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FINANCIAL SECTOR ASSESMENT PROGRAM

June 2024

TECHNICAL NOTE ON CLIMATE RISK ANALYSIS

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TECHNICAL NOTE

CLIMATE RISK ANALYSIS

Prepared By
Monetary and Capital Markets Department

This Technical Note was prepared by IMF staff in the context of the Financial Sector Assessment Program (FSAP) in the Netherlands. It contains technical analysis and detailed information underpinning the FSAP's findings and recommendations. Further information on the FSAP can be found at http://www.imf.org/external/np/fsap/fssa.aspx

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Glossary

CBS	Statistics Netherlands (*Centraal Bureau voor de Statistiek*)
DNB	De Nederlandsche Bank
ESRI	Environmental Systems Research Institute
ENW	The Expertise Network for Flood Protection (*Expertise Netwerk Waterveiligheid*)
GMM	Global Macro-financial Model
IPCC	Intergovernmental Panel on Climate Change
KNMI	Royal Netherlands Meteorological Institute (*Koninklijk Nederlands Meteorologisch Instituut)*
LIWO	National Water and Flood Information System (*Landelijk Informatiesysteem Water en Overstromingen*)
MIENW	Ministry of Infrastructure and Water Management *(Ministerie van Infrastructuur en waterstaan)*
NCR	The Netherlands Centre for River studies
NWB	The National Road Database (*National Wegenbestand*)
PBL	Netherlands Environmental Assessment Agency *(Planbureau voor de Leefomgeving*)
P&C	Property and Casualty
RCP	Representative Concentration Pathway

EXECUTIVE SUMMARY[1]

The Netherlands is exposed to both physical and transition risks from climate change. Due to unique geographic factors, about 60 percent of the land surface in the Netherlands is vulnerable to flooding from the sea and the large rivers, with nearly 26 percent of the land surface below sea level. Also, the Netherlands has high levels of nitrogen depositions from agriculture and transportation, exceeding the critical value set by EU Directives.

This FSAP analyzed potential risks to financial stability posed by physical risks from floods and transition risks from nitrogen. To assess physical climate risks, bank stress tests were conducted against flood events under a range of scenarios encompassing diverse regions, climate conditions, and flood protection reinforcement plans with different return periods. The flood maps for each scenario were carefully designed in collaboration with Dutch climate experts, and the damage rate from floods were estimated based on Deltares damage curve methodology. The scope of transition risk analysis is limited to an examination of the banks' exposure to nitrogen-emitting sectors due to data constraints.

Despite the sizeable land area in the Netherlands susceptible to flooding, the physical climate stress test has demonstrated that the banking sector exhibits resilience to flood events. While the current impact of floods on the banking sector is limited, climate change can amplify flood-related losses, potentially lowering bank capital ratios in the long run. However, the government's reinforcement plan could help mitigate some of the anticipated losses from climate change.

The insurance sector is exposed to weather-related disaster risks, and some are expected to become more frequent and/or severe with climate change, but net claims (after reinsurance) of a non-primary regional flood event are limited. While primary flood defenses are not insured by private insurers, non-primary defenses, in particular along rivers, form the largest exposure of the Property and Casualty (P&C) insurers. Still, the solvency impact of historic and hypothetic flood events is very limited, also because Dutch insurers retain very limited exposure for events with lower occurrence probabilities and are instead covered by reinsurance. However, modeling approaches used by insurers vary markedly.

As the government's efforts to reduce nitrogen depositions continue, the banking sector could face transition risks through the credit channel, particularly if loans are extended to financially vulnerable firms in high nitrogen-emitting sectors. Although the banks' exposure to high nitrogen-emitting sectors is relatively small compared to total assets, banks can proactively incorporate environmental disclosure information into their credit risk assessments in anticipation of the potential implementation of new policies.

[1] This Technical Note has been prepared by Junghwan Mok, Caterina Lepore, Javier Uruñuela López (IMF), and Timo Broszeit (external expert).

