2. CLIMATE RISK EXPOSURES OF THE FINANCIAL SECTOR IN LUXEMBOURG AND CLIMATE STRESS TESTING[6]

José Fique*, Max Gehrend◊, Kang-Soek Lee*, Federico Lubello*, Daniel Morell* and Joseph Yapi◊

ABSTRACT

The impact of economic activities on the climate has been constantly increasing over time, creating a situation of urgency in light of the amplification of climate risk and its repercussions, including on the stability of the financial sector. Indeed, climate shocks can lead to rapid and significant depreciations of assets held by financial institutions, thus affecting the stability of the financial system as a whole. It is therefore essential that the various players in the financial sector integrate climate risk in their risk management frameworks and engage in efforts to decarbonise their portfolios. To raise awareness of climate risk and to identify financial stability risks related to climate change, we present an analysis structured in two parts.

In part one, we provide an overview of the exposures of the financial sector in Luxembourg to climate risk. We find that almost half of the corporate exposures of banks and investment funds domiciled in Luxembourg are to carbon-intensive sectors.

In the second part, we conduct a climate stress test for banks and investment funds, the two core components of the financial sector in Luxembourg. Over the horizon of the stress test, we simulate the impact of three climate scenarios (namely, Current Policies, Delayed transition and Net Zero 2050) developed by the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) on banks' resilience and on investment funds' net assets. For banks, we explicitly model the evolution of corporate probabilities of default based on a panel data model that includes a set of macroeconomic variables. The simulated probabilities of default under the three scenarios are then used to derive banks' Tier 1 capital ratios. The results indicate that, compared to the Current Policies scenario, the banks in our sample would see their Tier 1 capital ratio stand at 2 percentage points higher under the Net Zero 2050 scenario and 0.6 percentage points higher under the Delayed transition scenario. For investment funds, we regress the growth of net assets of investment funds domiciled in Luxembourg on a set of macroeconomic variables, which we then combine with the above-mentioned climate scenarios to simulate the paths for investment fund net assets. The results indicate that investment fund net assets would be 17.6 % higher under the Net Zero 2050 scenario and 7.4 % higher under the Delayed transition scenario compared to the Current Policies scenario. Hence, the results for banks and for investment funds both suggest that the benefits of policies favouring the transition towards net zero emissions in 2050 clearly outweigh potential costs associated with the transition, for example those stemming from a carbon tax.

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1. INTRODUCTION

It is widely recognized that climate change poses significant and unprecedented challenges to the soundness of the financial system, with the potential to reshape it. Against this background, this study contributes to the debate on the impact of climate-related risks on the economy and financial stability by examining the case of Luxembourg.

Climate-related risks encompass both physical and transition risks. Physical risk refers to the risk stemming from the materialization of nature-related hazards. It includes the economic costs and financial losses resulting from the increasing severity and frequency of extreme weather events that damage physical assets (acute physical risk) as well as longer-term progressive shifts of the climate stemming from global warming, sea level rise and precipitation (chronic physical risk). More severe and frequent extreme weather events could undermine balance sheets of households and firms, and lead to damage of physical assets, increases in defaults, and potential financial sector distress. Transition risk refers to the economic and financial cost of adjustment towards a low-carbon economy. It translates into financial risk for lenders and investors while affecting the profitability of businesses, the wealth of households and the valuation of stranded assets. For instance, the process of reducing the emissions of greenhouse gases (GHG) is likely to dampen all sectors of the economy and affect the value of financial assets. The implementation of climate policies could also lead to a sudden repricing of climate-related risks and stranded assets, which could negatively affect the balance sheets of financial institutions.

Therefore, it is crucial for financial institutions to properly understand climate risks and evaluate their potential impacts. Additionally, supervisors and regulators also need to monitor these risks and take preventive actions. Indeed, the Network for Greening the Financial System (NGFS, 2019) asserts that climate-related risks are a source of financial risk and it therefore falls within the mandates of central banks and supervisors to ensure the financial system is resilient to these risks. The NGFS (2019) also recommends integrating climate-related risks into financial stability monitoring and microprudential supervision. In this context, several central banks and supervisors have carried out climate-related analyses to assess the climate-related risks faced by the financial system. In parallel, climate stress testing has been emerging as an important tool for assessing and managing climate-related risks in the financial sector by quantifying the effects of these risks on the resilience of financial entities such as banks, insurers and investment funds.

In 2022, the European Central Bank (ECB) carried out a climate stress test aiming at deepening the understanding of banks' climate stress-testing framework as well as their level of preparedness. Similarly, several national central banks (NCB) undertook climate risk analyses to assess the exposure of their financial system to climate-related risks. For instance, the Autorité de contrôle prudentiel et de resolution (ACPR, 2021) published the main results of the climate pilot exercise conducted in 2020 by the Banque de France, which aimed at raising awareness of climate change while quantifying the climate-related risks and vulnerabilities to which French financial institutions are exposed. Furthermore, the Bank of England (BoE, 2022) published the results of its Climate Biennial Exploratory Scenario (CBES) carried out in 2021, which aimed at exploring the financial risks posed by climate change for the largest UK banks and insurers. More recently, the US Federal Reserve Board has been conducting, since January 2023, a pilot Climate Scenario Analysis (CSA) exercise aiming at evaluating climate-related financial risks. In particular, this exercise allows for a better understanding of the participating financial institutions' resilience under different climate scenarios, which cover a range of possible climate pathways and associated economic and financial developments. However, the Federal Reserve Board highlights that this exercise differs from regulatory stress tests in that it is exploratory in nature and does not have consequences for bank capital or supervisory implications, even though it also aims to enhance the ability of banks and supervisors to identify, measure, monitor, and manage climate-related financial risks.

In a similar vein, the present study has two objectives. First, it aims to provide an overview of the exposures of the Luxembourg financial sector to climate risk. We find that almost half of the corporate exposures of banks and investment funds domiciled in Luxembourg are to carbon-intensive sectors. This holds for banks' loan and corporate bond portfolios, as well as for investment funds' equity and corporate bond portfolios. Moreover, the ratio of exposures to carbon-intensive sectors to total corporate exposures did not materially decrease over the last years for banks or investment funds, highlighting the need to increase decarbonisation efforts in these two main sectors. Second, our analysis aims to assess the resilience of banks and investment funds in Luxembourg to different climate-related risks. For this purpose, we conduct a climate stress test using three climate risk scenarios developed by the NGFS (2023) to simulate the impacts of climate-related risks on banks' resilience and on investment funds' net assets.

The first scenario consists of an "orderly transition" to net zero greenhouse gas emissions in 2050 (Net Zero 2050). The second is a disorderly scenario, in which transition only starts in 2030 (Delayed transition). The last scenario assumes no further policies are enacted to reduce net emissions beyond what has already been implemented, resulting in a "hot house" world (Current Policies).

In our bank stress test, we use a three-step approach. The first step consists in estimating a panel data model. The corporate probability of default is regressed on a set of macroeconomic variables to assess the sensibility of the probability of default to these variables, which determines the so-called "translation parameters". Then, in the second step, the estimated translation parameters are applied to the NGFS scenarios to get the trajectory of the "stressed" probability of default (SPD). It results in a set of possible trajectories of the stressed probability of default for each selected NGFS scenario. The SPD reflects the creditworthiness of the banks' counterparties given the climate ambitions adopted in the scenarios. Finally, in the third step, the SPD series are used to estimate banks' Tier 1 capital ratios under the three scenarios. For investment funds, we use an auxiliary regression for the growth of net assets of investment funds domiciled in Luxembourg on a set of macroeconomic variables, which is then combined with the above-mentioned climate scenarios to simulate the paths for investment fund net assets.

Turning to the results of the climate stress test, we find that the change in the stressed probability of default underscores not only the urgency of addressing climate change but also the need to act in the appropriate manner. Indeed, in the case where no additional climate policies are implemented, the stressed probability of default is the highest. If the climate policies are implemented in a disorderly manner or lately, the stressed probability of default increases significantly at the time of policy implementation, before decreasing over time. On the contrary, for the more favourable scenario, the stressed probability of default is lower, highlighting the importance of implementing national climate policies in a smooth manner. The results also reveal that, compared to the Current Policies scenario, banks' aggregate Tier 1 capital ratio would be 2 percentage points higher under the Net Zero 2050 scenario and 0.6 percentage points higher under the delayed transition scenario. Regarding investment funds, the results indicate that, compared to the Current Policies scenario, investment fund net assets would be 17.6 % higher under the Net Zero 2050 scenario and 7.4 % higher under the Delayed transition scenario.

The remainder of this analysis is structured as follows. Section 2 provides an overview of Luxembourg banks' and investment funds' exposures to carbon-intensive sectors, illustrating the importance of conducting climate stress tests. This part also presents the regulatory framework and action plan to combat climate change and promote sustainable finance in Europe and Luxembourg, as well as the environmental situation in Luxembourg. Section 3 describes our climate stress-testing model and presents the results for banks and investment funds. Section 4 concludes.

2. CLIMATE RISK EXPOSURES OF THE FINANCIAL SECTOR IN LUXEMBOURG

2.1 ACTION PLANS AND GREENHOUSE GAS EMISSION

2.1.1 Climate action in Europe and Luxembourg

The Paris Climate Agreement[7] is the cornerstone of the global climate action and calls on countries to implement environmental policies to limit global warming to 2 degrees Celsius compared to pre-industrial levels.[8] Limiting global warming to such threshold is imperative if the world is to limit the potential adverse effects of climate risks. Many policies and measures, at both regional and national levels, have been adopted to achieve this goal.

At the European level, the "European Green Deal",[9] published in 2019 by the European Commission (EC), sets out the action plan and roadmap to steer European Union (EU) countries through the environmental transition. It aims to achieve carbon neutrality by 2050 with an intermediate target for 2030 of reducing greenhouse gas (GHG) emissions by at least 55 % compared with 1990 levels in a responsible manner. In June 2021, the EU adopted the European Climate Law[10] which enables to revise all relevant climate-related policy instruments for achieving climate neutrality within the Union by 2050.

In Luxembourg, the climate law of 15 December 2020[11] defines the legal and institutional framework for achieving carbon neutrality in Luxembourg by 2050, with an intermediate target of a 55 % reduction in GHG in 2030 compared to 2005.[12] Luxembourg's national energy and climate plan[13] for the period 2021-2030 (PNEC) establishes the roadmap for Luxembourg's climate action up to 2030. The PNEC identifies the main fields of action and guidelines for transformation in the sectors most concerned by the fight against climate change and focuses on several dimensions, including decarbonisation, renewable energy, energy efficiency and security of energy supply.

However, the fact that countries are lagging behind in implementing concrete actions is indicative of the gap between the objectives set by the parties at COP 21, when adopting the Paris Agreement, and

7 The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at COP 21 in Paris on 12 December 2015 and entered into force on 4 November 2016. See https://unfccc.int/process-and-meetings/the-paris-agreement for more details.

8 See https://unfccc.int/process-and-meetings/the-paris-agreement for more details.

9 See https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en for more details.

10 Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing a framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119.

11 See https://legilux.public.lu/eli/etat/leg/loi/2020/12/15/a994/jo for more details.

12 Other intermediate targets by 2030 include to achieve a 35-37 % share of renewable energies in final energy consumption, and to improve energy efficiency by 44 %.

