels by which the environmental crisis can lead to macrofinancial instability. To present these channels we will follow the now standard distinction between physical risks and transition risks. Physical risks capture the financial implications of physical phenomena related to the environmental crisis. Transition risks are associated with the financial implications of changes in policies, technologies and preferences that can lead to a more environmentally sustainable economy.

4.1 Physical risks

We will first focus on the channels linked to physical risks. As shown in Figure 8, physical risks are the result of various ecosystems drivers which are associated with physical stocks that have either become too high (e.g. high atmospheric carbon stocks as a result of energy and land emissions) or too low (e.g. low forest stocks due to deforestation and low water stocks due to unsustainable water use). Physical risks can cause both acute and chronic effects. Acute effects include floods, droughts, hurricanes, and other extreme events that stem from climate change, as well as soil quality collapse which can be the result of land conversion, most notably deforestation. Chronic effects include, for example, a reduction in soil fertility and a reduction in the available water stock through permanently more evaporation or increased water pollution. Material depletion can also cause chronic risks related to a reduction in material availability.

Figure 8: Financial materiality channels of the environmental crisis: physical risks



Source: Authors' depiction drawing on NGFS (2019).

Both acute and chronic risks affect the economy. First, there are some important cost effects. For example, floods, droughts and soil quality collapse can increase the costs for the production of food; water stress can lead to higher energy costs; reduced material availability can be conducive to higher cost of materials. These increases in costs can directly affect the profitability of the agriculture & forestry and the energy & mining sectors, in particular in the case in which the costs are not passed on to prices. The lower the profitability of the corporate sector, the lower the ability of the firms to pay their dividends, repay their debt and cover interest payments. This can be reflected in the prices of their bonds and stocks in the financial markets. It can also be reflected in higher rates of default that can deteriorate the solvency of the banking sector.

Second, acute risks, related for example to typhoons and hurricanes, can destroy the properties of firms and households. The resulting reduction in the value of the collateral of firms and households can increase the credit risk of borrowers and the insolvency of banks. As a response to property destruction, firms and households might face costs to rebuild their properties. If properties are uninsured, then the reconstruction burden falls on firms and households. This can reduce the wealth of households and corporate profitability. If losses are insured, the burden falls on the insurance sector which might experience underwriting losses. As a response to this, insurers might also ask for higher fees from households and firms.

Third, acute and chronic risks can also contribute to supply-side constraints. For example, water stress can restrict the ability of the agriculture & forestry sector to produce food and the ability of the energy & mining sector to produce energy;[36] or the decrease in pollinators caused by deforestation can reduce agricultural productivity. These can restrict the amount of goods that companies in these sectors can sell (demand might not be possible to be satisfied). This in turn can reduce the profitability and solvency of the corporate sectors and can affect financial markets and the solvency of the banking sector. Labour constraints might also arise as a result of the health implications of environmental degradation and the high stocks of hazardous waste.

All these are the direct channels by which physical risks can affect the economy. However, there are indirect channels as well. If firms in the agriculture & forestry and mining & energy sector pass the higher food, material and energy costs on to their prices, this can result in what we call *ecoflation*, which is inflation related to instability in the ecosystems.[37], Ecoflation can reduce consumption demand. In addition, climate damages and supply-side constraints might induce households to consume less and firms to reduce investment due to the broader uncertainty and lower returns on investment. This can reinforce the destabilising forces in the banking sector and financial markets. Other indirect effects may result from interactions between

[36] For some case studies that illustrate the importance of water for operations in the energy & mining sector, see Planet Tracker-CDP (2022). See also Colesanti Senni et al. (2024), for the impact of reduced water availability on hydroelectricity generation and the repercussions on financial markets.

[37] Ecoflation is a broader term than 'climateflation' (see Schnabel, 2022) since it refers to both climate and non-climate inflationary effects of ecosystem instability.

ecosystems (see the analysis about physical stock-flow interactions in Section 2), as well as from interactions within value chains and financial institutions.[38]

Importantly, all the above direct and indirect effects on the financial system can have feedback effects on the economy. Banks that face insolvency challenges and low capital adequacy ratios might be less willing to provide loans and banks that face liquidity shortages might not be willing to invest in the stock and bond market or might decide to quickly sell some of their assets to get access to liquidity. Additionally, a reduction in asset prices or an increase in risk premia can make it more costly for firms to get funding from the stock and bond markets. These feedback effects on the economy can be reinforced by contagion effects between the different components of the financial system. For example, banks that have not directly provided loans to firms and households that are affected by environmental risks might be interlinked with other banks (e.g. through the interbank market) that are affected by physical risks and face insolvency challenges.

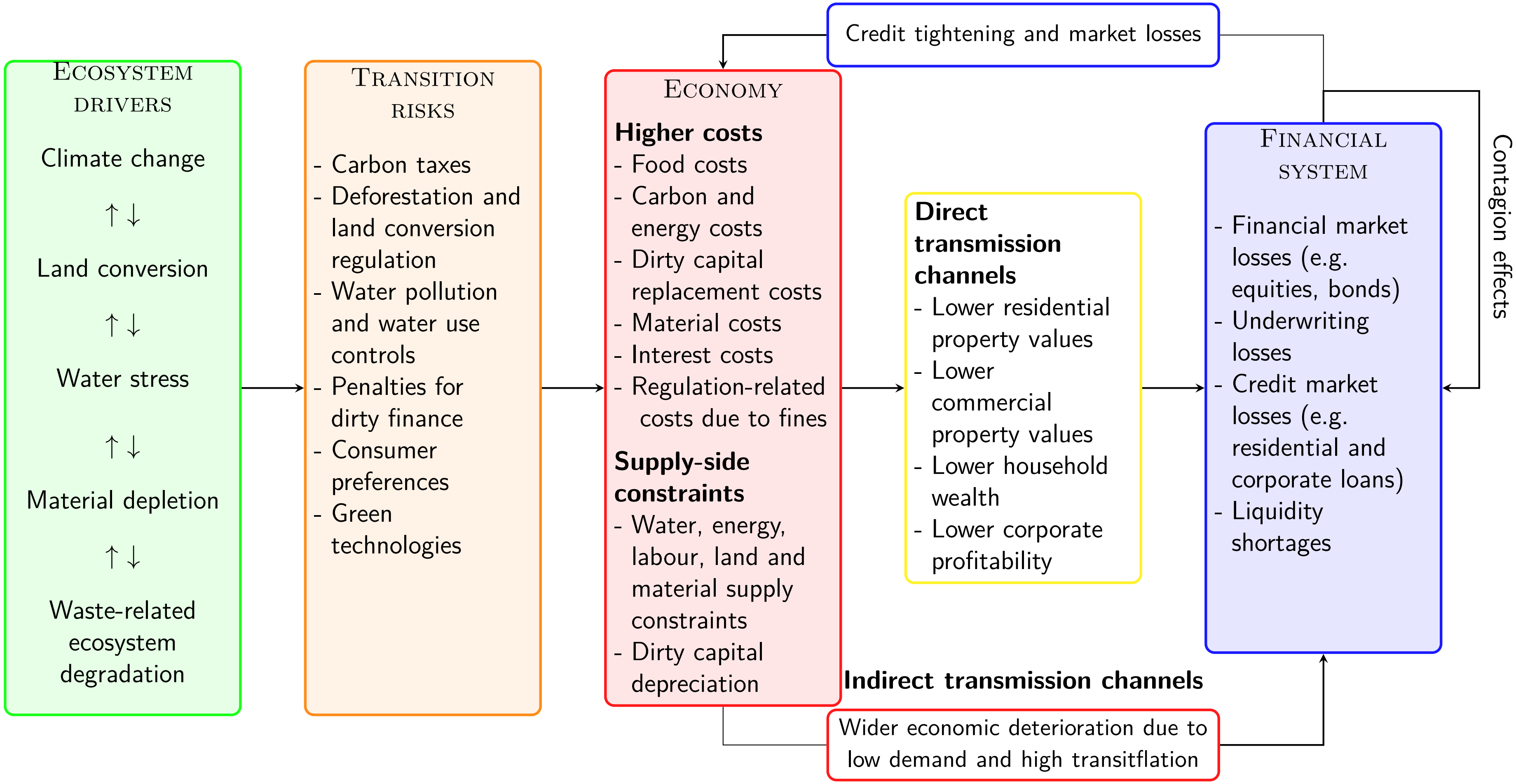
All these can cause a further decline in spending, including adaptation spending that reduces the exposure of households and firms to physical risks. Therefore, credit tightening and financial market losses can significantly amplify the adverse effects of acute and chronic risks on the economy. This, once again, illustrates why it is significant for central banks and financial supervisors to take action to reduce the environmental materiality of finance: the more the financial system is allowed to contribute to climate change, land conversion and water stress, the more difficult it becomes to prevent its instability due to the environmental crisis.