The Dutch government should strengthen data sharing and collaboration with floods and climate experts. Flood scenarios designed with detailed flood maps under future climate conditions would provide a more accurate assessment of both climate change impact and adaptation measures. Moreover, access to the bank loan level data will enhance the analysis, particularly in estimating damages to collateral at the local and firm levels.

Table 1. The Netherlands: Key Recommendations

	Recommendation	Addressee	Timing*	Priority**
1	Conduct physical risk analysis using forward-looking medium and long-term flood scenarios accounting for the impact of climate change.	DNB	ST	M
2	Intensify discussions with P&C insurers on flood risk modeling approaches and relate insights from these discussions to the planned development of dashboards for physical climate risks and—more generally—climate risk supervision.	DNB	ST	M
3	Develop an approach to assess the impact of policies to reduce nitrogen depositions on the financial sector once the transition path and its implications on the economy becomes clearer.	DNB	ST	H
4	Strengthen data sharing and collaboration with floods, climate and environment experts in the Netherlands (Ministry of Infrastructure and Water Management, Deltares, HKV, KNMI, RIVM).	DNB, Ministry of Infrastructure and Water Management	ST	H
5	Ensure that authorities have clear legal basis to access granular transaction/loan-level data, including residential and commercial real estate loans.	DNB	I	H
6	Develop and make publicly available flood scenarios under future climate conditions using the new climate scenarios (KNMI'23) aligned with the IPCC Sixth Assessment Report.	MIENW	MT	M

* Timing: C = Continuous; I = Immediate (within one year); ST = Short Term (within 1-3 years); MT = Medium Term (within 3-5 years).
** Priority: H = High; M = Medium; L = Low.

PHYSICAL RISK ANALYSIS – BANKING SECTOR

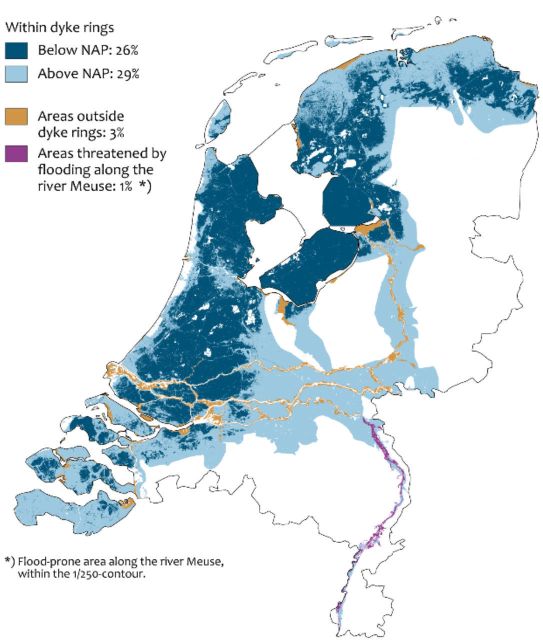
A. Overview: Physical Risks in the Netherlands

1. Due to the unique geographic factors, about 60 percent of the land surface in the Netherlands is vulnerable to flooding from the sea, the large rivers, and the lakes (Figure 1). Nearly 26 percent of the surface in the Netherlands is below sea level, land which has been reclaimed from the sea and lakes over the past 800 years. Heavy precipitation is another cause of flooding in the whole of Netherlands. The ongoing climate changes pose a potential threat by increasing sea levels and precipitation, thereby heightening the vulnerability of the Netherlands to flooding.

Figure 1. The Netherlands: Physical Climate Risks

Nearly 26 percent of the surface in the Netherlands is below the sea level.

Flood-prone Area and Area below Sea Level



Note: NAP (The Amsterdam Ordnance Datum) is a benchmark for measuring sea levels in most of Europe.

Source: PBL.

The Water Act sets the flood probability standards for primary defenses.

Maximum Permissible Flood Probabilities

Source: The Netherlands Centre for River studies (NCR).