13 See https://gouvernement.lu/en/dossiers/2023/2023-pnec.html for more details.

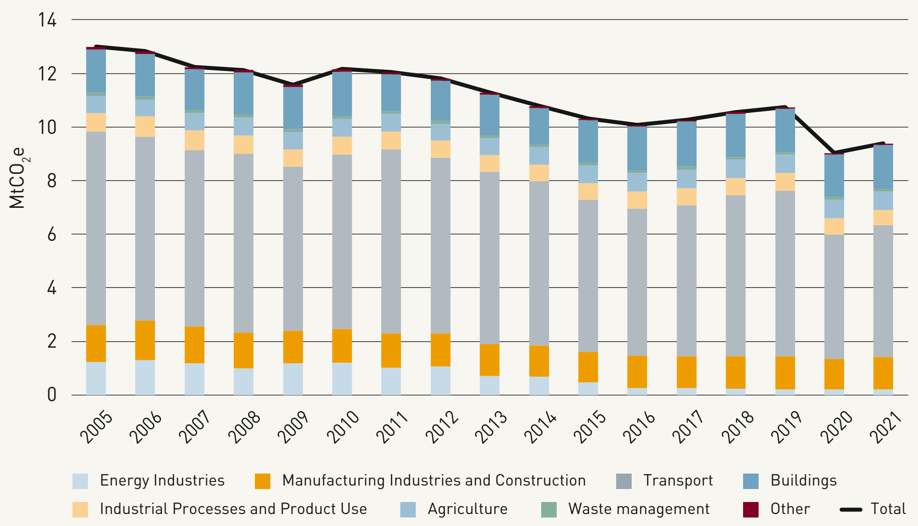
the efforts already made. Indeed, the latest report of the Intergovernmental Panel on Climate Change[14] (IPCC) highlights that the actions carried out to fight climate change remain insufficient. The experts warn of the urgent need to significantly reduce emissions linked to human activity in order to achieve the objectives set by the Paris Agreement.

Achieving all the climate objectives, whether they are set at national level (such as the PNEC) or at European level (such as the "European Green Deal"), requires significant investments not only from all national authorities but also from all actors in the financial system. According to the European Commission,[15] Europe would need additional investments of up to 260 billion euros per year in order to meet the 2030 deadline. The financial sector therefore appears to be one of the key players in achieving carbon neutrality and, in this context, Luxembourg could become a centre of excellence in sustainable finance. In order to achieve this objective, the financial system in Luxembourg must continue to renew itself, in particular by redirecting a significant part of its investments towards sustainable economic activities. This transformation will enable the achievement of a double objective, namely: (i) a more active participation of the financial sector in the fight against climate change (ii) and a reduction of the exposure of banks and investment funds to climate risks, in particular to transition risk.

2.1.2 Greenhouse gas emissions in Luxembourg[16]

Between 2005 and 2021, yearly GHG emissions in Luxembourg fell by almost 3.6 million tonnes of CO_2 ($MtCO_2e$): from 13 $MtCO_2e$ in 2005 to 9.4 $MtCO_2e$ in 2021, i.e. a drop of around 28% (Figure 1).[17] Over the period from 2005 to 2019, this downward trend was less significant, at around 17%. This is due to the exceptional situation of 2020. Indeed, the Covid-19 pandemic and more particularly the lockdown measures in spring 2020 explain the exceptional decrease in GHG emissions for the year 2020. The level of overall GHG emissions dropped from 10.7 $MtCO_2e$ in 2019 to 9.03 $MtCO_2e$ in 2020, a decrease of about 16% over one year. Some sectors that were completely shut down due to containment showed a very significant decrease in GHG emissions. The halting of air transport and the decline in road transport account for the majority of the overall effect. Transport sector emissions experienced a 25% decrease in 2020 compared to 2019 levels. However, there was a minor uptick in 2021, with total emissions increasing around 4% compared to 2020.

Figure 1:
Total GHG emissions in Luxembourg

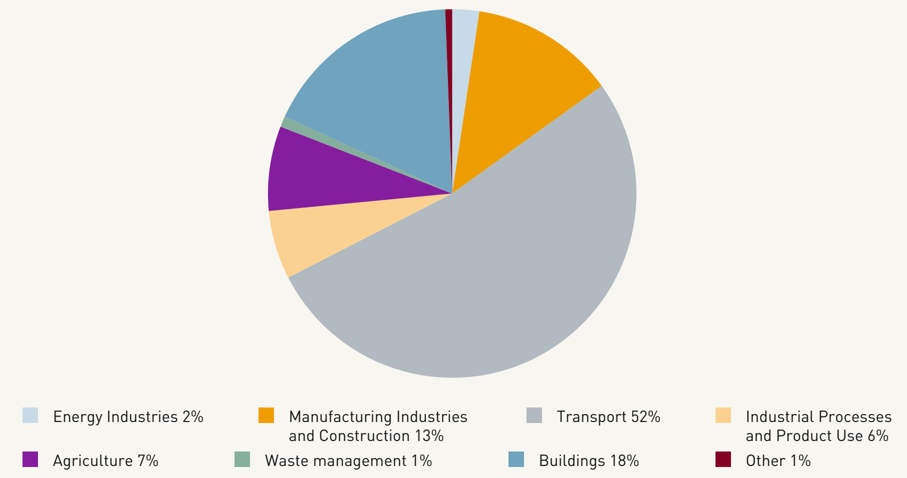


Source: European Environment Agency/Reporting United Nations Framework Convention on Climate Change (UNFCCC).

For more details: https://www.eea.europa.eu/en.

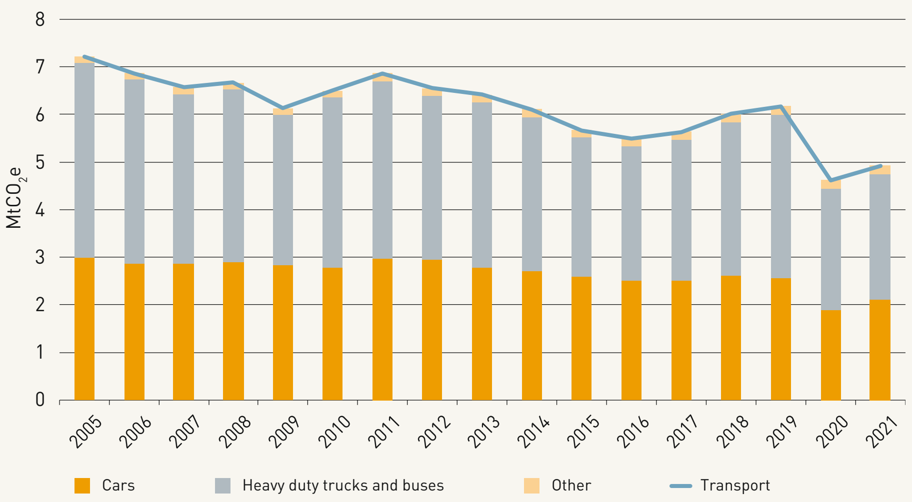
14 See IPCC reports here: https://www.ipcc.ch/reports/.
15 See https://ec.europa.eu/commission/presscorner/detail/en/ip_20_17 for more details.
16 The data used in this section comes from the United Nations Framework Convention on Climate Change (UNFCCC) reporting.
17 Net emissions, including the Land Use, Land Use Change and Forestry (LULUCF) sector, amount to 8.8 $MtCO_2e$ in 2021.

Figure 2:
Sectoral breakdown of GHG emissions in 2021



Source: European Environment Agency /Reporting UNFCCC.

Figure 3:
Breakdown of GHG emissions in the transport sector



Source: European Environment Agency /Reporting UNFCCC.

Nevertheless, the decline of GHG emissions demonstrates Luxembourg's efforts to reduce GHG emissions in all sectors. GHG emissions in the agricultural sector, nevertheless, increased slightly between 2005 and 2021 from 0.63 $MtCO_2e$ to 0.7 $MtCO_2e$, i.e. an increase of around 11% over the period.[18]

In 2021, 52% of GHG emissions in Luxembourg came from the transport sector (Figure 2), with road transport (mainly cars and heavy trucks) accounting for the majority of GHG emissions (Figure 3). According to the report on the national long-term climate action strategy,[19] 70% of GHG emissions from the transport sector come from the sale of fuel to non-residents.[20] This is likely due to Luxembourg's geographical location (at the crossroads of several European transit routes) and the fuel price differential with its neighbouring countries.

Emissions of the energy industry amounted to 0.22 $MtCO_2e$ in 2021, i.e. 2% of total GHG emissions (Figure 2). This level is explained by the fact that a large part of the electricity consumed in Luxembourg is imported (mainly from Germany), thus counting as GHG emissions in the country of production.[21]

18 This remains relatively low over 15 years.
After 2015, GHG emissions from the agricultural sector stabilised at around 0.7 $MtCO_2e$.

19 See https://gouvernement.lu/dam-assets/documents/actualites/2021/10-octobre/29-strategie-nationale-action-climat/Strategie-nationale-a-long-terme-en-matiere-d-action-climat-octobre-2021.pdf for more details.

20 It is important to note that GHG emissions in the transport sector depend mainly on the amount of fuel sold and the distance travelled. See https://www.ipcc-nggip.iges.or.jp/public/2006gl/french/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf for more details.

21 See the notions of scopes 1, 2 and 3 of the carbon footprint.

Overall, we note that GHG emissions in Luxembourg are following a decreasing trend. Notwithstanding, in order to reach the 2030 objectives, efforts must be pursued and some high-carbon sectors must become more engaged in decarbonising their activities.[22]

2.2 PHYSICAL RISK IN LUXEMBOURG

Physical risks include the risks of natural disasters and extreme events (acute risks) but also more gradual risks such as rising temperatures or sea level rise (chronic risks).

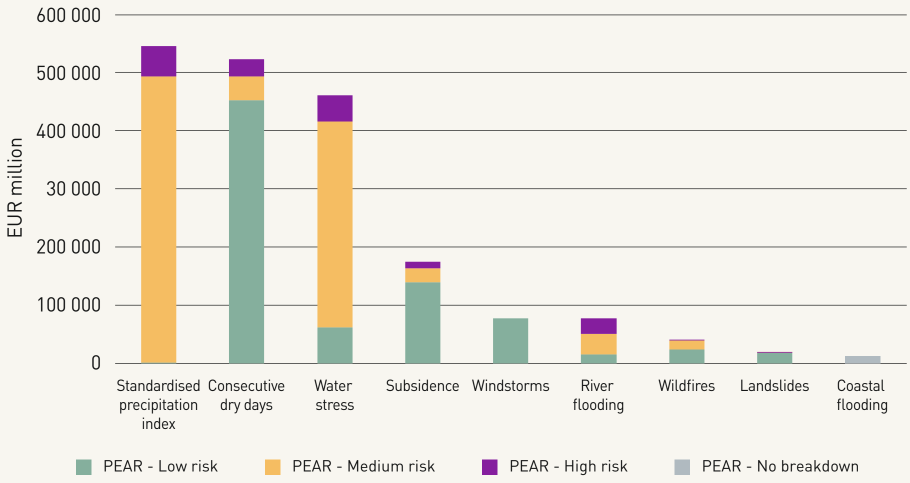
2.2.1 Potential exposure at risk and risk scores

The European Central Bank (ECB) has developed indicators of the financial system's exposure to physical risk.[23] These indicators cover nine acute natural risks, namely coastal flooding, river flooding, wildfires, landslides, subsidence, windstorms and water stress,[24] drought and extreme precipitation conditions. The potential exposure at risk (PEAR) is one of the indicators proposed by the ECB. The PEAR provides information on the share of the portfolios of financial institutions exposed to non-financial corporations (NFCs) located in areas prone to natural hazards. The indicator on risk scores (RS) complements the PEAR. The RS indicator classifies exposures according to risk level categories and assesses the share of the portfolio associated with a specific risk score. The risk score ranges from 0 (no risk) to 3 (high risk). It should be noted that the PEAR is calculated only for RS above zero. For three of the nine indicators (windstorms, landslides, subsidence), only current hazard profiles are available. For river flooding, consecutive dry days, standardised precipitation index, coastal flooding, water stress and wildfires, projections are available up to 2100.

Figure 4 shows the PEAR for each risk score. Two points stand out from this figure. First, the standardised precipitation index (SPI, which captures excessively dry or overly wet conditions), Consecutive dry days (CDD, which captures drought conditions) and water stress indicators exhibit the highest PEAR. Second, for the majority of natural hazards studied, a high share of the PEAR is associated with the lowest risk category. For example, the PEAR associated with windstorms is largely associated with the low-risk class.

Figure 4:

PEAR and RS for Luxembourg



Source: ECB.