4.2 Transition risks

We will now turn to present the channels linked to transition risks and how they can lead to macrofinancial instability (Figure 9). Climate change, land conversion, water stress and other ecosystem drivers can lead to transition risks. In particular, transition risks are linked to policies that can be implemented to address the economic causes of climate change, water stress, deforestation and conversion practices, including the financing of polluting companies. These policies can take, for example, the form of carbon taxes or regulations that limit deforestation practices (by limiting deforestation allowances directly or through supply chains) and control water pollution and water use. Transition risks are also linked with shifting consumer preferences (e.g. preferences for plant-based food, deforestation-free products, and the use of bikes and public transport instead of cars) as well as green technologies that can improve energy and material efficiency and increase the use of renewables, making dirty technologies obsolete.

[38] In NGFS (2023b), there is a distinction between compounding risks (risks transmitting between ecosystems), cascading risks (risks transmitting via value chains), and contagion risks (risks transmitting between financial institutions).

Figure 9: Financial materiality channels of the environmental crisis: transition risks



Source: Authors' depiction drawing on NGFS (2019).

Transition risks can have adverse financial effects through several channels. First, the transition can affect the costs of companies. For example, an increase in carbon taxes might increase carbon costs and reduce the profits of carbon-intensive companies if they are not able to pass the higher carbon costs on to their prices. Similarly, regulations focused on land restoration of mine sites can result in substantial financial burdens for mining companies which might strive to meet more stringent environmental standards. Regulations could also introduce standards for wastewater before it can be returned to water bodies, which might increase the operating costs of companies that significantly rely on the use of water.[39] Other types of regulation might forbid energy & mining companies to use part of their dirty capital. This can create replacement costs. As far as the agriculture & forestry sector is concerned, moratoria on logging concessions or regulations that control the palm oil trade can increase the operating costs of companies either because they have to pay fines or because they need to change their business practices.[40] But apart from these more traditional transition policies, financial policies that might be introduced to protect the environment (such as higher capital requirements for dirty finance that supports deforestation) can increase interest rates and, thus, the overall financial costs of companies.

As a result of these higher costs, the agriculture & forestry and the mining & energy sectors might experience a decline in their profitability. This might not allow them to repay their loans, negatively affecting the capital of banks. In cases in which companies issue equity or bonds, the pricing of the equity and bonds might be adversely affected as well.

Second, the introduction of some of the above-mentioned policies can impose supply-side constraints. For example, water pollution and water use controls can directly lead to water supply-side constraints if the controls are too restrictive. Similarly, deforestation and land conversion regulations can impose constraints on the use of land. This means that some companies might reduce the amount of food, timber, energy, metals and other goods that they produce. Other sectors that rely on these intermediate goods produced by the agriculture & forestry and energy & mining sectors might be affected as a result, reducing their ability to provide sufficient goods to satisfy consumption demand.

As in the case of physical risks, there are significant indirect effects as well. In terms of demand effects, companies might decide to fire their workers to retain their profitability. In this case, there is a direct negative effect on the income of households and their consumption expenditure might decrease, as well as their ability to repay their liabilities. As a result of this, household wealth might be affected as well.

Other indirect effects are linked to what we call *transitflation*, i.e. inflation that can be caused during the transition to a more environmentally sustainable economy.[41]

[39] For an overview of the operating costs related to water, see WWF (2019c).

[40] For the economic and financial costs of policies tackling deforestation in Indonesia, see OECD (2023). For the potential financial effects of the EU deforestation rules, see Standard and Poors (2023).

[41] Transitflation is a broader term than 'fossilflation' (see Schnabel, 2022) since it captures inflationary effects

If firms are able to pass some of the costs mentioned above on to their prices then the income of the households might be negatively affected. For example, an increase in carbon prices might induce the energy & mining sector to increase the prices of energy and materials. Moreover, policies limiting deforestation may lead to a lower supply of palm oil, coffee, cocoa and other commodities that rely on deforestation, driving up their price and, as a result, the cost facing food processing industries.

Industries reliant on water may face rising operational expenses due to water stress, potentially leading to inflationary pressures as well.[42] However, water is not traded on global markets in the same way that, for instance, timber or oil is. This implies that the price increase due to higher operational costs is less likely to be passed on to consumers. Still, energy companies and owners of power plants might face losses that can lead to higher default rates, asset devaluation or stranded assets[43] and potential disruptions in financial markets.

As in the case of physical risks, the effects described above can also have feedback implications due to credit tightening and financial market losses. This is important not only because this can create additional recessionary pressures, but also because it can lead to lower green credit availability as well, disrupting the transition. The feedback impacts can be reinforced due to financial contagion effects.

To illustrate the financial materiality of green transition policies, in Box 2 we zoom in on the recently introduced EU regulation on deforestation-free products which is expected to have a significant impact on deforestation both in the EU and the rest of the world. Similar deforestation regulations might be implemented in other regions in the coming years. Although such regulations are necessary for addressing deforestation, they can have adverse financial stability implications.

Box 2

The EU regulation on deforestation-free products and its financial materiality

The EU Regulation on deforestation-free products, which became effective in June 2023, aims at reducing the deforestation and forest degradation that is caused by EU consumption and production. Under the regulation, companies are not allowed to place specific products on the European market or export them unless they are deforestation-free, are produced in accordance with relevant local legislation and are covered by a due diligence statement. The legislation covers the products derived by seven commodities: cattle, cocoa, coffee, oil palm, soya, wood and rubber. This corresponds to a wide range of

stemming from a wide range of green transitions, not only those related to the phase out of fossil fuels.

[42] Currently, water use for irrigation is both the most wide-spread, but also the least consistently priced. Prices vary substantially with geographic location, even within countries and even within developed economies. In an OECD report on agricultural water pricing in the US, (Wichelns, 2010, see p. 88) reports prices ranging from 5 USD per 1,000 m^3 for farmers with water rights or exchange agreements to 100 USD per 1,000m^3 for farmers "purchasing water in market transactions to finish an irrigation season or to ensure water supply for perennial crops." The same report finds that the variability and prices overall are rising.

[43] See, for example, Planet Tracker-CDP (2022).

products, such as furniture, soybean, meat, chocolate, pulp, leather, oilcake and palm kernel.

As part of the due diligence statements, companies need to provide the geographic coordinates of the plots of land where the commodities were produced. If companies are not in a position to obtain the necessary information from upstream suppliers, they should not place the relevant products on the market or should not export them. Failure to comply with the regulation can lead to fines, exclusion from public procurement processes and loss of access to public funding. It can also lead to the confiscation of the relevant products. Companies have been given a period of 18 months to comply with the regulation (for SMEs this period is 24 months).[a]

From a financial materiality perspective, the regulation has several important implications. To be able to comply with it, companies might need to cover costs associated with the re-design of their supply chains and the appropriate collection of regulation-related information. Costs will also increase for companies that might fail to comply since they will need to pay fines – they might also lose access to sources of revenues and funding. All these can lead to a weaker financial position that can create challenges with respect to the repayment of debt and can reduce the demand for the stocks and bonds issued by these companies. At the same time, if companies pass higher costs onto consumers, this will create transitflation. In some cases, due to broader land constraints, companies might not be able to ensure that their supply chains are deforestation-free. This can result in lower revenues for these companies, but it can also lead to a reduced production of deforestation-related products more broadly, which might be an additional source of transitflation.