2. In safeguarding the nation from flooding, the Dutch government has developed a comprehensive flood protection system. This system comprises polders – a set of dikes, embankments, dunes, and structures that surround reclaimed land or other floodplains along the sea, rivers, or lakes. In addition, strategically placed dams and barriers in rivers and estuaries control water levels and withstand elevated wave heights during extreme conditions. These structures have earned the Netherlands global recognition for its robust water management system.

3. The flood defenses have been continuously reinforced since the major flood in 1953, including a supporting legal and administrative framework. The flood, which claimed the lives of over 1,800 people in the southwest of the Netherlands, galvanized continuous reinforcements. The legal framework governing flood protection is the Environment and Planning Act (*De Omgevingswet*), which sets safety standards for defenses and outlines the methodology for monitoring barrier strength. It also requires publication of a policy document every six years for reviewing and planning the latest water policy. Additionally, a Delta Programme Commissioner is appointed to oversee the annual Delta Programme, detailing measures to implement water policies. This program involves the collaboration between the central government, provincial and municipal authorities, water authorities, and stakeholders from private sectors and civil organizations.

4. Since 2017 the Dutch flood risk legislation builds upon a risk-based approach, which takes account of both the probability of a flood and the consequences of a flood. The probability of a flood is determined by water level, hydraulic load, strength, and height of the dike. (Figure 1). The consequences consist of (direct and indirect) economic damage and (direct and indirect) mortality, which are determined by the flood progress and pattern, and the evacuation rate (Lanz, 2020). The goal of current policies is, by 2050 at the latest, to limit the probability of mortality due to flooding behind the dikes to no more than 1 in 100,000 per year (or 0.001 percent). To achieve this goal, upgrades to approximately 1,500 kilometers of dikes and over 400 engineering structures are planned.

5. As a consequence of this policy, there is limited insurance coverage for the damages from floods. Private insurers only cover floods caused by local precipitation, canals, streams, or small rivers. Damages arising from the failure of primary defenses, such as large-scale infrastructure and national-level projects designed to prevent flooding, including dikes and the Delta Works, are not covered by insurance. Currently, there is a law in place, so called "Reimbursement for Damages due to Disasters Act" (*Wet tegemoetkoming schade bij rampen; Wts*) that gives the government the opportunity to provide damage compensation in the wake of disasters.

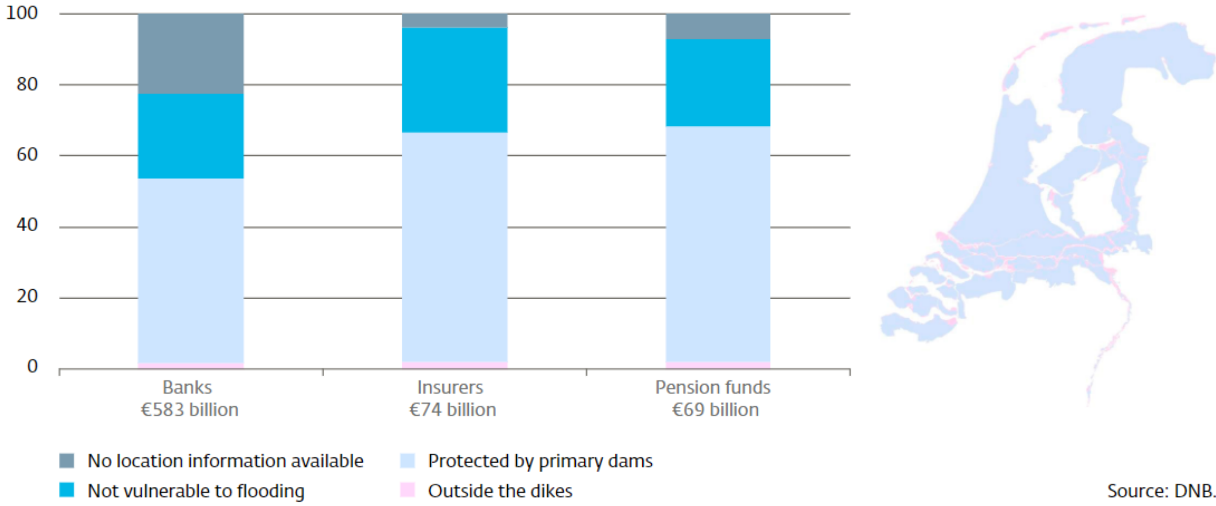
6. Dutch financial institutions are exposed to physical climate risks from floods, due to their substantial holdings of domestic real estate located in areas vulnerable to flooding. As of the end of 2020, of the total 700 billion euros exposure to real estate, 52 percent, 66 percent, and 65 percent of bank, insurer, and pension fund assets, respectively, are located in areas vulnerable to flooding (Figure 2). While most of these areas are protected by flood defenses, in the event of failure of dikes, a large portion of the real estate could be damaged by flooding. Moreover, these impacts could increase over time, as sea-level rise and more frequent extreme rainfall intensify.