For more details: https://www.ecb.europa.eu/stats/ecb_statistics/sustainability-indicators/html/index.en.html.
Note: Projection horizon varies. Scenario 'RCP-8.5' used.

22 For further details see, for example, https://www.eea.europa.eu/en/analysis/indicators/total-greenhouse-gas-emission-trends and https://ccpi.org/country/lux/.

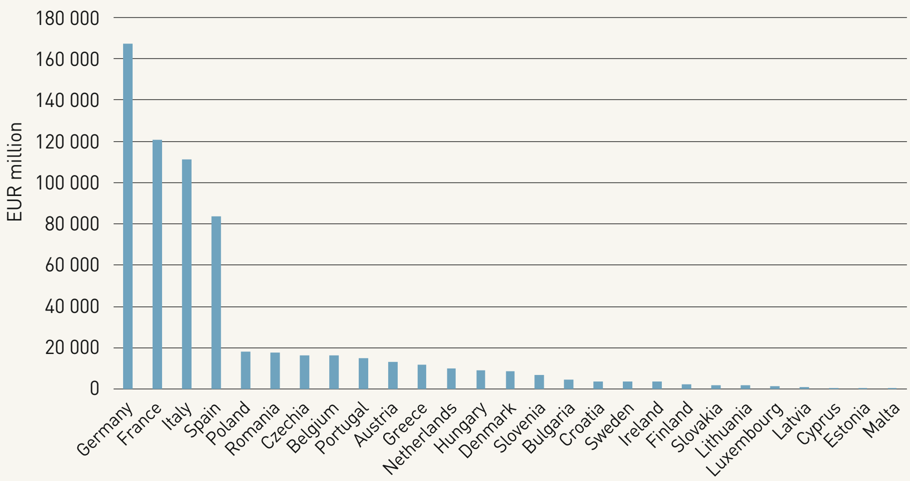
23 See https://www.ecb.europa.eu/pub/pdf/other/ecb.climate_change_indicators202301~47c4bbbc92.en.pdf for more details.

24 Baseline water stress measures the ratio of total water demand to available renewable surface and groundwater supplies. Water demand include domestic, industrial, irrigation, and livestock uses. Available renewable water supplies include the impact of upstream consumptive water users and large dams on downstream water availability. Higher values indicate more competition among users. See https://www.wri.org/aqueduct.

However, this is not the case for the SPI and water stress indicators. For these indicators, more than 75 % of the PEAR is assigned to a medium-risk category, while 10 % is assigned to a high-risk category. Therefore, from a physical risk perspective, extreme precipitation conditions and water stress represent the most important threats to the financial system in Luxembourg, both in terms of potential exposure and risk score.

Figure 5:

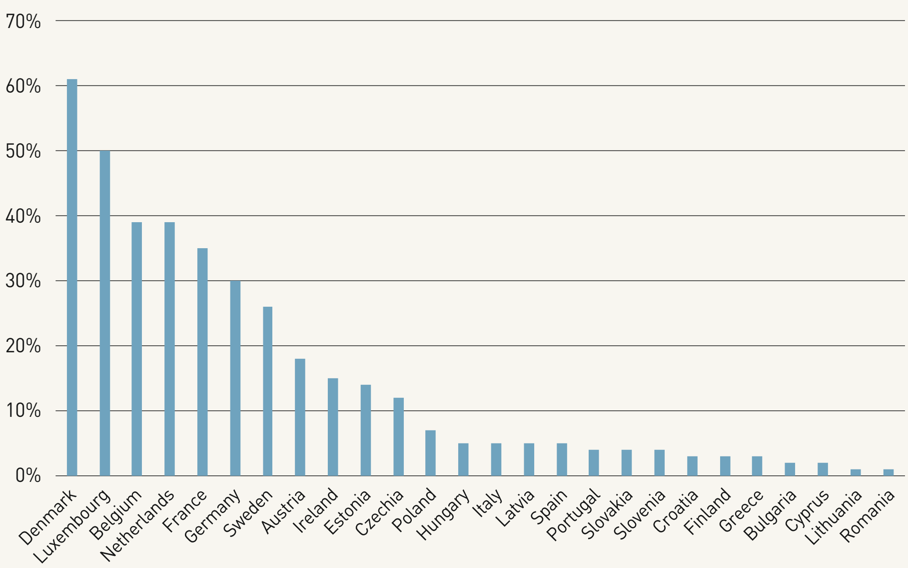
Economic damage caused by weather- and climate-related extreme events in EU member countries (1980-2022)



Source: RiskLayer / European Environment Agency.

Figure 6:

Share of insured losses following weather- and climate- related extreme events in EU member countries (1980-2022)



Source: RiskLayer / European Environment Agency.

2.2.2 Share of losses insured and geographical breakdown of banks' exposures

Despite the wide variations in the data, the economic losses caused by natural hazards in the EU have been steadily increasing since the 1980s. For example, over the period 1980-2022, the losses caused by weather and climate events for the 27 EU Member States amounted to about 650 billion euros.[25] The average loss for all 27 EU Member States was around 24 billion euros. In the same period, the losses for Luxembourg were relatively limited at around 1.25 billion euros. The countries with the largest losses are Germany, Italy, France and Spain respectively (Figure 5). Moreover, a large share of losses in Luxembourg are insured (50 %), which makes it the second best covered country in the European Union in the event of weather- and climate-related extreme events (Figure 6).

With regards to the geographical breakdown of its assets, the banking sector seems to have a limited exposure to physical risk insofar as its exposures are mainly concentrated in geographical areas with low vulnerability to extreme

25 See https://www.eea.europa.eu/data-and-maps/daviz/economic-damage-caused-by-weather#tab-chart_2 for more details. The data are presented in Euro 2020 values and are from Munich Re.

weather events. The total amount of risk-weighted assets (RWA) of banks in Luxembourg varied slightly around 192 billion euros between December 2015 and December 2018, before rising sharply from 2019 onwards, reaching 256 billion euros in December 2023 (Figure 7a). These exposures are generally located in countries with a temperate climate, and are therefore unlikely to be strongly affected by climate change (Figure 7b). In the fourth quarter of 2023, more than 75 % of the RWA of banks in Luxembourg were located in Europe, including 23 % in Luxembourg and 25 % in the neighbouring countries, namely France, Germany and Belgium while 11 % of the total RWA of banks in Luxembourg were located in Brazil.

Nevertheless, the Luxembourg financial system is not spared from physical climate risks, even if these remain very low. Importantly, its impact increases over time and should not be underestimated. Certain natural risks such as extreme precipitation conditions and water stress should be closely monitored.

Figure 7a:
Risk-weighted assets of banks in Luxembourg

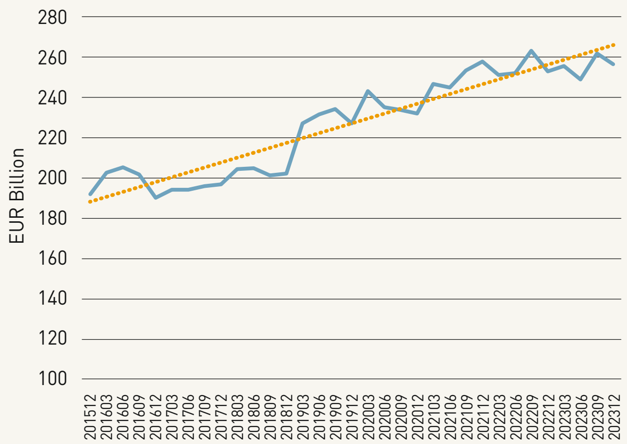
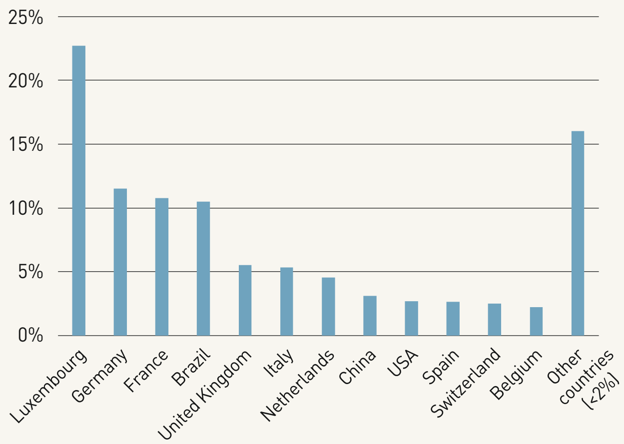


Figure 7b:
Geographical breakdown of RWA of banks in Luxembourg – December 2023



Source: COREP.

2.3 TRANSITION RISK IN LUXEMBOURG

Transition risks refer to the financial impacts on the financial system of a low-carbon and more environmentally sustainable economic model. Energy- and carbon-intensive sectors of activity are those most exposed to transition risks. Indeed, a transition to a low-carbon economy requires these sectors to adapt their business models to new regulations or to the use of new production technologies, thus increasing their innovation and production costs which may affect their profitability and increase their probability of default. As a result, the more the financial system is exposed to carbon-intensive sectors, the greater the transition risk for the financial system. Financial institutions would benefit from shifting their exposures and investments towards greener activities.

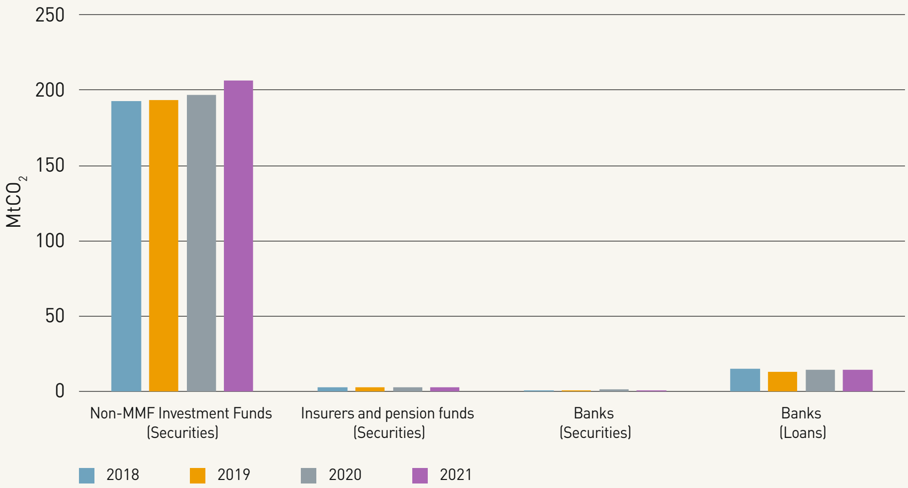
2.3.1 Carbon emissions indicators

The ECB has developed several indicators to assess the exposure of the financial system to transition risk.[26] These indicators are calculated for different types of financial institutions, namely the banking

[26] See for more details: https://www.ecb.europa.eu/pub/pdf/other/ecb.climate_change_indicators202301~47c4bbbc92.en.pdf.

sector,[27] investment funds and the insurance and pension funds sector. A first category of indicators assesses the extent of financing provided by the financial system to carbon-intensive activities. In other words, these indicators relate the GHG emissions of non-financial corporations (NFC) to the total loan and securities portfolios of financial institutions. Financed emissions and carbon intensity are included in this category.

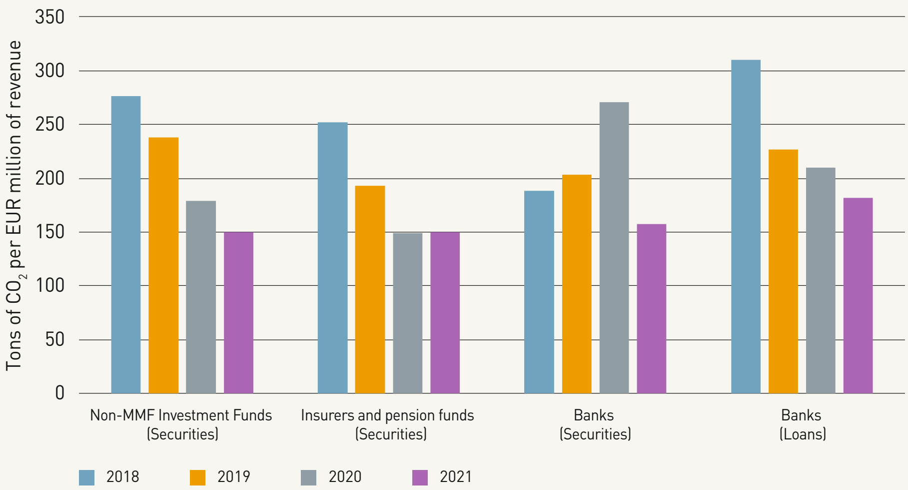
Figure 8:
Emissions financed in Luxembourg, broken down by financial subsector



Source: ECB.