[a] For more information about the EU regulation on deforestation-free products, see European Commission (2023), European Council (2023) and European Parliament (2023).

However, green technologies and transition policies can also have some beneficial economic effects. In particular, they can improve the profitability of green companies which can, as a result, increase their investment. In this case, firms might be in a better position to repay their loans smoothly. These firms might also increase the number of people they employ and offer higher wages, which can in turn place downward pressures on the default of households. However, the proportion of companies engaging in green technologies and practices is not currently sufficiently large in order for these beneficial effects to offset the negative effects described above.

5. The role of central banks and financial supervisors

Central banks and financial supervisors have several tools at their disposal to address the challenges related to double materiality. They should adjust these monetary and financial policy tools to both account for the transition and physical risks that the financial system is exposed to and incentivise the reduction of the environmental materiality of the financial system.

By adjusting their tools based on environmental materiality, central banks and financial supervisors can also mitigate transition risks since borrowers with higher environmental impacts are, generally, more exposed to transition risks arising from the introduction of environmental policies. Moreover, by actively contributing to the reduction of environmental materiality, central banks and financial supervisors cannot only help address the environmental crisis, but they can also reduce the physical risks the financial system is exposed to. For example, if several central banks and financial supervisors implement zero deforestation policies, the physical risks that the financial system is exposed to due to deforestation will be reduced. Therefore, environmental adjustments to monetary and financial policy tools should never be based only on financial materiality perspectives: financial materiality adjustments should act as a complement to environmental materiality adjustments.

In what follows we first explain how central banks and financial supervisors can capture the environmental materiality of companies, with a specific focus on climate change, deforestation, land conversion and water stress. We then discuss the challenges related to financial materiality, highlighting (i) that environmental materiality metrics can be used to proxy transition risks and (ii) that central banks and financial supervisors need to be particularly cautious when using metrics that capture the exposure of companies to physical risks. Finally, we explain how monetary and financial tools can be adjusted to capture environmental materiality.

5.1 Identifying environmental materiality

Central banks and financial supervisors can use several metrics to capture environmental materiality related to climate change, land conversion and water stress at the company level. Drawing on the discussion in Section 3, metrics need to capture i) the physical flows that borrowers generate, ii) the types of activities that they engage in and iii) the projects that they might run to reduce negative environmental impacts. Table 2 summarises the features of these metrics, provides examples of such metrics and of relevant databases/taxonomies and illustrates how the metrics can be used in monetary and financial policy tools.

Physical flow-based metrics

Physical flow-based metrics refer to metrics that quantify the impact that companies have on the environment. These metrics are measured in physical units (e.g. hectares, m^3 or tCO_2e). In the case of climate, the metrics that are typically used are related to the GHG emissions that companies generate. In the case of deforestation, land conversion and water stress, the environmental impact of companies can be quantified by using metrics such as forest areas converted into other types of land, water pollutant emissions, water discharged, water withdrawal and water use per revenue.[44]

Physical flow-based metrics have the following features. *First*, they can be reported in absolute terms or they can be normalised, for example by dividing them by the revenues of companies in which case the environmental intensity of economic activities is captured (see Section 3). When they are used in absolute terms, comparisons need to be made with specific targets for the reduction of environmental impacts (e.g. targets can be specified about how much water use and land conversion should decline within a specific time frame). When they are normalised, comparisons can be made between companies and those that perform better can be treated more favourably.

Second, the metrics can capture both the past environmental performance (backward-looking) and the plans of companies to reduce their environmental footprint (forward-looking). For instance, energy & mining companies that have transition plans to reduce their negative climate impact should be treated more favourably compared to companies in the same sectors that do not have such plans. The transition plans of companies should be very explicit on the intended reduction of environmental impacts in physical terms, which are the ultimate targets of transition plans. However, these ultimate targets can be accompanied by intermediate targets, which refer to how companies can achieve their ultimate targets. These include environmental Research & Development (R&D) and environmental capital expenditure.[45] Importantly, transition plans need to rely on common methodologies for reporting metrics and targets to avoid greenwashing and achieve credibility. Frameworks such as the Science Based Target initiative (SBTi) and the SBTi Forest Land and Agriculture (FLAG), which have developed a common methodology for companies to report their GHG emission or land-related emission reduction targets, can help in this direction.[46] Ideally, the targets need to be reported in percentage change of physical variables from a reference year (e.g. percentage change of emissions or water use). In the absence of such information, binary variables that indicate whether a target exists or not can be used.

[44] For useful databases and metrics that capture climate change, land conversion and water stress, see CDP (2020), Eikon (2022), TNFD (2023), WWF (2022c), WWF (2022d) and WWF (2022f).

[45] See Bingler et al. (2023).

[46] See SBTi FLAG (2022), WWF (2022a) and SBTi (2024).

Table 2: Environmental materiality metrics

<table>
<tr><th>Categories of metrics</th><th>Features</th><th>Examples of metrics</th><th>Databases/classifications for supporting the development of metrics</th><th>Examples of use in monetary and financial policy tools</th></tr>
<tr><td>Physical flow-based metrics
Measure in physical units the impact that companies have on climate change, land conversion and water stress</td><td>1. Reported in absolute or intensity terms
2. Capture past environmental performance (backward-looking) and transition plans and commitments (forward-looking)
3. Capture direct and indirect impacts (supply chains)
4. Report physical flows in both net and gross terms</td><td>Climate change: GHG emissions (tCO_2e); emission intensity (tCO_2e/million USD); GHG emissions reduction target (percentage decline relative to a base year); forward-looking fossil-based energy production (KWh)
Deforestation and land conversion: forest areas converted into other types of land (hectares); land use emissions reduction target (percentage decline relative to a base year); geolocation coordinates of plots of land
Water stress: Water pollutant emissions (m^3); water pollutant emissions per revenue (m^3/million USD); water discharged (m^3); water withdrawal (m^3); water use per revenue (m^3/million USD); water intensity reduction targets (percentage decline relative to a base year)</td><td>• Bloomberg (e.g. GHG emissions, GHG emission reduction target)
• CDP (e.g. water intensity reduction targets)
• Eikon (e.g. GHG emissions, water use per revenue)
• SBTi (e.g. GHG emissions reduction target)
• SBTi Forest Land and Agriculture (FLAG) (e.g. land use emissions reduction target)</td><td rowspan="3">Monetary policy tools
• Collateral framework (e.g. haircut adjustment based on physical flow-based metrics, concentration limits on specific dirty activities)
• Asset purchases (e.g. tilting based on physical flow-based metrics, exclusion of always environmentally harmful activities)
• Refinancing operations (e.g. differentiated interest rates based on activity-based metrics for bank loans)
• Reserves tiering (e.g. the threshold for the remuneration of reserves can be adjusted based on activity-based metrics for bank loans)

Financial policy tools
• Capital requirements (e.g. higher capital requirements for dirty activities)
• Credit controls (e.g. credit floors for green activities)</td></tr>
<tr><td>Activity-based metrics
Capture environmental impact by distinguishing between ‘green’ and ‘dirty’ activities</td><td>1. Distinguish between (i) always environmentally harmful and (ii) environmentally harmful activities.
2. Define green activities as those activities that reduce negative environmental impacts
3. Can be binary or continuous</td><td>Green binary metric: Specifies whether main activity of a company is green or not.
Always harmful activity binary metric: Specifies whether main activity of a company is always environmentally harmful or not.
Green continuous metric: Specifies the proportion of activities of a company that are green.
Examples of green activities (based on TRBC): Renewable Energy Equipment & Services (NEC) (5020101010); Waste Management, Disposal & Recycling Services (5220301012); Wind Systems & Equipment (5020101011)
Examples of always environmentally harmful activities (based on GICS): Oil & Gas Drilling (10101010); Fertilisers & Agricultural Chemicals (15101030)</td><td>• Climate Policy Relevant Sectors (dirty activities)
• EU Taxonomy (green activities)
• Urgewald’s Global Coal Exit List and Global Oil and Gas Exit List (dirty activities)
• WWF (2022d) (dirty activities)</td></tr>
<tr><td>Project-based metrics
Capture environmental impact by identifying ‘green’ projects</td><td>1. Can be used for classifying financial instruments related to specific projects
2. Are binary
3. Require a verification process</td><td>Green binary metric: Specifies whether a certain financial instrument (e.g. green bonds or loans) finances a project that reduces negative environmental impacts</td><td>• Bloomberg (e.g. green bonds)
• Climate Bonds Initiative (e.g. green bonds)
• Eikon (e.g. green bonds, green loans, EU taxonomy bonds)</td></tr>
</table>

Source: Authors’ depiction.
Note: Always environmentally harmful activities are activities that their negative environmental impact cannot be reduced through mitigation and, therefore, they need to be decommissioned. Environmentally harmful activities refer to activities whose harm can be reduced if companies take appropriate action.