7. Against this background, this analysis aims to assess the credit risks of banks under a set of different flood scenarios, following the IMF physical risk analysis framework (Adrian et al., 2022). The process involves several steps: first, collaboration with Dutch climate experts to design multiple flood scenarios; next, estimating damages from floods using the Deltares damage estimation methodology (described in Section C). Due to the lack of up-to-date bank loan-level data, the analysis does not link damages to individual bank balance sheets. Instead, it computes the nation-wide damage rates, serving as input to the IMF Global Macro-financial Model (GMM) for generating corresponding macro scenarios. Finally, similar to the bank solvency stress tests, the analysis estimates bank credit losses from floods over the next three-year horizon.

Figure 2. The Netherlands: Dutch Financial Sector's Exposure to Physical Risks

Most Dutch financial institutions' domestic real estate exposures are in areas prone to flooding, giving rise to physical risks.

Flood Risks and Real Estates in the Netherlands



Note: The chart reports the percentage of domestic real estate exposures of banks, insurers, and pension funds by location. Locations that can be affected by flooding include areas which are not protected by flood defense systems (outside the dikes) and areas protected by primary defense.

Source: DNB Financial Stability Report (2021).

B. Flood Scenarios

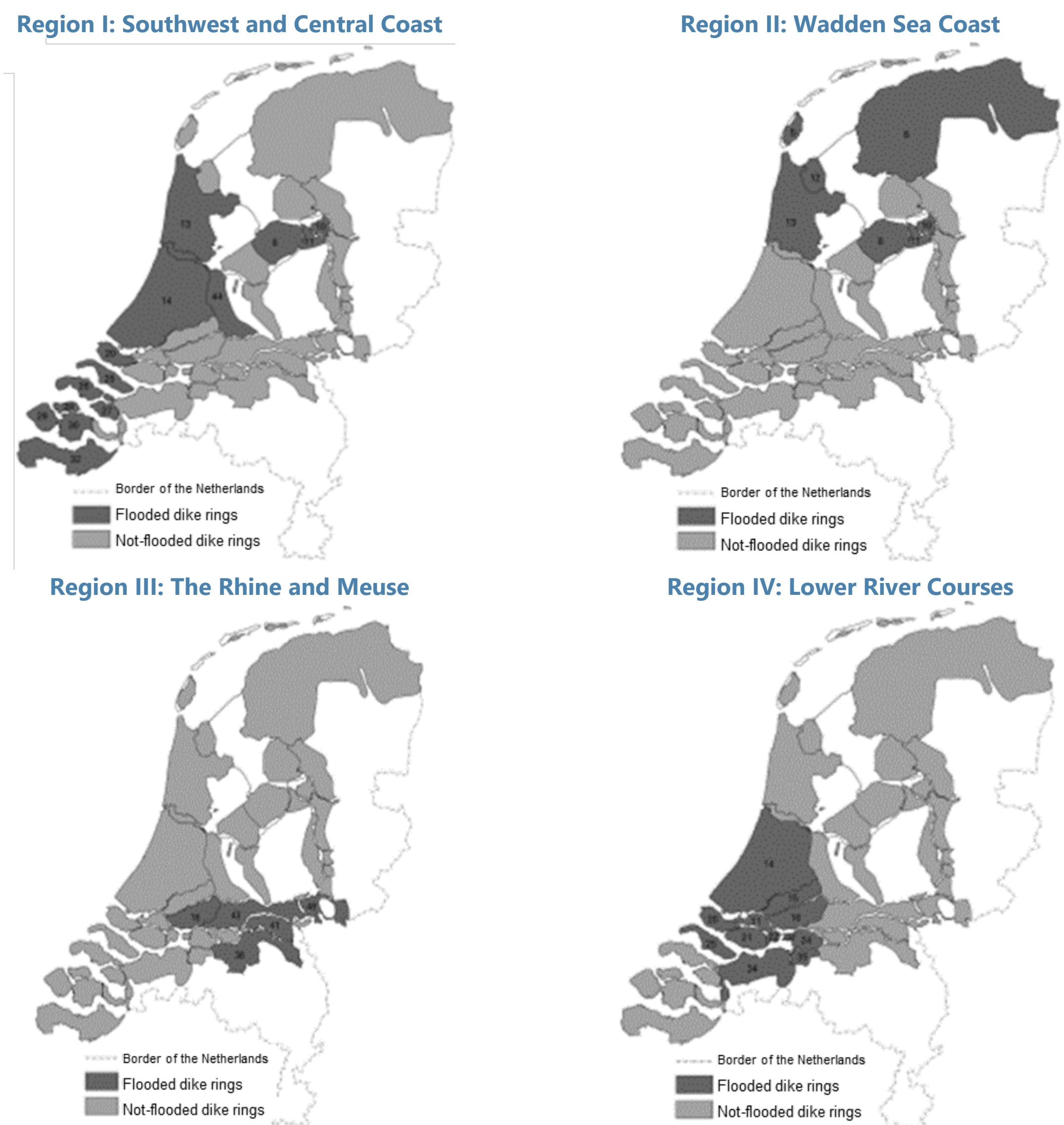
8. A range of flood scenarios was chosen, encompassing various regions, flood types, climate conditions, and flood protection for different return periods. The corresponding flood maps for each scenario were carefully designed in collaboration with Dutch climate experts from HKV, a private consulting firm in partnership with the Ministry of Infrastructure and Water Management (MIENW). They provided information on breach locations, the number of breaches occurring at the same time, for different return periods.