For more details: https://www.ecb.europa.eu/stats/ecb_statistics/sustainability-indicators/html/index.en.html.

Figure 9:
Carbon intensity in Luxembourg, broken down by financial subsector



Source: ECB.

For more details: https://www.ecb.europa.eu/stats/ecb_statistics/sustainability-indicators/html/index.en.html.

Financed emissions are the total GHG emissions of a debtor/issuer weighted by the investment held by financial institutions in the total value of the NFC. They allow for an assessment of the magnitude of GHG emissions induced by the financing activities of financial institutions. Figure 8 shows the evolution of financed emissions by Luxembourg's financial institutions between 2018 and 2021. Almost all of the financing of direct emissions by financial institutions in Luxembourg is done through investment funds. Between 2018 and 2021, the Luxembourg investment funds sector financed an average of 197 million tonnes of CO_2. This figure is not surprising considering the size of the investment fund sector in Luxembourg.

Carbon intensity is calculated as the ratio of financed emissions to NFC revenues weighted by the investment held by financial institutions in the total value of the NFC. It expresses financed emissions in terms of the revenue generated by the NFC. Overall, carbon intensity decreased between 2018 and 2021 (Figure 9). The carbon intensity of investment funds fell from 277 tonnes of CO_2 per million euros of revenue to 150 in this period. For insurance and pension funds, the carbon intensity dropped from 252 in 2018 to 150 tonnes of CO_2 per million euros

[27] For the banking sector, a distinction is made between securities and bank loans.

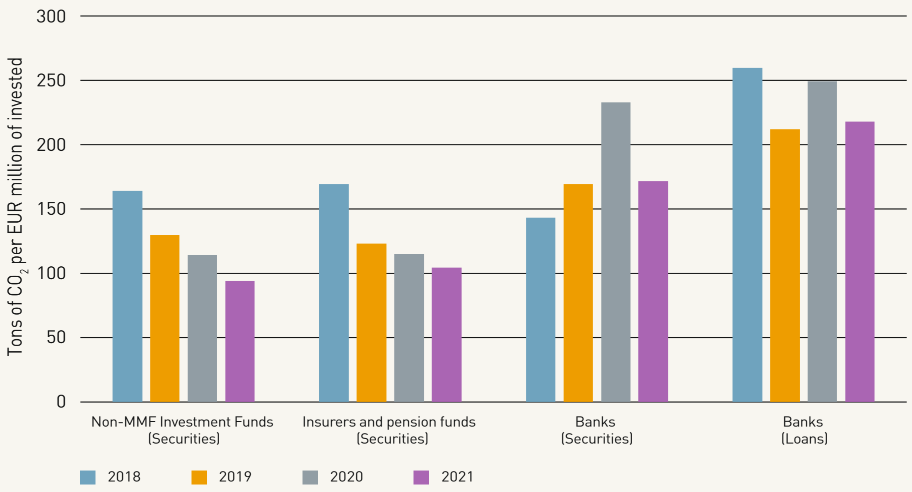
of revenue in 2021. Similarly, the carbon intensity of banks (considering both securities and loans) decreased between 2018 and 2021.

The second category of indicators provides information on the transition risk faced by the financial system by taking into account the exposure of loan and securities portfolios to carbon-intensive economic activities. This category of indicators includes the carbon footprint, which is defined as the financed emissions standardised by the total value of the investment portfolio.

In general, the carbon footprint of non-bank financial institutions declined between 2018 and 2021 (Figure 10). The carbon footprint of investment funds decreased by around 43 % (from 164 in 2018 to 94 tonnes of CO_2 per million euros invested in 2021) whereas that of the insurance and pension fund sector decreased from 169 in 2018 to 105 tonnes of CO_2 per million euros invested in 2021 (a decrease of approximately 38 %). Conversely, the carbon footprint of the banking sector loan (securities) portfolio decreased (increased) from 260 (143) tonnes of CO_2 per million euros invested in 2018 to 218 (171) in 2021. These dynamics show that changes in the financial system's exposure to transition risk varied across its subsectors depending on the financial instrument considered.

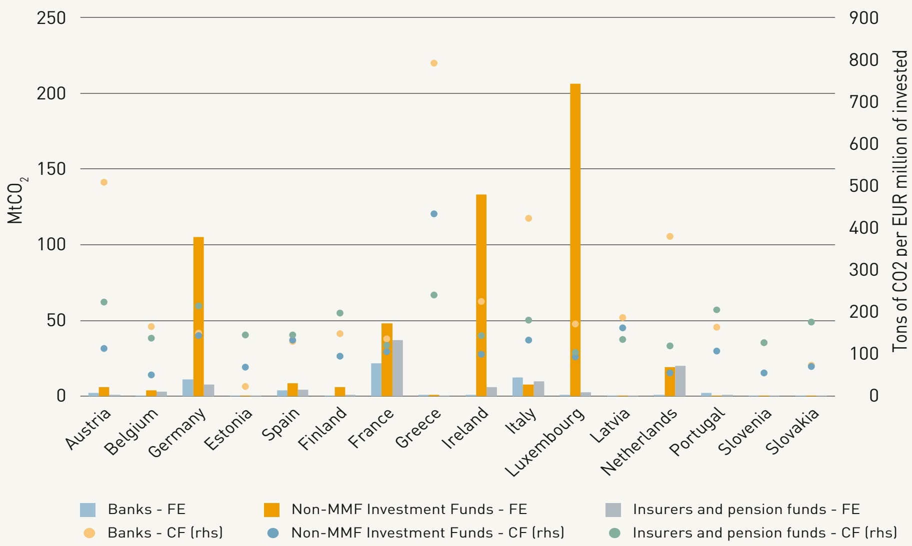
Comparing with its European peers, Luxembourg has the highest financed emissions in the euro area (Figure 11), which follows from the importance of its investment fund sector. However, with regard to the carbon footprint, we note that the exposure of Luxembourg's financial institutions to transition risk is among the lowest in the euro area.

Figure 10:
Carbon footprint in Luxembourg, broken down by financial subsector



Source: ECB.
For more details: https://www.ecb.europa.eu/stats/ecb_statistics/sustainability-indicators/html/index.en.html.

Figure 11:
Comparison at the euro area level

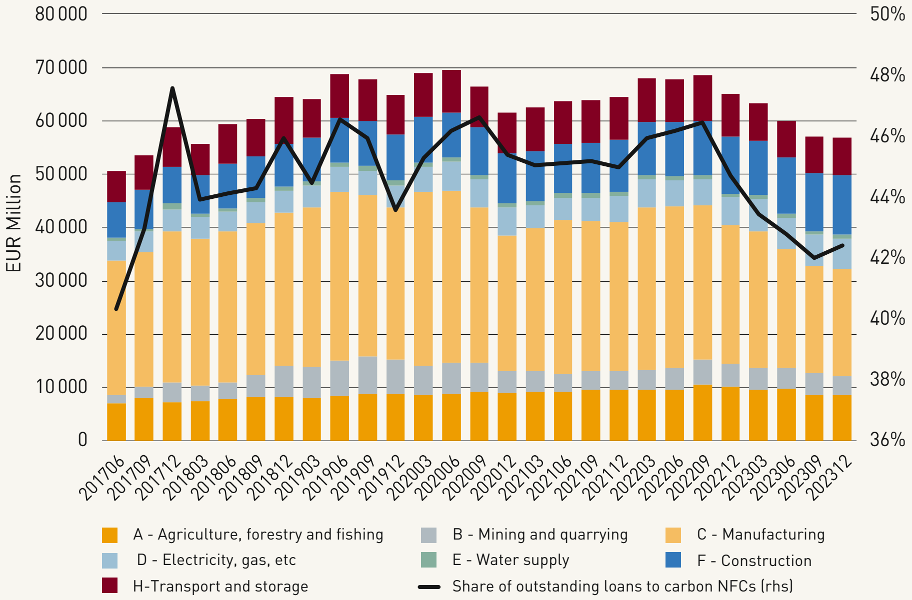


Source: ECB.
For more details: https://www.ecb.europa.eu/stats/ecb_statistics/sustainability-indicators/html/index.en.html.
Note: Data refers to securities portfolios at at 2021. "FE" and "CF" refer, respectively, to "Financed emissions" and "Carbon footprint".

2.3.2 Banks' and investment funds' exposures to carbon-intensive sectors

Figure 12:

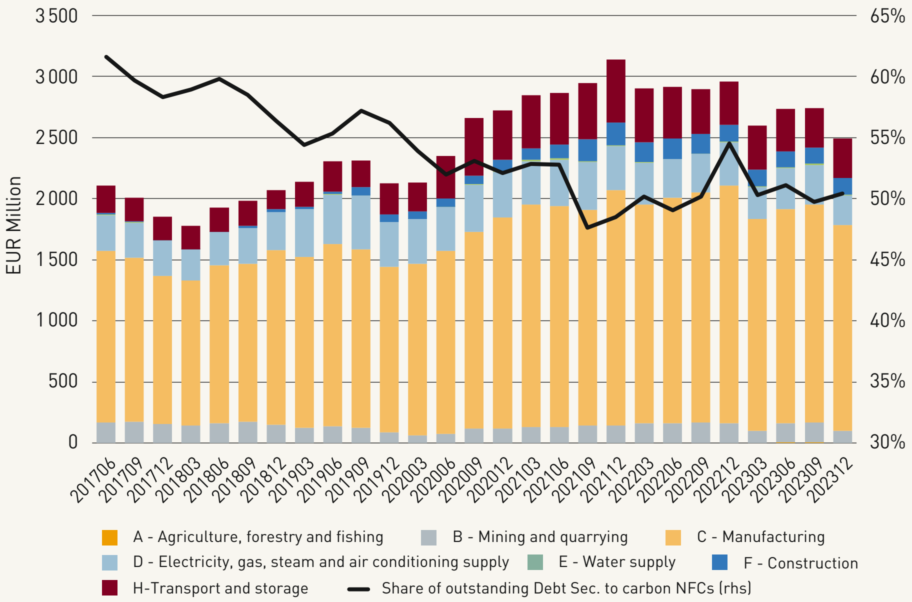
Banks' outstanding loans to carbon-intensive sectors



Source: BCL, FINREP.

Figure 13:

Banks' holdings of debt securities issued by carbon-intensive sectors



Source: BCL.

Figure 12 displays banks' outstanding loans to carbon-intensive sectors in absolute amounts and as a share of total outstanding loans to NFCs. It shows an increase in the amounts granted by the Luxembourg banking sector to carbon-intensive economic sectors, from 51 billion euros in the second quarter of 2017 to 57 billion euros in the fourth quarter of 2023. The figure also highlights that the share of banks' outstanding loans to carbon-intensive sectors grows from around 40% in June 2017 to 42.4% in the last quarter of 2023, albeit this share has been declining noticeably since the third quarter of 2022. Conversely, the share of carbon-intensive sectors in banks' holdings of corporate debt securities has been broadly declining since the second quarter of 2017 (Figure 13). Additionally, much like in the case of bank lending, manufacturing sectors are the largest recipient of banks' debt securities financing (Figures 12 and 13, and Box 1).

Therefore, Figures 12 and 13 underscore the weight of banks' exposure to carbon-intensive sectors and, consequently, the importance of carrying out climate stress tests for banks.