Third, the metrics need to capture both direct and indirect environmental impacts. For example, agricultural impacts on land conversion related to cattle, palm oil or soy should not only be attributed to companies in the agriculture & forestry sector, but also to companies in other sectors whose business models rely on agricultural inputs (e.g. companies in the food manufacture and food service industries).[47] Similarly, in the case of transport-related emissions, these emissions should not only be attributed to transport companies, but also to fossil fuel companies that extract fossil fuels – this is achieved by using Scope 3 emissions for evaluating the performance of fossil fuel companies. In other words, supply chain effects should be considered based on input-output interactions. The importance of considering indirect effects when analysing environmental impacts has also been highlighted by the recent NGFS report on nature scenarios.[48]

Fourth, the physical flows that the metrics capture should be reported both in net and gross terms. This means that companies need to report their physical flows with and without carbon removals and other environmental offsets. This is so because many companies that contribute to climate change, land conversion and water stress often report a large number of environmental offsets in one place to compensate for environmental damages in another place. These companies can have relatively small net physical flows, but their gross physical flows might be large. The reporting of physical flows with and without offsets allows putting a cap on offsets which often have adverse justice effects[49] and are used as excuses for avoiding reductions in gross physical flows.[50]

Due to the interactions between climate, land conversion and water that were discussed in Section 2, it is important that companies are evaluated holistically using metrics that capture all their environmental impacts. Otherwise, there is a risk that some companies that do not harm directly one element of the ecosystem, but do so indirectly, are incorrectly assessed favourably in terms of their impact on this element of the ecosystem. For example, a company might have low adverse direct effects on water use according to water-based metrics, but might indirectly contribute to water stress by causing deforestation that leads to increased water runoff or evapotranspiration. Using both land-based and water-based metrics would prevent such an incorrect assessment.

However, when we analyse environmental impacts that move beyond climate, some metrics are more relevant for specific sectors than other sectors. For example, land conversion and water use metrics are more relevant for the agricultural sector, while hazardous waste is more relevant for the mining, energy and manufacturing sectors. On the contrary, when we analyse climate issues, GHG emissions are relevant for all sectors, in particular when we include Scope 1, Scope 2 and Scope 3 emissions. There are also metrics that might be more relevant for companies/suppliers located

[47] See, for example, WWF (2021b).
[48] See NGFS (2023c), chapter 4.
[49] See Dafermos (2023).
[50] See WWF (2018).

in specific geographical areas. For example, physical flow-based metrics about the use of water might be more relevant for companies/suppliers located in areas with a limited available freshwater stock (e.g. areas in North Africa and the Middle East). This means that in many cases physical flow-based metrics need to be reported in combination with geolocational information.

Activity-based metrics

Let us now turn to metrics that evaluate companies based on the activities that they engage in.[51] These metrics rely on classifications that distinguish between 'dirty' and 'green' activities. They have the following features. *First*, in identifying dirty activities, these metrics can make a distinction between (i) always environmentally harmful activities and (ii) other environmentally harmful activities whose harm can be reduced if companies take action that can be captured by the metrics described above (which can reduce environmental intensity).[52] Examples of always environmentally harmful activities are activities related to coal, oil and gas production, the use of fertilisers and the logging of primary or old growth forests. As long as companies engage in these activities without any plans to phase them out, central banks and financial supervisors should penalise them (as actions that focus on reducing the environmental intensity of these activities cannot counteract their adverse environmental effect). Environmentally harmful activities whose negative impact can be reduced include, for example, gas utilities and the manufacture of steel and cars. For these activities, transition plans play a key role. As long as credible – that is, clear, targeted, time-bound, science-based, accountable and comparable – transition plans[53] are in place by companies that engage in such activities, these companies can be treated more favourably in environmentally adjusted monetary and financial policy tools compared to similar companies that do not have transition plans.

Second, activity-based metrics identify green activities as those activities that contribute to the reduction of negative environmental effects. Examples of such activities include the manufacture of renewable energy equipment, the treatment of water and the rehabilitation and restoration of forests. Central banks and financial supervisors can treat these activities more favourably.

Third, activities-based metrics can be either binary or continuous. For example, when they are constructed based on a company's main activity they are binary, since the main activity can be either green or not, or can be either dirty or not. However, several companies engage in more than one activity. In this case, metrics can capture the proportion of companies' activities that are green and dirty. On top of it, it is possible to develop continuous metrics about the degree of greenness and dirtiness of specific activities.

Project-based metrics

[51] The EU Technical Expert Group on Sustainable Finance (2020) and the taxonomy developed by Alessi and Battiston (2022), can be used as a basis to determine these activities (see also Dafermos et al., 2023).

[52] See WWF (2016) and WWF (2022e) for an analysis of the always environmentally harmful economic sectors.

[53] See Bingler et al. (2023).

Project-based metrics refer to financial instruments that are used to finance specific projects that reduce negative environmental impacts. These instruments can green bonds or loans that support, for example, a project on water management that intends to reduce water stress. The metrics are binary: a bond or loan can be either green or not based on a verification process. This process needs to be robust enough to reduce greenwashing risks.

From company-based environmental materiality to the environmental materiality of financial institutions and portfolios

The metrics discussed above refer to the environmental materiality of companies. These metrics can be easily used to generate the environmental materiality of financial institutions or portfolios. In the case of climate, an index that is normally used to evaluate the environmental performance of financial portfolios is the Weighted Average Carbon Intensity (WACI), which takes into account the carbon intensity of borrowers in combination with the representation of each borrower in the financial assets held by banks or financial investors.[54] In similar lines, the deforestation impact of a pool of loans or bonds can be captured by taking into account the deforestation flows attributed to all borrowers in this specific pool.

Financial institutions can also report the proportion of assets in their portfolios that are related to dirty or green activities. The higher the amount of loans/bonds that are linked to dirty activities compared to total assets, the worse the environmental performance of these institutions, especially if the dirty activities are always environmentally harmful.