Regions

9. The flood scenarios focus on four independent geographical areas in the Netherlands. These areas have been selected from Ten Brinke et al. (2010) on contingency planning for large-scale floods, so-called EDO scenarios (*Ergst Denkbare Overstromingen*; worst credible floods). They represent areas that are flood-prone, based on different threats (sea, rivers, lakes), and where floods would cause the largest damage due to higher population and economic activity density/concentration (based on Table 1 in the paper). Among their six regions, the focus is on the following four regions (Figure 3):

- Region I: Southwest and Central Coast
- Region II: Wadden Sea Coast
- Region III: Rhine and Meuse Rivers
- Region IV: Lower River Courses

Figure 3. The Netherlands: Regions for Flood Scenarios



Note: The maps illustrate the areas or dike rings susceptible to flooding in each region. It does not necessarily imply that floods occur simultaneously across the entire (dark shaded) area.

Source: Ten Brinke et al. (2010)

10. Two coastal regions, the Southwest and Central coast and the Wadden Sea coast, were selected. A storm surge in the Straits of Dover can affect both the southwest region and the central coast, while a storm surge more to the north can affect the Wadden sea coast. These regions are considered as independent because the likelihood of a flood occurring across the entire coastal zone in the Netherlands is low. For example, extreme conditions from a storm surge in the North Sea cannot simultaneously affect the entire coast.

11. Two river regions, the Rhine and Meuse and lower river courses, were selected. The Rhine and Meuse represents an area where floods can occur from the largest Rhine branch (the Waal) and Meuse in the central part of the Netherlands. Floods in the lower river courses can result from a combination of peak discharges on the Rhine and Meuse and a storm surge in the North Sea.