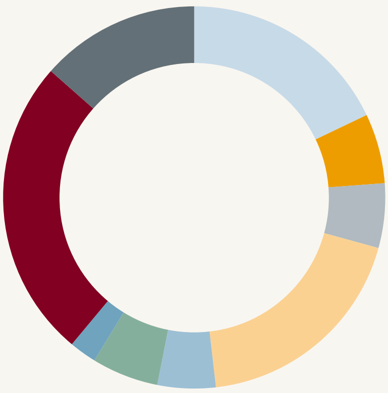
Box 1 :

A BREAKDOWN OF DOMESTIC MANUFACTURING EXPOSURES FOR SEVEN LARGE DOMESTIC BANKS

Not only is manufacturing the sector with the highest weight among the carbon-intensive ones in banks' non-financial corporations (NFCs) loan portfolio but it is also a sector with varying degrees of Green House Gas (GHG) emissions amid its constituting sub-sectors. For this reason, this box leverages on AnaCredit to break-down the domestic manufacturing exposures of seven large domestic banks.

As the figures show, for the sample considered, domestic manufacturing exposures are concentrated in three subsectors: i) pharmaceuticals and rubber; ii) food, beverages and tobacco; and iii) basic metals. Therefore, the analysis suggests that the weight of higher emitting industries, namely minerals and basic metals, comprises less than a quarter of the considered banks' domestic manufacturing exposures.

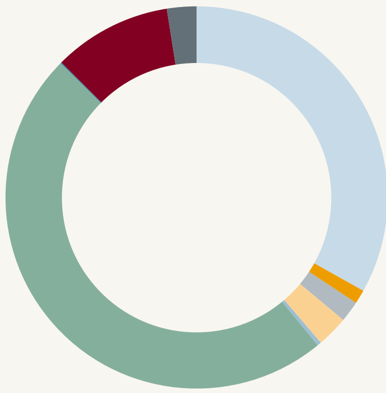
Figure B.1:
Net carrying amount – seven large banks



Source: AnaCredit.

Note: Exposures refer to December 2023.

Figure B.2:
GHG emissions of manufacturing sub-sectors

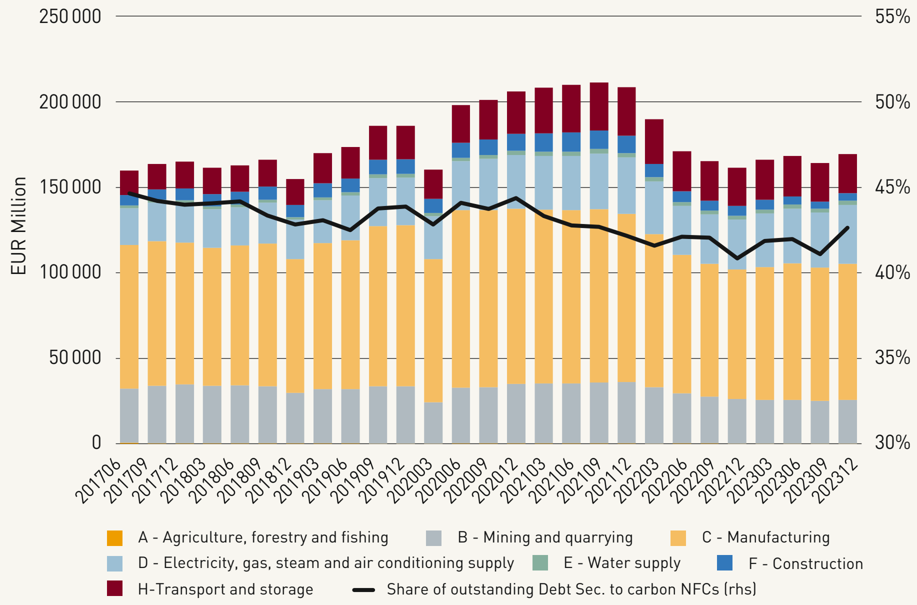


Source: Eurostat.

Note: GHG emissions refer to 2021.

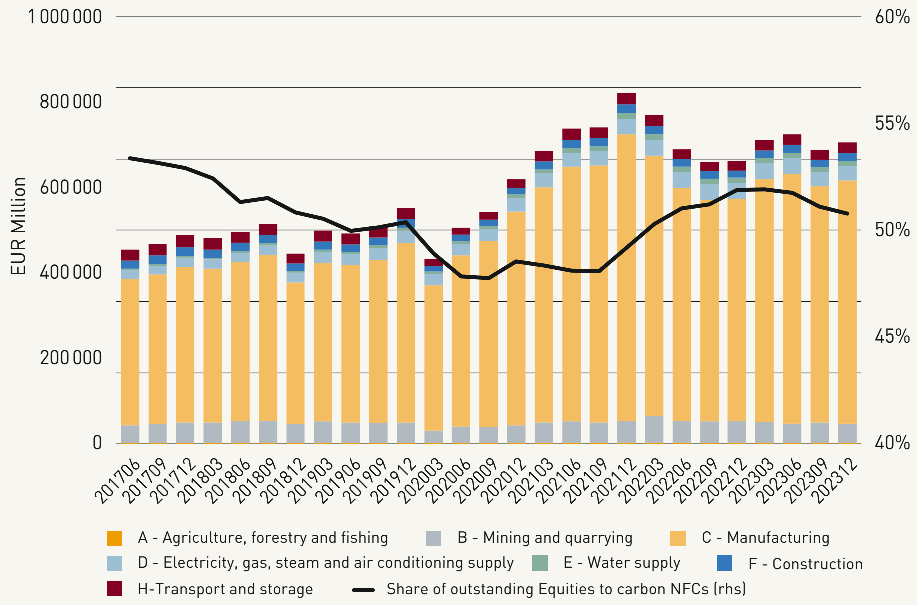
2.3.3 Breakdown of debt securities and equities

Figure 14:
Investment funds' holdings of debt securities issued by carbon-intensive sectors



Source: BCL.

Figure 15:
Investment funds' holdings of equities issued by carbon-intensive sectors



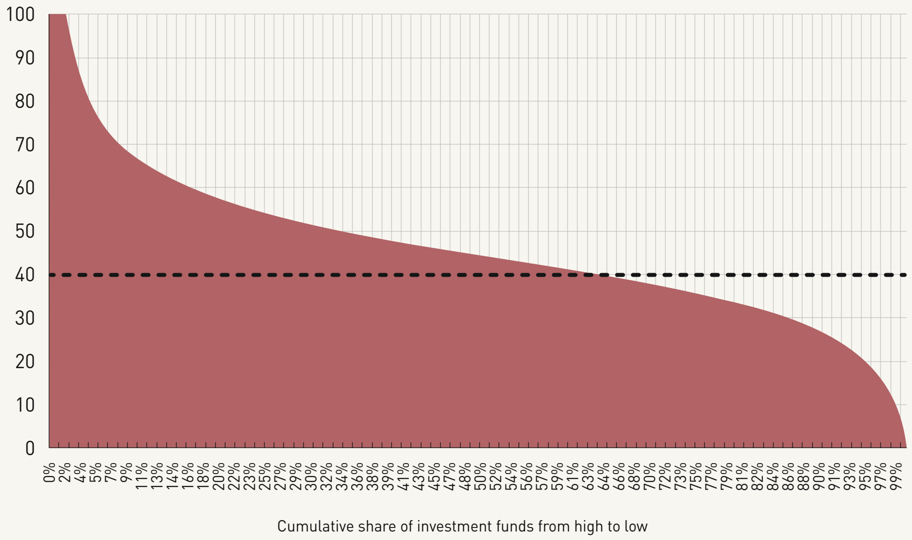
Source: BCL.

Figures 14 and 15 display the amounts of debt securities and equities issued by carbon-intensive sectors that are held by investment funds, as well as their shares relative to total corporate debt securities and equities held by funds. As for banks, around half of investment funds' corporate exposures are towards NFCs active in carbon-intensive sectors and a large part of these carbon-intensive exposures are towards manufacturing companies (Figures 14 and 15).

In order to understand better investment fund exposures to securities issued by carbon-intensive sectors, the distribution and concentration of these securities in investment funds' NFC portfolios was analysed based on the latest available data (Figures 16 and 17). The analysis of the distribution of the share of carbon-intensive securities in investment funds' NFC portfolios (Figure 16) indicates the weight of securities issued by carbon-intensive NFCs exceeds 40% for around 64% of investment funds, which is substantial. Moreover, a concentration analysis (Figure 17) suggests that these exposures might be quite concentrated, with the top 25% of investment funds holding just over 88% of overall carbon-intensive securities held in investment funds' NFC portfolios.

Figure 16:

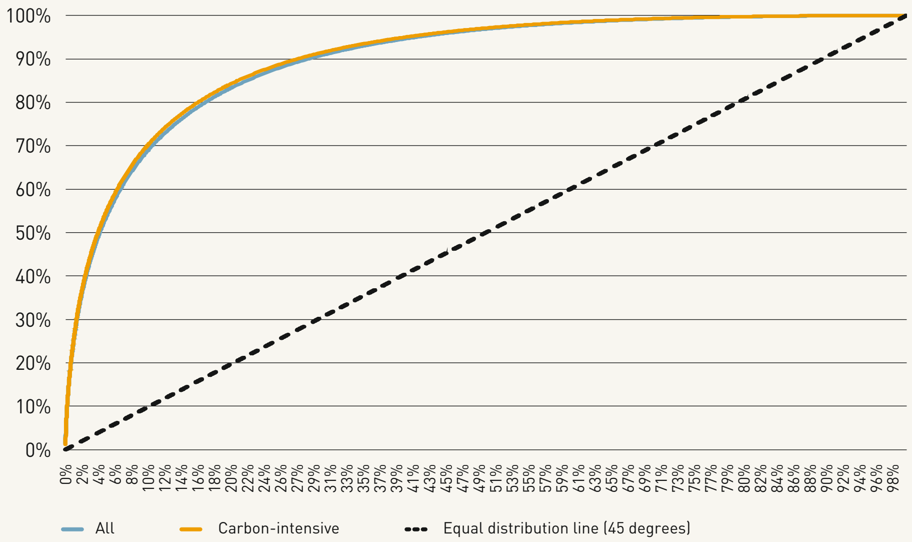
Distribution of securities issued by carbon-intensive NFCs in investment funds' NFC portfolios, December 2023



Source: BCL.

Figure 17:

Concentration of securities issued by carbon-intensive NFCs in investment funds' NFC portfolios, December 2023



Source: BCL.

3. CLIMATE STRESS TEST FOR BANKS AND INVESTMENT FUNDS IN LUXEMBOURG

3.1 OVERVIEW OF PREVIOUS CLIMATE STRESS TESTS

Climate stress testing has emerged as an important tool for assessing and managing climate-related risks in the financial sector by quantifying the exposures of financial entities such as banks, insurers and investment funds to both transition and physical risks.

Several national central banks, such as the De Nederlansche Bank (DNB), the Bank of England, and the Autorité de contrôle prudentiel et de resolution (ACPR) of the Banque de France, have performed stress testing exercises by focusing mainly on transition risk, with physical risk being taken into account only indirectly through the dynamics of macroeconomic variables (Vermeulen *et al.*, 2018; Bank of England, 2019; ACPR, 2020). Additionally, EU-wide climate stress testing exercises have been conducted by European Authorities, namely the European Central Bank (ECB), the European Securities and Markets Authority (ESMA, 2023), and the European Insurance and Occupational Pension Authority (EIOPA, 2022).

Alogoskoufis *et al.* (2021) describe the methodology of the 2021 ECB climate risk stress test under three scenarios ("orderly transition", "delayed transition", and "hot house world").[28] They report the results on the resilience of non-financial corporations (NFCs) and euro area banks to transition and physical risks based on an assessment of the implications of climate risks for the firms and banks by applying a dedicated set of models that capture the specific transmission channels for such risks. This stress test was a pure top-down exercise as it relied solely on internal ECB datasets and models. It is also worth noting that the stress test allowed for transition and physical risks, as well as their mutual interaction over a 30-year time horizon. Overall, the results support the view that there are benefits stemming from an early transition. In particular, the results for banks provide clear evidence of the benefits of an orderly transition as compared with other adverse scenarios: the short-term costs of a green transition are more than compensated by the long-term benefits, while physical risk tends to prevail in the medium-to-long run if climate policies are not implemented.