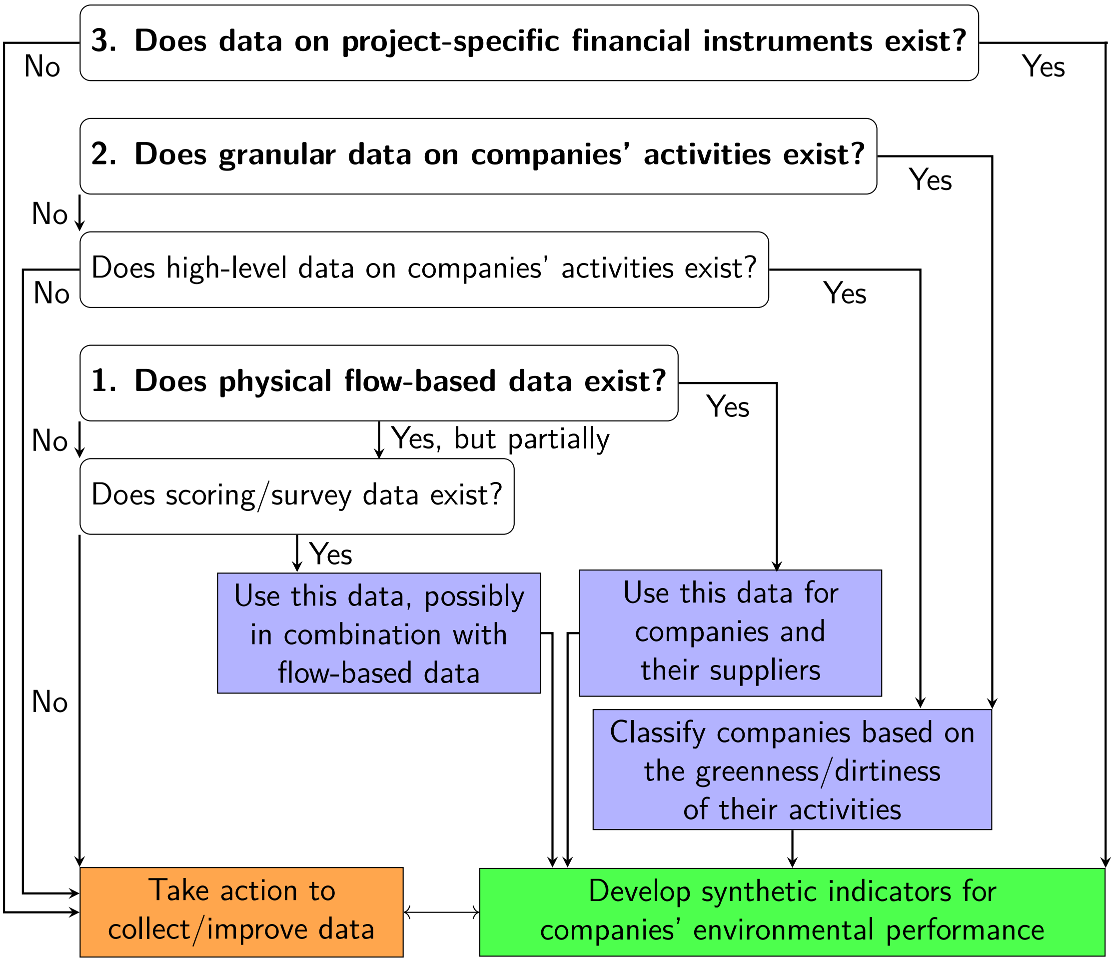
How can central banks and financial supervisors address data challenges?

Many central banks and financial supervisors do not have sufficient data about the climate performance of companies. This information is not currently available in many countries, and when it is, it is provided in a fragmented way. The data gap challenges are even higher in the case of water and land-related environmental effects.

To address the data gaps, central banks and financial supervisors can follow the decision-making process specified in Figure 10. The first issue refers to the data related to physical flow-based metrics. If data about such metrics exist, they can be directly used by central banks and financial supervisors. If physical flow-based data partially exists (e.g. if there is Scope 1 and Scope 2 GHG emissions data but not water data and Scope 3 emissions data) and scoring/survey data exists (see e.g. FOREST500), then the scoring/survey data could be combined with the physical flow-based metrics to evaluate the environmental performance of companies. If neither physical flow-based data nor scoring/survey data exists, central banks and supervisors need to take action to collect physical flow-based data. This should be done in collaboration with other public authorities in the context of initiatives that intend to improve the availability of environmental data. For the data collection process, it is very important for central banks and financial supervisors to have clear

[54] Other emissions-based indicators include financed emissions, carbon intensity and carbon footprint (see ECB, 2023).

Figure 10: Decision-making flowchart for addressing data gaps in the development of environmental materiality metrics



Source: Authors' depiction

timelines so as to make sure that the data collection will not be a very lengthy process that will delay action.

The second issue refers to activity-related data. Ideally, granular data on the activity types of companies (e.g. NACE 4-digit) should exist. If this is the case, then the greenness/dirtiness of the activities of companies can be identified and can be used to adjust monetary and financial policy tools. If such data is absent, high-level data on the activity types of companies (e.g. NACE 2-digit) can be alternatively used by central banks and financial supervisors. If such high-level data is absent as well, central banks and financial supervisors need to take action to collect activity-based data, again in collaboration with other public authorities.

The third issue is about data for project-specific financial instruments. It is possible to collect data for green bonds from data providers, such as Bloomberg and Eikon.

However, the availability of data for other green financial instruments, such as green loans, is more fragmented. This means that central banks and financial supervisors might need to take data collection action on that front as well.

Once data for physical flow-based metrics, activity-based metrics and project-specific financial instruments has been collected, central banks and financial supervisors can develop synthetic indicators by combining these metrics. These indicators can be the basis for adjusting monetary and financial policy tools as explained below. However, central banks and financial supervisors should make sure that the data that these indicators rely on will continuously improve.

5.2 Identifying financial materiality

When it comes to financial materiality, central banks and financial supervisors can take measures that reduce the exposure of the financial system to transition and physical risks. The quantification of transition and physical risks is not, however, straightforward: an accurate quantification of these risks requires the use of scenario and stress testing analysis about the transition and physical risk drivers discussed in Section 4. Based on Figures 8 and 9, two broad steps are necessary as part of stress testing. First, central banks and financial supervisors need to collect environmental data about the exposure of companies (and households) to transition and physical risks. For transition risks, it is necessary to collect data about the environmental materiality metrics discussed above. These metrics capture the environmental impacts of companies and, thus, how exposed they are to policies that might try to reduce these impacts. For physical risks, data about environmental dependencies are necessary, including data about the exposure of companies to acute and chronic climate risks.[55] In the case of land and water, environmental dependencies have some overlapping with environmental materiality. For instance, agricultural companies that report a large extent of land conversion are by default reliant on land and will face physical risks if this land is degraded. However, environmental dependencies can be high even when environmental impacts are low. Take an agricultural company that is not responsible for land conversion, but relies on soil fertility for its operations.[56] This company has a high land-related environmental dependency, even though its environmental impact is small. If soil fertility collapses due to the environmental impacts of other companies, this company will be exposed to physical risks.

Second, central banks and financial supervisors need to identify specific scenarios about how transition and physical risks might evolve in the coming years. These scenarios need then to be translated into macrofinancial effects based on the channels depicted in Figures 8 and 9. This requires financial data and modelling at the micro level to capture for example how increasing costs related to physical and transition risks can affect the profitability and the leverage of companies, but also data and modelling at the macro level to capture macroeconomic effects that also affect the

[55] For environmental dependency metrics and their translation into financial risks, see e.g. Svartzman et al. (2021) and Colesanti Senni and von Jagow (2022).

[56] For examples of environmental dependencies, see the ENCORE database.

financial position of companies.[57] Ideally, contagion effects should also be considered e.g. through the use of network modelling.

Although environmental stress testing is necessary, the incorporation of environment-related financial risks into monetary and financial tools is not straightforward and should be treated with caution.[58] Environmental stress testing can never generate accurate results due to the uncertainties related to how transition policies might be implemented and how the ecosystems will react to human interventions, but also because of the lack of sufficient data and the weaknesses of modelling methodologies.[59] The challenges and gaps are even more in the case of non-climate environmental risks, due to the lack of sufficient land- and water-related data. Moreover, risks differ substantially between different scenarios. For example, in the NGFS climate scenarios, physical risks are high and transition risks are low in the Hot House World scenarios, while the opposite holds in Disorderly Transition scenarios. Hence, the scenario that central banks and financial supervisors will select to calibrate their tools matters. But despite the central role of the selected scenario in identifying risks, it is unclear which scenario or scenarios should be the basis for a climate risk calibration. This is even more challenging in the case of environmental risks due to the lack of financial scenarios for risks that move beyond climate change.[60]

Third, incorporating transition risks into monetary and financial policies does not necessarily imply that borrowers who cause environmental harm will be treated unfavourably. Consider, for example, a company that engages in unsustainable palm oil activities and has issued a 2-year bond. In a scenario in which regulations about deforestation are introduced 6 years from now (late transition), this bond is not risky at all (unless it is assumed that these policies are anticipated by financial markets). This is also the case in a scenario with no transition. So, from a transition risk perspective, this bond should not necessarily be treated less favourably than other bonds. But, from an environmental materiality perspective, this bond should be penalised by central banks and financial supervisors since it contributes to deforestation.