12. In particular, the Rhine and Meuse area can extend to the neighboring countries: Germany and Belgium. This was evident during the 2021 Limburg flood case when flooding in the Rhine and Meuse area coincided with floods in Germany and Belgium. Hence, flood scenarios for this area in the Netherlands will be enhanced by incorporating flood scenarios for Germany and Belgium, focusing on locations near the Rhine and Meuse river basins.

Flood Types

13. For each of these four geographical regions, two flood types are considered: Type A and B. According to the European Flood Directive Floods are classified into five categories based on the protection, region, and sources of threat (Table 2). This analysis focuses on flood types A and B because they cannot be privately insured and hence are potentially the most damaging for the banking sector. These are the same type of floods that DNB has focused on for their own physical risk stress testing (Caloia and Jansen, 2021). Their results indicate that flood type B are more damaging relative to flood type A. However, they do not incorporate granular (geolocational specific) flood scenarios or account for future climate conditions; instead, they rely on a grid of increasingly severe inundation depths for these two types of floods.

Table 2. The Netherlands: Flood Types Classification

Type	Description
A	Flooding in unembanked areas
B	Breaches in primary flood defenses
C	Breaches in regional flood defenses
D	Flooding from bank overflow by regional water bodies
E	Water on streets due to extreme rainfall

14. Additionally, EDO scenarios are included as a separate flood type, representing extreme scenarios, although categorically they align with type B floods since they result from breaches in flood defenses. These EDO scenarios are designed for contingency planning, focusing on potential future events rather than what has already happened. According to Ten Brinke et al.

(2010), there were meetings with Dutch experts on meteorology, storm surges, river floods, and flood defenses of provinces, water boards, the state (*Rijkswaterstaat*) and research institutes to define the worst credible flood scenarios. The possible hydrodynamics (water level, wave height and duration) and the possible number, locations, and size of the breaches in the flood defenses were decided based on expert judgement. The scenarios are independent of the likelihood of these floods' occurrence, making it challenging to express them in terms of return periods, possibly extending to 1-in-1,000,000 years or more.

Climate Conditions and Flood Protection

15. For each region and flood type, current climate and future climate conditions are considered. Future climate conditions are considered under the Dutch scenario, so-called W+ (from KNMI'14 scenario), which broadly aligns with the RCP 8.5 (IPCC 5th Annual Report).[2] Although flood depth maps under *current* climate conditions are available, there are currently no estimates for flood depth maps under *future* climate conditions. In the collaboration with flood risk experts from HKV and MIENW, the impact of future climate conditions on floods scenarios and associated damages are considered under specific assumptions described below.

16. For flood type A, the water level under higher return periods is considered as that under future climate conditions. Kolen et al. (2022) find that the return periods of water levels in most water systems decrease by approximately a factor of 3 in 2050 W+ and by about a factor of 10 in 2100 W+. In other words, the exceedance probability of a water level increases by a factor of 3 and 10 respectively. Leveraging these findings, the flood maps for 2050W+ and 2100W+ are generated by applying the current flood depth maps with different return periods: 1-in-10, 1-in-100 and 1-in-1,000 years (as higher return periods than 1-in-10,000 years are not available for current climate).

17. For flood type B, the analysis needs to account for both the impact of future conditions on hydraulic loads as well as the future reinforcement of flood defense, as these floods arise from breaches in flood defenses. *By legal mandate, primary flood defenses will be reinforced to meet the floods safety standards at the latest in 2050 to account for climate change and socio-economic developments.*Hence, scenarios for flood type B incorporate both future climate conditions with and without these safety standards reinforcements. The strength of flood defenses are expressed in terms of return periods, representing the acceptable failure probability, which varies by location and depends on the impact of flooding and the costs of reinforcement. Table 3 presents the scenarios for flood type B.