In 2022, the ECB carried out a climate risk stress test among the significant institutions as its annual stress test in the context of the supervisory review and evaluation process (SREP). As opposed to the 2021 exercise, the 2022 edition was a constrained bottom-up exercise as the participating banks provided their own data and stress projections governed by a common methodology and scenario narratives. The exercise was a learning experience for both banks and supervisors and highlighted a number of key results. First, around 60 % of banks do not yet have a well-integrated climate risk stress testing framework, and most of them envisage a medium to long-term time frame for incorporating physical and/or transition climate risk into their framework. The results also suggest that many banks are not yet accurately accounting for climate risk in their credit risk modelling. Moreover, more than half of banks' income from non-financial corporate customers comes from greenhouse gas-intensive industries. Finally, the results point to the benefits of an orderly green transition as it would lead to lower loan losses compared to disorderly or no transition scenarios.

28 Under the "orderly transition scenario", climate policy measures are well calibrated and implemented in a timely and effective manner, thus the costs stemming from transition and physical risks are comparatively limited. Under the "delayed transition scenario", policy action is delayed and introduced in 2030 in an abrupt manner, hence transition risks and their associated costs are significant. Additionally, as global warming starts being mitigated only from 2030, this "disorderly transition" scenario also implies the build-up of greater physical risk than what would be the case with an orderly transition. Under the "hot house world scenario", no regulation or policy aimed at limiting climate change is introduced, thus leading to extremely high physical risks. Thus, the costs associated with the transition are very limited, but those related to natural catastrophes are extremely high.

More recently, in September 2023, the ECB published the results of its second economy-wide climate stress test (Emambakhsh *et al.*, 2023). This stress test analysed the resilience of firms, households and banks to three transition scenarios: (i) an "accelerated transition", which brings forward green policies and investment, leading to a reduction in emissions by 2030 in line with the goals of the Paris Agreement; (ii) a "late-push transition", which continues on the current path, but does not speed up until 2026 yet it foresees the Paris-aligned emission reductions by 2030; and (iii) a "delayed transition", taking place on from 2026 onwards but falls short of reaching the Paris Agreement goals by 2030. The results suggest that firms and households would stand to gain from bringing forward the green transition. Regarding banks, these would be exposed to the highest credit risk in face of a sudden, late transition. Moreover, inaction and late transition result in even higher costs and risks in the long run.

However, it is not only in Europe that climate scenario analysis has been increasingly used as a risk-assessment tool. In 2022, the Financial Stability Board, jointly with the Network for Greening the Financial System (NGFS), published a report informed by a survey of FSB and NGFS member authorities on their climate scenario analyses (FSB, 2022). The report shows that the NGFS scenarios at the centre of the financial authorities' climate scenario analysis exercises. Moreover, the respondents note the value of these exercises in raising awareness and developing capabilities and capacity in climate scenario analysis. The results of these analyses tend to suggest that, while the impacts of climate risks can be material, they seem to be concentrated in some sectors but appear to remain contained from the domestic financial system's perspective.

In line with these earlier exercises performed by other central banks and supervisory authorities, we attempt in this section to quantify the impact of different NGFS scenarios on banks and investment funds domiciled in Luxembourg. To this end, we first provide an overview of the climate stress test scenarios we use before describing our modelling approach and presenting the results for banks and investment funds.

3.2 CLIMATE STRESS TEST SCENARIOS

The climate stress test exercise presented here makes use of the latest (i.e. Phase IV) climate reference scenarios developed by the NGFS. These scenarios provide a common framework to assess climate-related risks by exploring the transition and physical impacts of climate change on the way to reaching net zero CO_2 emissions by 2050 globally.[29] The NGFS has defined seven long-term reference scenarios and grouped them into four broad categories, which reflect different degrees of transition risk and physical risk, as well as an intensity that depends on the level of policy ambition, policy timing, regional policy coordination, and technology development. The four scenario categories are "Orderly Transition", "Disorderly Transition", "Too-Little Too-Late" and "Hot House World". More specifically, the "Orderly Transition" category comprises three scenarios, namely "Net Zero 2050", "Below 2°C" and "Low Demand". The "Disorderly Transition" category comprises only one scenario entitled "Delayed transition". The "Hot House World" category comprises two scenarios: "Nationally Determined Contributions (NDC)" and "Current Policies". The "Too-Little Too-Late" category comprises only one scenario entitled "Fragmented World".[30] For the purposes of our climate stress test exercise for Luxembourg banks and investment funds, we focus on three long-term NGFS reference scenarios.

29 Achieving global net-zero CO_2 emissions by 2050 will require significant investment flows towards clean energy, such that by 2050 renewable and biomass meet 70% of global primary energy needs.

30 NGFS (2023). NGFS Scenarios for Central Banks and Supervisors. Network for Greening the Financial System. Workstream on Scenario Design and Analysis. November 2023.

The first scenario, "Net Zero 2050", assumes a high level of policy ambition. Policy action is timely (that is, climate-related measures are implemented immediately) and coordinated. The timely manner of implementation allows the policy response of the economy to be smooth. The pace of technology innovation is assumed to be fast, supporting a high rate of adoption of carbon dioxide-removal technologies. In this scenario, transition risk is subdued and physical risk partially mitigated. Global warming is contained at 1.5°C.

The second scenario, "Delayed transition", assumes a slow policy reaction, with climate policies being implemented as of 2030. Until then, annual emissions do not decrease. Strong policy actions are needed to limit global warming below 2°C, at 1.7°C for instance, by setting higher carbon prices. As a result, technological innovation in the green sector develops later, but with stronger intensity. This scenario also assumes a moderate use of carbon-dioxide removal technologies and low regional policy coordination (i.e. countries implement climate policies with different intensities, resulting in a lack of coordination across jurisdictions with respect to carbon pricing and emission targets). This leads to higher transition risk compared to the Net Zero 2050 scenario. The delay in implementing policies leads to a greater increase in temperature and a subsequent rise in the frequency and magnitude of extreme weather-related events. Therefore, compared to the Net Zero 2050 scenario, physical risk is also higher.

The third scenario, "Current Policies", assumes that only currently implemented policies are maintained, without the implementation of any further policies. The lack of global policy ambition results in low variations in regional policies, limited technological development in the green sector and a low use of carbon sequestration technologies. In this scenario, the transition to a carbon-neutral economy is assumed to never take place. As a result, transition risk is negligible (carbon prices do not increase). However, physical risk is high, as it remains unmitigated and worsens due to the adverse physical impacts of extreme weather events on the economy. In this scenario, global warming reaches 2.9°C by end of the century, well above the limit set in COP21.[31]

It is worth noting that compared to the previous vintage (i.e. Phase III), all the latest NGFS scenarios are more disorderly as a result of delays in policy action and of the current geopolitical environment (e.g. consequences to the energy sector stemming from the Russian war in Ukraine).

The NGFS scenarios have been derived by using a suite of models. Integrated Assessment Models (IAM) have been used to derive transition pathways in alignment with different temperature targets. A structural model, suggested by the National Institute for Economic and Social Research model (NiGEM), has been used to produce scenario-conditional economic variables at a jurisdiction-granularity level. NiGEM's output has been used to feed a framework developed by the Banque de France and the ACPR (ACPR, 2020) to obtain NGFS scenario-conditional financial variables such as equity prices and corporate bond spreads.[32] In most cases, the availability of economic variables is at country-level.

Luxembourg is not featured in the NiGEM-based iteration of NGFS scenarios. To overcome this limitation, we use Belgium as a benchmark, given that it is also a small open economy and has important bilateral trade links with Luxembourg. In this context, it is also worth mentioning that the climate

31 COP21 refers to the 21st Conference of Parties held in Paris in 2015, which set to limit global warming to well below 2°C above pre-industrial levels by 2100.

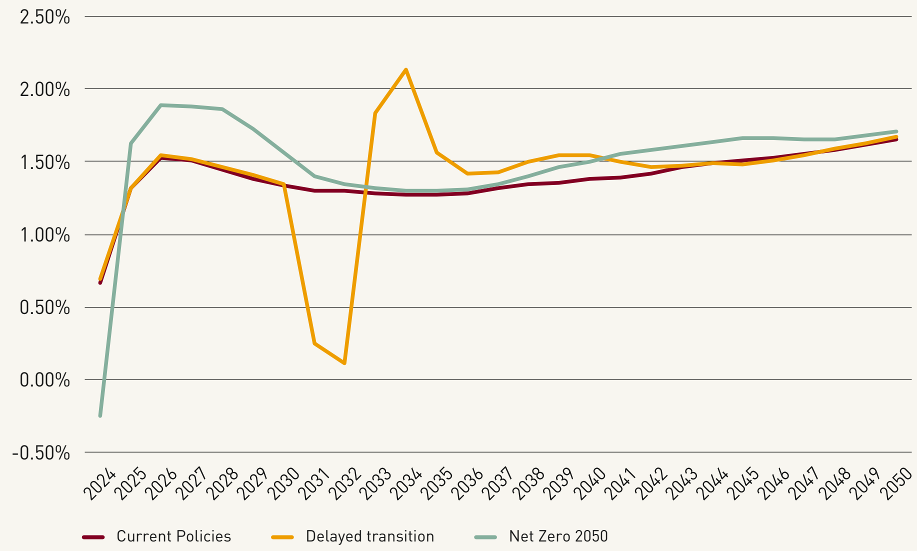
32 Allen *et al.* (2020). Climate-Related Scenarios for Financial Stability Assessment: An Application to France. Working Paper Series no. 774. Economic and Financial Publications, Banque de France.

policies in Luxembourg and the EU are aligned,[33] which supports our choice of another EU country as a benchmark to calibrate Luxembourg macroeconomic variables. In a first step, we conduct separate regressions of Luxembourg macroeconomic variables on the same Belgian macroeconomic variables. In a second step, we apply the regression coefficients resulting from step one to the Belgian NGFS scenarios-conditional variables to obtain NiGEM-based (and NGFS scenario-consistent) economic variables for Luxembourg. The variables are real GDP and equity prices. As an illustration, Luxembourg real GDP growth is shown in Figure 18 below.

Additionally, our modelling approach for banks has a crucial sectoral dimension. Therefore, in order to obtain paths under the three scenarios for sectoral value added for carbon-intensive and non-carbon intensive sectors, we apply scaling factors to aggregate GDP shocks resulting from the sectoral model developed by Frankovic (2022). The approach relies on input-output tables, and accounts for general equilibrium effects that would occur in the event of a rise in carbon prices, including substitution across sectors and energy sources.[34] The sector-level macro-financial variables are used to derive the impacts on probabilities of default (PDs).

Figure 18:

Luxembourg real GDP growth under the three climate scenarios



Sources: NGFS, BCL calculations.

3.3 CLIMATE STRESS TEST FOR LUXEMBOURG BANKS

3.3.1 Methodological approach and data

In this section, we evaluate the sensitivity of banks' corporate portfolios to the climate-related scenarios. Using a three-step methodology, we assess how corporate PDs and Tier 1 capital ratio of banks would evolve given a set of climate-related risks. The first step consists in estimating the relationship between the PDs and a set of macroeconomic and financial variables, in a way that the estimated parameters can be interpreted as "translation parameters". The second step consists in applying the estimated translation parameters to the NGFS scenarios so as to obtain the projections of the stressed

[33] In light of the 2050 climate-neutrality objective, Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 foresees that net greenhouse gas emissions are reduced economy-wide and domestically by at least 55% by 2030 compared to 1990 levels. The Luxembourg Loi du 15 décembre 2020 relative au climat et modifiant la loi modifiée du 31 mai 1999 portant institution d'un fonds pour la protection de l'environnement defines the intermediate objective of a 55% emission reduction compared to 2005 levels. Since emission levels in 1990 and 2005 were almost identical in Luxembourg, these intermediate objectives are also equivalent (please see the Stratégie nationale à long terme en matière d'action climat "Vers la neutralité climatique en 2050" for more details on Luxembourg emissions).