Fourth, reducing exposure to physical risks might have adverse side effects. Suppose, for example, that central banks and financial supervisors make access to finance more costly for those companies that are more dependent on forests and water because they are perceived to be more exposed to physical risks.[61] Although this might reduce risk exposure at the micro level, from a systems-based perspective this might be counterproductive because it would undermine investments that could allow these

[57] See, for example, Emambakhsh et al. (2023).

[58] See also Dafermos (2022) and Dafermos et al. (2022b).

[59] See Chenet et al. (2021).

[60] For some directions on how to develop such scenarios, see NGFS (2023c)

[61] Generally speaking, physical risks are perceived to be higher for companies that belong to sectors, or have operations in areas, that are more vulnerable to climate-related events, biodiversity loss, water availability etc. For example, in the case of water, there are specific locations that are more exposed to water basin risks (floods, water pollution etc.) and specific sectors that rely heavily on water use (the agriculture sector, the energy and mining sector, the food and beverage industry etc.). See WWF (2019a).

companies to adapt to the environmental crisis by reducing this dependence. A more constructive approach could be for central banks and financial supervisors to encourage financial institutions to engage with borrowers and help them develop resilience plans, i.e. plans about how companies will transform their assets, operations and business models to reduce their exposure to physical risks.

Fifth, as double materiality suggests, the actions and decisions of central banks and financial supervisors affect environment-related financial risks. As a result, the risks that central banks and financial supervisors try to quantify are not exogenous to their actions and decisions. For example, the introduction of financial regulation that does not permit the financing of deforestation in a specific country can reduce the physical risks that the financial system of this country faces, but can increase transition risks for specific sectors. This endogeneity of risks further complicates the quantification of environment-related financial risks.

Because of these challenges, a pragmatic starting point for central banks and financial supervisors could be to adjust their tools based on environmental materiality metrics which also capture approximately some transition risks: borrowers with higher environmental impacts are, on average, more exposed to transition risks since they are more susceptible to changes in environmental policies. This is, for instance, the approach that the ECB adopted when it incorporated climate environmental materiality criteria into its corporate bond purchase programme. Through the use of emissions-based metrics that capture environmental impact, the ECB tried to both reduce the environmental materiality of the euro area bond market and the exposure of the Eurosystem to climate transition financial risks.[62] At the same time, central banks and financial supervisors should also analyse environment-related risks and incorporate these risks into their tools, taking into account the caveats mentioned above. In the next sub-section, we discuss how environmental issues can be incorporated into monetary and financial policy tools both from an environmental and financial materiality perspective.

5.3 Incorporating environmental issues into monetary and financial policies

Monetary policy tools are used by central banks to achieve some of their targets about inflation, employment, financial stability and exchange rate stability. They include, for example, asset purchases, collateral frameworks and refinancing operations. Financial policy tools are used by financial regulators and supervisors to make sure that the financial system is stable. They include, for example, capital requirements, loan concentration limits and stress testing. Financial policy tools also include credit controls that affects the allocation of credit in the economy.

Tools such as refinancing operations, capital requirements and credit controls have a direct impact on bank loans, so they are more relevant for Global South central banks since loans typically play a more important role than market-based finance

[62] See ECB (2022b).

in the Global South.[63] Loans are also more important for the agriculture & forestry sector both in the Global North and the Global South since the bonds that this sector issues are relatively limited.[64] This means that the tools that mostly target bank loan provision are very important for addressing deforestation and land conversion issues.

From an environmental materiality perspective, the general purpose of incorporating environmental issues into monetary and financial tools is to create more favourable financing conditions for borrowers with positive environmental materiality and less favourable financing conditions for borrowers with negative environmental materiality. Again, it is important to highlight that environmental materiality should be understood within a dynamic context whereby forward-looking information (most notably transition plans) plays an important role. From a financial materiality perspective, the main aim is to capture the exposure of the financial system to transition and physical risks.

Adjusting monetary policy tools

Recent years have seen a significant increase in the asset purchases of several central banks around the globe. Most of these purchases refer to government bonds. However, several central banks have also bought a significant amount of corporate bonds. Asset purchases have an impact on the prices of bonds since they create a source of demand for these bonds creating upward pressures on their prices. However, central banks also have an impact on the bond markets (and other financial markets) through their collateral frameworks. Collateral frameworks in many countries include government and corporate bonds that commercial banks can use as collateral to get access to central bank liquidity. Therefore, if central banks wish to change the financing conditions in the bond markets in line with environmental materiality they need to introduce environmental criteria both for their asset purchases and the collateral frameworks.

Central banks can introduce environmental criteria for corporate assets that serve as collateral. For example, in 2018, the People's Bank of China (PBoC) broadened its asset classes and included green bonds as collateral for its Medium Term Lending Facility.[65] But apart from providing preferential treatment for green bonds, central banks can also adjust haircuts[66] and eligibility based on environmental materiality metrics. Bond issuers with a better (worse) environmental performance could see a reduction (increase) in the haircuts that are assigned to their bonds. On top of it, bonds related to always environmentally harmful activities would be excluded from collateral frameworks. Collateral concentration limits can also be posed on other environmentally harmful activities.

As far as corporate asset holdings are concerned, the Bank of England (BoE)

[63] See e.g. OECD (2017).

[64] See e.g. Ross et al. (2023).

[65] See Macaire and Naef (2023).

[66] Central banks determine the haircut on the eligible assets (based on various criteria such as the credit rating and the maturity of bonds): the higher the haircut of an asset the lower the liquidity that can be obtained using this asset as collateral. For example, if the value of a collateral is EUR 1,000,000 and the haircut is 10% then the amount of liquidity that a bank that owe this collateral can get is EUR 900,000.

and the ECB have recently introduced climate criteria into their corporate bond holdings.[67] They have measured the climate performance of bond issuers by relying on emissions data and have tilted their holdings towards issuers that have a strong climate performance based on specific scores. In their climate scoring frameworks, they have considered both backward-looking and forward-looking indicators. Their tilting approach also treats green bonds preferably.

This climate tilting can be extended by using broader environmental scores based on the environmental materiality approach described above. But, at the same time, tilting must become stricter. The BoE and the ECB have decided to not exclude companies from their purchases.[68] For companies that engage in always environmentally harmful activities and have no plans to phase out these activities, exclusion could provide strong signals to the financial markets and could be conducive to a lower environmental materiality of the financial system. However, this exclusion needs to be done carefully using a holistic perspective. For example, in the case of land, if the contribution to deforestation is used as the sole land-related exclusion criterion, there is a risk that a company that does not contribute to deforestation but converts grasslands and savannahs into agricultural land would not be excluded.

As far as government bonds are concerned, recent years have seen a growing issuance of green sovereign bonds.[69] Most of these bonds refer to climate projects. However, there is a potential for green sovereign bonds to start covering spending related to broader environmental projects of governments. For example, governments can start issuing green sovereign bonds for projects that aim to protect forests and other ecosystems, improve freshwater storage systems, modernise water pipelines and increase water recycling. If central banks tilt their asset purchases towards these types of bonds, their interest rates can decline and governments can be incentivised to issue more such bonds. Central banks can also provide preferential treatment to green government bonds in their collateral frameworks.

Monetary policy tools can also affect the provision of loans. The banking system currently provides a significant amount of loans to companies that engage in dirty activities (including deforestation practices).[70] A monetary policy tool that can have an impact on loan provision is refinancing operations.[71] To make refinancing operations greener, central banks can make the cost of refinancing a function of the greenness and dirtiness of loans that are on the balance sheet of commercial banks: the higher the proportion of green loans compared to dirty loans, the lower the cost of borrowing from the central bank. This can incentivise banks to allocate lending towards borrowers with a better environmental performance.

Apart from adjusting the cost of lending for banks based on environmental criteria, central banks can also calibrate the interest rate related to the reserves that

[67] See Bank of England (2021), ECB (2022a) and Dafermos et al. (2022a, 2023).