[2] While a new set of climate scenarios for the Netherlands was published in October 2023 (KNMI'23), the estimates of water levels or hydraulic loads based on these scenarios are not available yet. KNMI'23 is aligned with the sixth assessment Report (AR6), and the scenarios are based on the amount of greenhouse gas emissions (and therefore global warming) and the degree of precipitation change in the Netherlands. (https://www.knmi.nl/kennis-en-datacentrum/achtergrond/knmi-23-klimaatscenario-s)

Table 3. The Netherlands: Scenarios for Flood Type B

Scenario Name	Failure Probability (Reinforcement)	Hydraulic Loads (Climate Conditions)	Description
B1	Current Situation	Current Situation	Readily available flood water depth map
B2	2050 Safety Standard	2050 (W+)	Combined effects of reinforcement and climate changes
B3	Current Situation	2050 (W+)	Impact of climate changes on current failure probability

Return Periods

18. For flood type B, the analysis considers return periods of 100, 1,000 and 10,000 years. For each region and return period, the maximum number of possible or realistic simultaneous breaches are specified based on the study by Kolen and Nicolai (2023). It is assumed that these numbers are consistent across the three cases considered above. In case of a 1-in-100 years return period in the Southwest and central coast and Wadden sea coast, no breaches occur, resulting in no damages.

Table 4. The Netherlands: Numbers of Breaches by Region and Return Period

Region	Return Period		
	100	1,000	10,000
I: Southwest and Central Coast	0	4	7
II: Wadden Sea Coast	0	4	7
III: Rhine and Meuse Rivers	1	3	4
IV: Lover River Courses	1	3	3

Source: Kolen and Nicolai (2023).

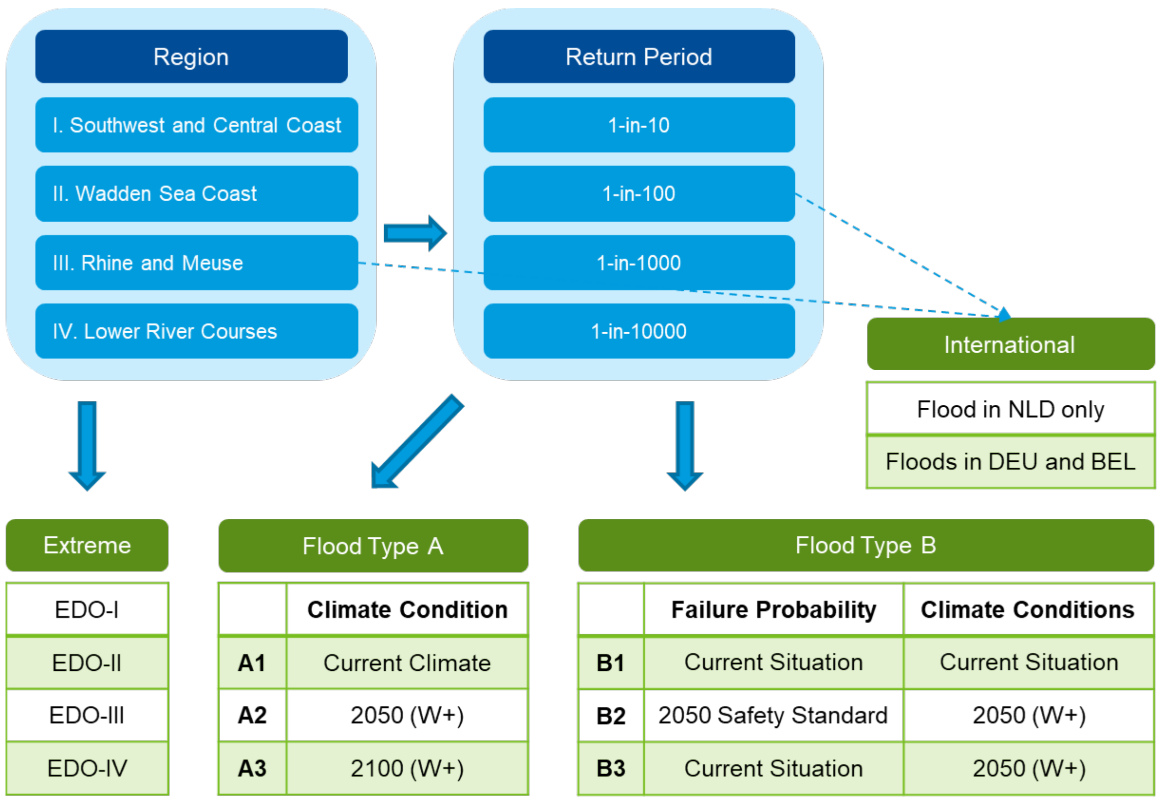
19. For every scenario outlined in Table 3, the selection of breach locations and return periods varies. In B2, lower failure probabilities under the 2050 safety standards lead to different breach locations compared to those in B1. However, the return periods are higher than B1, as it is adjusted to the 2050 W+ climate condition. On the other hand, since B3 has the same failure probability as B1, the breach locations are also the same, but with higher return periods.