[34] See the reports of the ECB/ESRB Project Team on climate risk monitoring (2022; 2023).

probabilities of default (SPDs). Finally, the third step consists in simulating the series of Tier 1 capital ratio of banks by combining the projections of the SPDs with some assumed values of loss given default (LGD) and net profit projections under the three scenarios.

To carry out this procedure, we rely on multiple data sources. First, we use the ratio of exposures in default to original exposures as a proxy for the PDs. We use corporate exposures from the Common Reporting Framework (COREP), which are then combined with the sectoral breakdown of banks' loans and advances from Financial Reporting Standards (FINREP) in order to obtain a proxy for corporate PDs for carbon- and non-carbon-intensive sectors.[35] Furthermore, we use sectoral value added and equity price (year-over-year) growth as the main drivers of PDs. Data on sectoral value added is sourced from Eurostat and UNData,[36] while data on equity price growth come from Bloomberg.[37] For the sake of this study, we construct weighted-average bank-specific macroeconomic variables for each bank involved in the analysis. This means that these macroeconomic variables correspond to a weighted-average of each variable across a set of countries, with the weight corresponding to the share of each country's exposure in a given bank's total exposures. As an example, the bank-specific value-added growth for bank k and sector category s (with s either carbon-intensive or non-carbon-intensive) is calculated as follows:

$$VA_{k,s,t} = \sum_{i=1}^{10} \gamma_{i,k,t} * VA_{i,s,t} \tag{1}$$

where $VA_{k,s,t}$ refers to the bank-specific value added growth associated with bank k for sector category s at time t, $\gamma_{i,k,t}$ denotes the share of country i in bank k's total exposures at time t and $VA_{i,s,t}$ is the value added growth of sector category s of country i at time t. The different weights, γ, of each country i $(i = 1, \ldots, 10)$ are calculated based on ten countries to which Luxembourg banks report the largest corporate exposures: Brazil, China, France, Germany, Italy, Luxembourg, the Netherlands, the United Kingdom, the United States and Switzerland. Our final sample consists of annual data for all variables and spans the period from 2014 to 2023.[38] It includes 21 banks active in Luxembourg, thus covering the main domestically oriented banks, other systemically important institutions (O-SIIs) and significant banks under direct ECB supervision.

We apply a logit transform to the PD, based on the following equation:

$$y = \log\left(\frac{PD}{1 - PD}\right). \tag{2}$$

Then, we estimate the following regression model:

$$y_{k,s,t} = \alpha_k^s + \delta * y_{k,s,t-1} + \sum_{m=1}^{2} (\beta_m * X_{m,k,t-h}) + \varepsilon_{k,s,t}, \tag{3}$$

where $y_{k,s,t}$ refers to the logit PD proxy of bank k for sector category s at time t, α_k^s denotes the bank-sector category fixed effect and X_k denotes the two (i.e. $m = 2$) bank-specific macroeconomic variables for bank k.[39] These variables enter the equation as follows: contemporaneous VA (i.e. $h = 0$) while equity price growth with a one-order lag (i.e. $h = 1$).

35 The definition of carbon-intensive sectors is the same as in the first part of this analysis.

36 Since our analysis considers different countries corresponding to the domicile of the key exposures of Luxembourg banks, Eurostat data is used for European countries and UNData for the remaining ones.

37 For more details: https://ec.europa.eu/eurostat/web/products-datasets/, https://data.un.org/ and https://stats.oecd.org/.

38 The starting period is constrained by COREP data availability and the end point is constrained by VA data availability for 2023 for some countries.

39 Note that sectoral VA for the two sector categories is collapsed into a single variable, such that logit PD proxy for bank k and sector category s is regressed against the corresponding weighted average sectoral VA growth rate.

The estimated translation parameters (i.e. $\hat{\alpha}_k^s$, $\hat{\beta}_m$ and $\hat{\delta}$) from Equation (3) are then used to generate the series of SPDs. To do so, we apply the estimated translation parameters to the three NGFS scenarios. More specifically, we use the following equation:

$$\hat{y}_{k,s,t}^{scen} = \hat{\alpha}_k^s + \hat{\delta} * \hat{y}_{k,s,t-1}^{scen} + \sum_{m=1}^{2} (\hat{\beta}_m * NGFS_{k,m,t-h}^{scen}), \quad (4)$$

where $\hat{y}_{k,s,t}^{scen}$ refers to the estimated logit SPD for bank k, sector category under a given NGFS scenario $scen$. $NGFS_{k,m,t-h}^{scen}$ denotes the bank-specific climate scenario variables which we build by multiplying the NGFS-simulated value of each variable m at time $t-h$ by each country i's weight in total exposure of bank k at the end of 2023. As an example, the bank-specific series of equity price growth for bank k is generated by using the following equation:

$$NGFS\ EP_{k,t}^{scen} = \sum_{i=1}^{10} \gamma_{i,k}^{2023} * NGFS\ EP_{i,t}^{scen}, \quad (5)$$

where $NGFS\ EP_{k,t}^{scen}$ denotes the bank-specific path of equity price growth for bank k under NGFS scenario $scen$. $NGFS\ EP_{i,t}^{scen}$ stands for the NGFS-simulated series of equity price growth for country i under NGFS scenario $scen$, and $\gamma_{i,k}^{2023}$ refers to the country i's weight in total exposures of bank k at the end of 2023. By using equation (4), we obtain a time series of logit SPD for each bank k and sector category s under each NGFS scenario $scen$. These series of logit SPD are then reconverted into series of SPD in the normal form by using the following formula:

$$SPD_{k,s,t}^{scen} = \frac{exp^{y_{k,s,t}^{scen}}}{1 + exp^{y_{k,s,t}^{scen}}}, \quad (6)$$

where $SPD_{k,s}^{scen}$ refers to the series of SPD for bank k and sector category s under scenario $scen$ in the normal form, whereas $y_{k,s}^{scen}$ stands for the simulated series of logit SPD for bank k and sector category s under scenario $scen$. The overall SPD is then calculated based on a weighted average of the sectoral SPDs.

3.3.2 Results for corporate probabilities of default

The results of the estimation of Equation (3) are presented in Table 1. We consider two estimation approaches. First, we use the fixed effects (FE) model as a benchmark. However, in order to address the potential bias stemming from the lagged dependent variable (see Nickell, 1981), we also estimate our equation of interest via the bias-corrected fixed effect estimator (LSDVC) put forward by Bruno (2005 a, b) and Kiviet (1995).[40]

The estimated parameter for sectoral valued-added growth is expected to have a negative sign. Indeed, an improvement in sectoral economic conditions is associated with lower corporate PDs. Table 1 shows that the estimated parameters for sectoral value-added growth match the expectations: when the sectoral value-added increases, the logit PD decreases. Consequently, as the logit PDs and the PDs are positively related, an increase in sectoral value-added growth results in a decrease in corporate defaults. Finally, the estimated parameter for equity price growth is negative, meaning higher stock market returns, result in a lower probability of default.

[40] An additional analysis carried out based on GMM estimation yielded qualitatively similar results.

Table 1:
Estimation results

	FE	LSDVC
Logit PD.L1	0.4788***	0.7021***
VA	-0.0706**	-0.1120***
Equity price growth.L1	-0.0150**	-0.0219**
Observations	185	
R2	0.56	

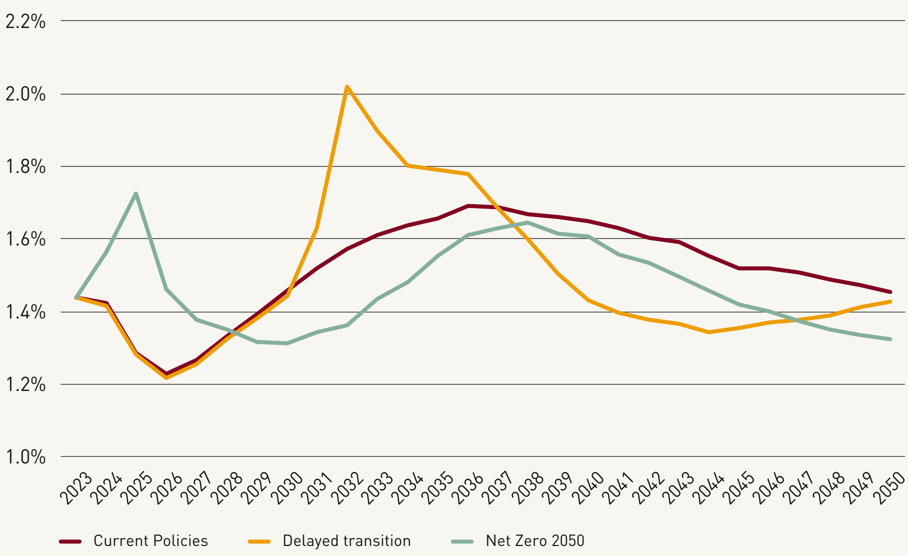
This table reports the estimation results of Equation (3) where the dependent variable is the logit transformation of the probability of default. R2 cannot be derived for the LSDVC model.
**p<0.1; **p<0.05; ***p<0.01*

Source: BCL calculations.

Based on the results of the LSDVC estimation and the three NGFS-based scenarios, we simulate the paths for the logit-transformed SPDs for the 2024-2050 period as per Equation (4).

As Figure 19 shows, the SPDs are consistent with the narratives that underpin the scenarios. First, under the Net Zero 2050 scenario, SPDs initially increase due to the immediate implementation and impact of climate-related policies that can result in short-term economic costs. Consequently, until 2028, the SPDs are temporarily higher under the Net Zero 2050 scenario compared to other two scenarios. However, from 2028 onwards, the economy benefits from the early introduction of climate-related policies and this eventually results in lower SPDs relative to the other policy trajectories towards the end of the scenario horizon. Therefore, even if the Net Zero 2050 scenario results in economic costs in the short-term, the underlying policies result in lower economic costs in the long-term, highlighting the need to implement adequate climate policies without delay. Second, there is a significant increase in the SPDs under the Delayed transition scenario that occurs just after 2030. This sharp increase is due to the late introduction of strong policies to limit warming below 2°C., which could potentially lead to disruptions in the banking sector and have an impact on banking profitability through the need for higher provisioning levels. Eventually, SPDs under the Delayed transition scenario decline but still remain above those under the Net Zero scenario, illustrating that later climate policy action, while better than no policy response at all, is still not optimal. Lastly, the costs resulting from inaction are clearly illustrated by the "Current Policies" scenario, which is clearly seen at the end of the scenario horizon where the SPDs are the highest across all scenarios.

Figure 19:
Aggregate corporate SPDs for banks



Sources: COREP, BCL calculations.

Note: The figure shows the median SPD obtained from 5000 bootstrap simulations for each scenario.

3.3.3 Impact on Tier 1 capital ratios

In order to translate the impact of changes in PDs to changes in banks' capital ratios, we complement the SPD projections with an assumption on banks' loss given default (LGD). In line with the first ECB economy-wide climate stress test conducted by Alogoskoufis *et al.* (2021), we assume that the LGD of banks' corporate portfolios increases cumulatively by 0.5 percentage points under the net zero scenario between 2023 and 2050. Under the Delayed transition and Current Policies scenarios, we assume respectively, 1 and 1.5 percentage points cumulative increases between 2023 and 2050.