[68] The only exception is the exclusion of coal companies from the Bank of England corporate bond purchase scheme.

[69] See Cheng et al. (2022).

[70] See RAN et al. (2023) and WWF (2016), for the financing of fossil activities and deforestation, respectively.

[71] For an overview of various countries' targeted refinancing operations, see Colesanti Senni and Monnin (2021).

commercial banks hold on the asset side of their balance sheet. A green tiering mechanism would remunerate banks at a zero interest rate up to a reserve holdings threshold with this rate becoming positive after this threshold is passed. Such a threshold would be dependent on green considerations. In particular, banks with a greener loan portfolio would benefit from a lower threshold that would allow them to get a positive remuneration for a lower level of reserves holding.[72]

Although the above-mentioned adjustments follow an environmental materiality perspective, some of these monetary policy tools can also be simultaneously adjusted using a financial materiality perspective. For example, in the collateral framework haircuts can be adjusted based on the environmental risks that the issuers of bonds are exposed to.

Adjusting financial policy tools

Let us now turn to how financial policy tools can incorporate environmental materiality. Capital requirements (a key component of Basel III) is an important financial policy tool. They have an impact on lending: higher capital requirements are associated with lower loan supply.[73] Therefore, an environmental adjustment of capital requirements would involve an increase in capital requirements for loans with a poor environmental performance (dirty penalising factor) and a decline in capital requirements for loans with a strong environmental performance (green supporting factor).[74] Additionally, loans linked to always environmentally harmful activities (see Table 2) can be subject to the so-called one-for-one rule: for every dollar of such loan financing, banks should set aside one dollar of their own funds.[75] Some central banks have made adjustments to the capital requirements of financial institutions taking into account environment-related risks and the greenness of the assets. For example, the Magyar Nemzeti Bank (MNB) in Hungary has implemented preferential capital requirements for green housing loans. The Bank allows financial institutions to hold lower capital requirements if they provide loans to energy-efficient properties. [76]

But financial regulation can move beyond incentives. Financial authorities can use credit controls by asking banks to allocate a specific proportion of their credit to green activities. The Bangladesh Bank and the Reserve Bank of India (RBI) have used such an approach.[77] Additionally, financial regulation can ban loans that support projects that are clearly inconsistent with the environmental crisis, such as projects that lead to deforestation. For example, the Banco Central do Brasil (BCB) has introduced several resolutions that restrict access to rural credit for cattle ranching activities in

[72] Reserve tiering has, for example, been used by the Swiss National Bank (SNB) (see Fuster et al., 2024). During the period that the policy interest rate was negative, the SNB was exempting reserves from the negative rate (remunerating them at a 0 rate) up to a specific threshold. The goal of this scheme was to reduce the losses of banks. In the current positive interest rate environment, the SNB uses a similar tiering to incentivise transactions among banks which are considered to be important for the transmission of monetary policy: reserves are remunerated at zero interest rate up to a reserves holding threshold.

[73] See e.g. Fraisse et al. (2020) and De Marco et al. (2021).

[74] For some key issues and challenges in designing green capital requirements, see Dafermos and Nikolaidi (2022b).

[75] See Philipponnat et al. (2020).

[76] See Baer et al. (2021) and MNB (2019, 2021).

[77] See Nabi et al. (2016).

Brazil.

All the adjustments of financial policy tools that intend to reduce the environmental materiality of the financial system should be understood as strong macroprudential interventions, in the sense that they contribute to the reduction of global warming,land conversion and water stress and, therefore, to the reduction of the physical systemic risks for the financial system.[78]

From a financial materiality perspective, environmental adjustments can be made using either a microprudential or a weak macroprudential approach. A straightforward microprudential adjustment of financial policy would be the modification of the risk weights of assets based on the environmental risks they are exposed to. This requires the incorporation of environmental risks into credit risk models.

Weak macroprudential tools are tools that aim at reducing the aggregate exposure of the financial system to environmental risks, without considering the feedback effects of the financial system on the environment. From a financial supervisory perspective, a weak macroprudential tool is environmental stress testing which can help supervisors understand the aggregate exposure of the financial system to environmental risks. The results of environmental stress tests could prompt supervisors to increase Pillar II capital requirements, for example due to excessive exposure of banks to deforestation-related financial risks.

From a financial regulatory perspective, a weak macroprudential tool is the environmental systemic risk buffer that would increase the capital related to the exposure of financial institutions to specific environmentally harmful activities or to geographical areas that suffer from climate risks, loss of biodiversity or water stress.[79] Another similar tool is the environmental exposure/concentration limit that would restrict the amount of credit that financial institutions can provide to environmentally harmful activities and geographical areas that have faced climate risks or have significant environmental dependencies.

The importance of environmental policy mixes

Incorporating environmental issues into monetary and financial policy tools would not be sufficient to avert the climate crisis, the conversion of forests and natural ecosystems as well as water stress. Fiscal, trade and regulatory policy tools need to be used at the same time. For example, the prevention of deforestation can be much more substantial if a deforestation-free credit policy is combined with a deforestation-free regulation or with green subsidies to farmers that help them improve agricultural productivity. This suggests that central banks and financial supervisors should coordinate with other public policy authorities. This coordination is not only necessary for the implementation of policy mixes, but also for the collection of data for the development of environmental metrics.

[78] For the distinction between strong macroprudential and weak macroprudential tools, see Dafermos and Nikolaidi (2022b).

[79] For the climate risk buffer, see Schoenmaker and Van Tilburg (2016), Monnin (2021) and Emambakhsh et al. (2022).

Recommendations

Central banks and financial supervisors should start paying attention to environmental challenges that move beyond climate change. Deforestation, land conversion and water stress are at the core of the environmental crisis. The financial system should, therefore, stop supporting activities that are conducive to the reduction of forest areas, the conversion of natural ecosystems and the intensification of water stress. Instead, central banks and financial supervisors need to adjust their policy tools to support activities and companies that reduce environmental pressures. At the same time, they should incorporate into their analytical frameworks the financial risks posed by deforestation, land conversion and water stress and take action that would help reduce these risks at the system level.

Based on the analysis in this report, our main recommendations are as follows:

1. **Central banks should stop being part of the problem and should take action to discourage the financing of always environmentally harmful activities via their monetary and financial policy tools.** Always environmentally harmful activities are activities whose negative environmental impact on climate change, land conversion and water stress cannot be reduced even with mitigation actions and, therefore, it is necessary for these to be decommissioned. Examples of these activities include coal, oil and gas production as well as logging of primary or old growth forests.

2. **Central banks and financial supervisors need to analyse and act on deforestation, land conversion and water stress using a systems-based double materiality lens**. Double materiality suggests that it is insufficient for central banks and financial supervisors to just try to protect the financial system from its exposure to environmental risks, as implied by financial materiality. The reason is twofold. First, from an environmental materiality perspective, the financial system is a contributor to the environmental crisis: financial institutions and financial markets provide credit to companies that rely on business models that are conducive to land conversion and water stress. Central banks and financial supervisors have a responsibility to take action that will reduce the environmental materiality of finance. Second, a mere emphasis on reducing the exposure of finance to environmental risks can be counterproductive.

3. **Stock-flow consistent approaches can help central banks and financial supervisors to enhance their understanding of the dynamic interactions between macrofinancial systems and ecosystems**. These approaches have two key advantages. First, they are well-suited to analyse the interactions between monetary stocks/flows (such as credit flows, bonds and interest payments) and physical stocks/flows (such as deforestation flows, water use and water resources). This permits an integrated understanding of how the environment interacts with the financial system, including macrofinancial feedback loops. Second, by using a systems dynamics perspective that moves beyond equilibrium analyses, these

approaches are particularly suitable for capturing instabilities that might emerge from the environmental crisis. Stock-flow consistent approaches should, therefore, be used systematically in the central banking community both for quantitative and qualitative analyses. This includes the development of scenarios about deforestation, land conversion and water (and their macrofinancial implications) as well as the design and run of environmental stress testing exercises.

4. **In collaboration with other public authorities, central banks and financial supervisors need to develop metrics that capture the environmental materiality of finance**. These metrics should mostly focus on the main activities undertaken by companies and their environmental impact in terms of physical flows (including geolocation information when this is relevant). Physical flow-based metrics should capture both the past environmental performance (backward-looking) and the targets of companies to reduce their environmental footprint with a specific emphasis on transition plans (forward-looking). They should also reflect not only direct but also indirect environmental impacts (for example through supply chains) and be reported both in gross and net terms to reduce the risk of greenwashing. Activity-based metrics should make a distinction between (i) dirty activities that are always environmentally harmful, (ii) dirty activities that have a potential to reduce their negative environmental impact and (iii) green activities.

5. **Due to data challenges, central banks and financial supervisors might need to use a gradual approach to the development and use of environmental materiality metrics**. They can first develop some imperfect metrics based on existing data (e.g. metrics that primarily rely on activities) and then improve them gradually as more data is becoming available.

6. **Central banks and financial supervisors should introduce environmental materiality metrics into their policy tools.** These tools, which refer both to monetary and financial policies, differ between countries due to different institutional structures and central bank mandates. Central banks and financial supervisors should identify those tools that are more relevant for their economies and mandates and start incorporating environmental criteria as soon as possible, in coordination with other public authorities that also need to incorporate environmental criteria into fiscal, regulatory and trade policies. Monetary and financial policies will stop supporting dirty activities that are always environmentally harmful if, for example, central banks and financial supervisors exclude bonds and loans related to these activities from collateral frameworks and quantitative easing programmes or if they substantially increase the capital requirements related to these dirty loans. At the same time, monetary and financial policies should support green activities as well as companies that have credible environmental transition plans in place. If data gaps act as a barrier to the environmental adjustment of monetary and financial tools, a timeline should be developed that will specify how and when these data gaps will be addressed and when the initial environmental calibration of the tools will take place. There is no need for central banks and financial supervisors to wait until perfect metrics are available. The costs of inaction are high both from a macrofinancial and an environmental

perspective.

7. **Central banks and financial supervisors should carefully monitor the financial materiality of the environmental crisis**. This requires a combination of metrics, scenario analysis and stress testing exercises. In terms of metrics, central banks and financial supervisors can capture transition risks by using environmental materiality metrics as proxies, while they can approximate physical risks by using environmental dependency metrics. However, proxies might provide an inaccurate depiction of environment-related financial risks. For this to be addressed, central banks and financial supervisors should translate environmental impacts and dependencies into specific financial effects using scenarios about how climate change, land conversion and water stress might evolve in the coming years, depending on transition policies (including monetary and financial policies). The stock-flow consistent approach can play a key role in the development of such scenarios and their translation into financial effects. Once financial risks have been identified, they can be incorporated into microprudential and macroprudential financial policies.

8. **The actions of central banks and financial supervisors need to be consistent with global environmental justice**. Climate change, land conversion and water stress have historically been associated with the consumption and production of Global North countries. Therefore, central banks and financial supervisors in the Global North have a responsibility to act decisively on reducing the financing of environmentally harmful activities in a way that respects human rights and social justice in the Global South. Global North countries should also support the environmental efforts of central banks and financial supervisors in the Global South in a way that fits the differentiated needs of Global South economies.

Glossary of environmental terms

Built-up area: Land under houses, roads, mines and quarries and any other facilities (including their auxiliary spaces) deliberately installed for the pursuit of human activities.

Condensation: The process by which water vapour in the air cools down and changes into liquid water.

Cropland: Land used for cultivation of crops. It includes (i) arable land, i.e. land under temporary agricultural crops, land under temporary meadows for mowing or pasture and land with temporarily fallow (typically less than five years); and (ii) land under permanent crops, i.e. land cultivated with long-term crops which do not have to be replanted for several years (such as cocoa and coffee), land under trees and shrubs producing flowers (such as roses and jasmine), and nurseries (except those for forest trees).

Deforestation: The conversion of forest to other land use irrespective of whether this conversion is human-induced or not. It includes permanent reduction of the tree canopy cover below the minimum 10 percent threshold and areas of natural forest converted to agriculture, pasture, water reservoirs, mining and urban areas. Excludes areas where the trees have been removed as a result of harvesting, and where the forest is expected to regenerate naturally or with the aid of silvicultural measures.

Embodied water stock: Water used from the available water stock to grow crops and feed animals and does not evaporate or is returned to the source but becomes embodied in the final product (e.g. plants or meat).

Evaporation: The process by which water changes from a liquid state to water vapour due to heating from the sun. It occurs in oceans, lakes, rivers and the soil.

Grasslands and savannahs: Lands on which the existing plant cover is dominated by grasses with or without scattered trees. Grasslands and savannahs can either be pristine (i.e. not been subject to major human impacts in recent history) or managed whereby ecosystems' composition, structure and ecological function remain present despite human interventions.

Hydrological cycle: Refers to the continuous and cyclical movement of water on, above and below the Earth's surface. It involves various processes through which water is redistributed around the planet. The main ones are condensation, evaporation, infiltration, precipitation, runoff, storage, sublimation and transpiration.

Infiltration: The process by which water on the surface of the ground enters the soil. This happens when rainwater, melted snow or irrigation water seeps through the soil surface and moves into the subsurface layers. The water that has been infiltrated can be stored in underground aquifers or can move through the soil and porous rock layers to reach rivers and lakes (this movement is called percolation).

Land conversion: Land conversion is a subset of land use change that specifically refers to the transformation of land from one land use category to another, often involving a more specific change in land function.

Logging: Selective or systematic harvesting of trees from forests for commercial purposes, primarily to obtain timber and wood products. Logging is a component of forestry management, and it can be done sustainably (selectively) or unsustainably (clear-cutting). Logging is typically done on a smaller scale and is focused on the extraction of specific tree species or sizes. While logging can still have environmental impacts, it can be managed more sustainably through practices like selective logging and reforestation to minimise long-term damage to the forest ecosystems.

Natural forests: Land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. Natural forests can be managed or unmanaged and do not include planted forests. Regenerated natural forests are forests that have regrown and now have ecosystems composition, structure and function similar to forests native to the site. Regrowth can, for example, be achieved through native vegetation for several years after agricultural abandonment or plantings of diverse native tree species as part of management practices for ecosystems restoration.

Other land: Land not classified as agricultural land (i.e. cropland and pastureland), forest area (i.e. natural and planted forests), grasslands/savannahs or built-up area. It includes non-forest ecosystems, such as peatlands and mangroves.

Pastureland: Land under permanent pastures and meadows used permanently (five years or more) to grow herbaceous forage crops through cultivation. It includes grazing in wooded areas (agroforestry areas, for example), grazing in shrubby zones (heath, maquis, garigue) and grassland in the plain or low mountain areas used for grazing.

Planted forests: Forests predominantly composed of trees established through planting and/or deliberate seeding. They include plantation forests, i.e. planted forests that are intensively managed and meet all the following criteria at planting and stand maturity: one or two species, even age class and regular spacing.

Precipitation: Any form of water that falls from the atmosphere to the Earth's surface. It includes rain, snow, sleet, hail and drizzle.

Runoff: Water that does not infiltrate into the ground and runs over the Earth's surface, forming streams, rivers, and eventually flowing into larger bodies of water, such as lakes and oceans.

Storage: Water temporarily stored in various forms, including surface water bodies (oceans, lakes, rivers), groundwater, glaciers and ice caps.

Sublimation: The process by which ice is directly transformed into water vapour without first melting.

Transpiration: The process by which water vapour is released into the atmosphere by plants through small openings on their leaves called stomata. Transpiration is often considered part of the overall evaporation process.

Unsustainable water use: Utilisation of water resources in a manner that exceeds the natural replenishment rate of those resources or that causes water pollution, leading to long-term negative impacts on the environment.

Water stress: The condition under which the local demand for water exceeds the available supply during a certain period. Water availability can be affected by unsustainable water use for production and consumption or by water pollution. In both cases, water is drawn from the available water stock.

Water vapour: The gaseous water stock distributed in the atmosphere at any given time point.

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