The SPDs obtained in Section 3.3.2, as well as the LGDs, are used as inputs in the Basel II formula described by the BCBS (2005) in order to obtain capital requirements for corporate exposures. As in Guarda, Rouabah and Theal (2013), the resulting changes in capital requirements for corporate exposures are used to update banks' Tier 1 capital ratios according to Equation 7:

$$Tier\ 1\ capital\ ratio = \frac{K + \Pi}{RWA - 12.5 * E^c * (k_c - k_c^*)} \quad (7)$$

In Equation 7, K denotes banks' Tier 1 capital, Π denotes profits, RWA denotes risk weighted assets, and E^c denotes corporate exposures. Capital requirements are denoted by k and the superscript asterisk on k denotes capital requirements under the climate scenarios. Since we only take into account changes in PDs and LGDs on corporate exposures to calculate changes in capital requirements, we also restrict ourselves to only considering banks' profits earned on their corporate exposures in Equation 7.

As a first step, we project banks' profits using a fixed-effects panel data model that regresses net profit growth on nominal euro area GDP growth, as in Equation 8 below:

$$Profit\ growth_{it} = a_i + b * EA\ GDP\ growth_t + u_{it}. \quad (8)$$

We obtain a coefficient b that equals 1.121 when estimating Equation 8. Using these results, annual profits are projected for each bank for the 2024-2050 horizon. As a second step, to obtain Π in Equation 7, we multiply the projected profits at the bank level (based on Equation 8) by the ratio of corporate exposures to total exposures. This allows us to proxy bank-level profits earned on corporate exposures and subsequently to calculate banks' Tier 1 capital ratios using Equation 7.

Figure 20 displays the aggregate Tier 1 capital ratio for the banks in our sample under the three climate stress test scenarios described above (i.e. Current Policies, Delayed transition and Net Zero 2050).[41] Overall, the aggregate Tier 1 capital ratio would increase over the long-term, driven by robust net profit growth (Figure 20). In this context, it should be noted that euro area GDP grows under all three scenarios, which drives net profit growth.

41 It should be noted that the starting level aggregate Tier 1 capital ratio in the climate stress test only applies to the sample considered in this analysis.

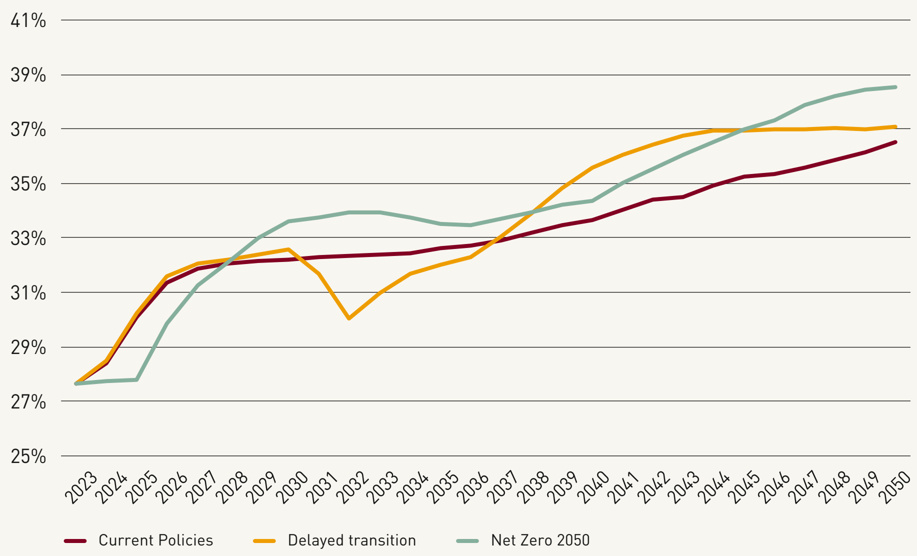
In the short-term, the aggregate Tier 1 capital ratio under the Net Zero 2050 would be lower, albeit still increasing, compared to the other two scenarios reflecting the transition costs incurred in the short-term. However, from 2028 onwards, the aggregate Tier 1 capital ratio would start exceeding that under the Current Policies scenario, reflecting increasing physical risk that is impacting banks' counterparties in the latter scenario. The figure also shows a sharp contraction of the aggregate Tier 1 capital ratio in the early 2030's under the Delayed transition scenario, which follows the increase in corporate PDs driven by heightened transition risk due to the late implementation of climate policies from 2030 onwards.

From 2040 onwards, banks' aggregate Tier 1 capital ratio under the Net Zero 2050 scenario is diverging increasingly from the level under the Current Policies scenario. The difference in Tier 1 capital ratios becomes larger over time, as physical risk continues to materialise under the Current Policies scenario. In 2050, the Luxembourg banking sector's aggregate Tier 1 capital ratio would be 2 percentage points higher under the Net Zero 2050 than under the Current Policies scenario.

Despite the temporary decline in capital ratios under the Delayed transition scenario after 2030, due to the late implementation of climate policies, banks' aggregate Tier 1 ratio would be higher than under the Current Policies scenario over the long-term. Hence, even a late transition would prove beneficial in terms of bank resilience over the long-term, as the aggregate Tier 1 capital ratio under the Delayed transition scenario would surpass the level under the Current Policies scenario from 2037 onwards. In 2050, the aggregate Tier 1 capital ratio would be 0.6 percentage points higher under the Delayed transition scenario than under the Current Policies scenario.

Figure 20:

Aggregate Tier 1 capital ratio for banks



Sources: COREP, FINREP, BCL calculations. Period: 2023-2050.

Note: The starting level aggregate Tier 1 capital ratio in this figure only refers to the banks in the sample used in this analysis.

3.4 INVESTMENT FUNDS

For investment funds domiciled in Luxembourg, we simulate investment funds net asset (year-over-year) growth based on the scenarios paths and the estimates from the following auxiliary regression:

$$IFAG_t = C + IFAG_{t-2} + USRGDPG_t + EARGDPG_t + v_t, \quad (9)$$

where $IFAG_t$ is the growth rate in the net assets of investment funds, $IFAG_{t-2}$ is its lagged value, $USRGDPG_t$ is the United States real GDP growth rate, $EARGDPG_t$ is the euro area real GDP growth rate. This equation is estimated with data sourced from the BCL investment funds statistics (for investment funds' net asset growth)[42] and from the OECD (real GDP growth series) for the period 2000Q4-2023Q4.

Table 2:

Estimation results

	ESTIMATE	STD. ERROR	T-VALUE
IFAG.L2	0.5569***	0.0997	5.586
USRGDPG	3.9109**	1.2402	3.153
EARGDPG	-3.5877***	0.8112	-4.423
C	0.2373	1.8815	0.126
Observations	91		
R2	0.42		

This table reports the estimation results of Equation (9) where the dependent variable is the investment funds net asset growth.
**p<0.1; **p<0.05; ***p<0.01*

Source: BCL calculations.

Applying the estimated coefficients to the scenario paths results in the simulated net assets of investment funds domiciled in Luxembourg displayed in Figure 21.

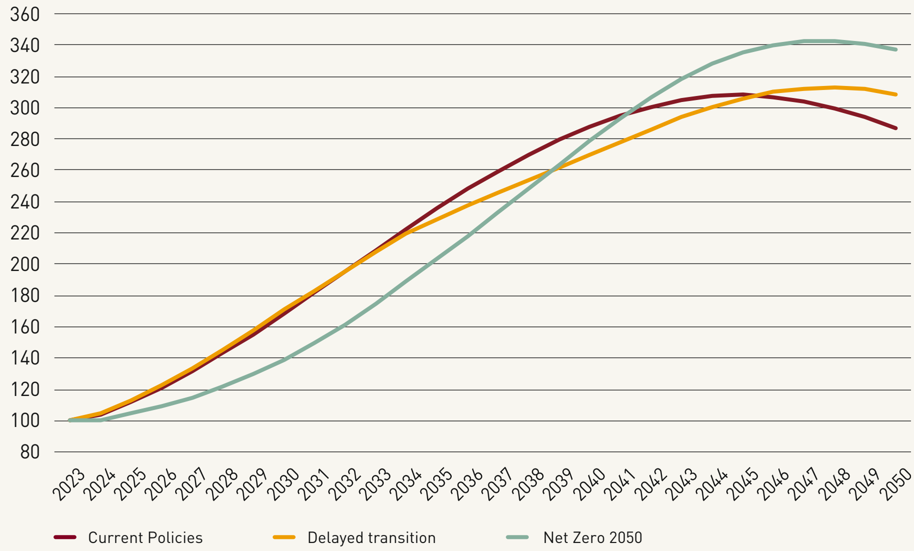
As Figure 21 shows, net assets of investment funds domiciled in Luxembourg under the Net Zero 2050 scenario would exceed those under the Current Policies scenario, reflecting the increasing benefits of timely and adequate policy actions over time. Starting around 2040, the benefits of lower physical risk under the Net Zero 2050 scenario start to outweigh the potential negative impact of heightened transition risk under the same scenario when compared to the Current Policies scenario. Concretely, in 2050, investment fund net assets would be 17.6 % higher under the Net Zero 2050 scenario than under the Current Policies scenario.

Figure 21 also illustrates the financial risks arising from only implementing the necessary climate policies from 2030 onwards. Under the Delayed transition scenario, transition risk is much more elevated than under the Net Zero 2050 scenario as policies are implemented in a disorderly manner. As a result, investment fund net assets would remain below those under the Current Policies scenario until 2045. Although investment fund net assets recover thereafter, the level remains below that under the Net Zero 2050 scenario. This suggests that the risks attached to a delayed transition are not temporary. A delayed transition may result in permanently lower investment fund net assets. At the same

[42] Please see Table 13.02 Global situation of undertakings for investment funds. https://www.bcl.lu/en/statistics/series_statistiques_luxembourg/13_investment_funds/index.html.

Figure 21:

Simulated investment fund net assets (Index 2023 = 100)



Source: BCL.
Period: 2023-2050.

time, the figure also exemplifies the benefits of a delayed transition compared to continuing current policies until 2050. In 2050, net assets of investment funds would be around 7.4 % higher under the Delayed transition than under the Current Policies scenario.

4. CONCLUSION

Since 2005 greenhouse gas emissions in Luxembourg have displayed a downward trend, demonstrating the efforts already made by the country to reduce emissions. However, climate risks remain important and are on the rise. The objectives set by the government through the PNEC are ambitious and in line with the environmental challenges. In order to achieve these objectives, the role of the financial sector in financing the ecological transition is essential. Moreover, in addition to financing the ecological transition, the financial sector will have to reduce its exposure to climate risk.

In this respect, the actors of the Luxembourg financial sector seem to have limited exposure to physical climate risk insofar as their exposures are mainly towards less vulnerable geographical areas or from countries with high climate resilience. Nevertheless, extreme precipitation and water stress deserve particular attention. Besides, our analysis shows that the financial sector is materially exposed to transition risk. Indeed, our sectoral study of banks' and investment funds' exposures suggests that the shift in strategies towards low-carbon sectors is still relatively limited, or in some cases inexistent, suggesting that transition risk remains important.

The combination of physical risk and the risks associated with implementing transition policies towards a low-carbon economy is assessed based on three climate scenarios developed by the NGFS. The results of the climate stress test conducted for the Luxembourg banking and investment fund sectors underscore the benefits of an orderly transition towards net zero greenhouse gas emissions in 2050 compared to Current Policies and Delayed transition scenarios.

In terms of resilience, the aggregate Tier 1 capital ratio of the banks in our sample would be 2 percentage points higher in 2050 under the Net Zero scenario than under the Current Policies scenario. Even under a delayed transition, which is sub-optimal compared to the Net Zero 2050 scenario and where the necessary climate policies would be implemented from 2030 onwards, the long-term benefits would clearly outweigh the short-term costs arising from the materialisation of transition risk. Indeed, the aggregate Tier 1 capital ratio of the Luxembourg banking sector would be 0.6 percentage points higher in 2050 under the Delayed transition than under the Current Policies scenario.

The investment fund sector would also benefit from an orderly transition towards net zero emissions in 2050. The results indicate that, compared to the Current Policies scenario, investment fund net assets would be 17.6% higher under the Net Zero 2050 scenario. Under the Delayed transition scenario, the investment fund sector would see, temporarily, lower net assets between 2030 and early 2040s due to transition risk materialisation compared to the Current Policies scenario. However, in 2050, investment fund net assets would be approximately 7.4% higher than under the Current Policies scenario.

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