20. In the combined scenario involving floods in Germany and Belgium, only floods with a return period of 1-in-100 years are taken into account due to data limitations in those countries. Unlike the Netherlands, acquiring detailed flood information for Germany and Belgium is constrained. Instead, water depth maps are obtained from the Jupiter database. The detailed methodology for selecting flooded area and calculating damages is elaborated in the next section.

21. Based on the outlined scheme, a total of 77 flood scenarios have been designed. Figure 4 provides a summary of the scenario design scheme introduced in this section. Water depth maps for certain return periods are unavailable due to the earlier described assumptions. A more detailed list of scenarios is presented in Tables A-1-A-4 in the Annex.

22. Water depth maps are retrieved from the LIWO (National Water and Flood Information System) database[3] for each breach location. Using the information on breach locations and return periods provided by climate experts, corresponding flood water depth maps are generated. If there are multiple breaches in a scenario, the water depth maps are manually combined using Geographic Information System (GIS Software).[4] In cases of overlapping inundated areas on the maps, the maximum level of water depth is selected.

Figure 4. The Netherlands: Flood Scenario Design Scheme



Source: IMF Staff Illustration.

C. Flood Damages Estimation

23. The Deltares methodology of the Netherlands, also known as the Standard Method 2017, is employed to estimate flood damage and casualty. This methodology was used to establish the water safety standards that were legalized as of 1 January 2017 (Slager and Wagenaar, 2017), and it has been continuously updated and improved based on new data. In this FSAP analysis,

[3] LIWO database can be found at https://basisinformatie-overstromingen.nl/liwo/#/maps.

[4] Although the LIWO database offers water depth maps for scenarios involving multiple breaches, it does not allow the download of raster files, hindering the calculation of damages.

the latest version of the software, Schade Slachtoffer Module (SSM; Damage and Casualty Module), which operates the Standard Method, is employed.

24. The SSM software contains granular data on real estate or objects located at each geographical grid.[5] The information includes the number of objects or area, location, type of buildings, maximum damage per the number of objects/m^2, and more. The main category of real estate includes business, residence, infrastructure, and other (Table 5).[6,7] This information serves as an input to calculate flood damage, combined with the flood water depth map from each scenario.

25. The focus is on computing the total direct physical damages for each flood scenario. As our interest lies in the impact of capital shocks to the macroeconomy, only direct damages are considered – physical capital loss resulting from direct physical contact with the flood – while excluding indirect damages, such as those associated with business interruption.[8]

26. The total flood direct physical damage under each scenario is calculated by multiplying the maximum flood damage per object or m^2 for each category, with the damage factors and the number of objects or m^2 affected by floods. The maximum flood damage represents the cost to reconstruct the building/infrastructure. The damage factor gives the percentage of the maximum damage which occurs given a certain water depth. The total direct physical damage under a scenario s, is calculated by:

$$Damage_s = \sum_{i=1}^{N} \alpha_{is}\, n_{i,s} S_i$$

where

- $\alpha_{i,s}$: damage factor of category i given a certain water depth
- $n_{i,s}$: number of objects or m^2 in category i affected by floods
- S_i : maximum damage per object or m^2 in category i affected by floods
- N : total number of categories

[5] The data can have the geographical resolutions of 5m, 25m, 50m and 100m grids.

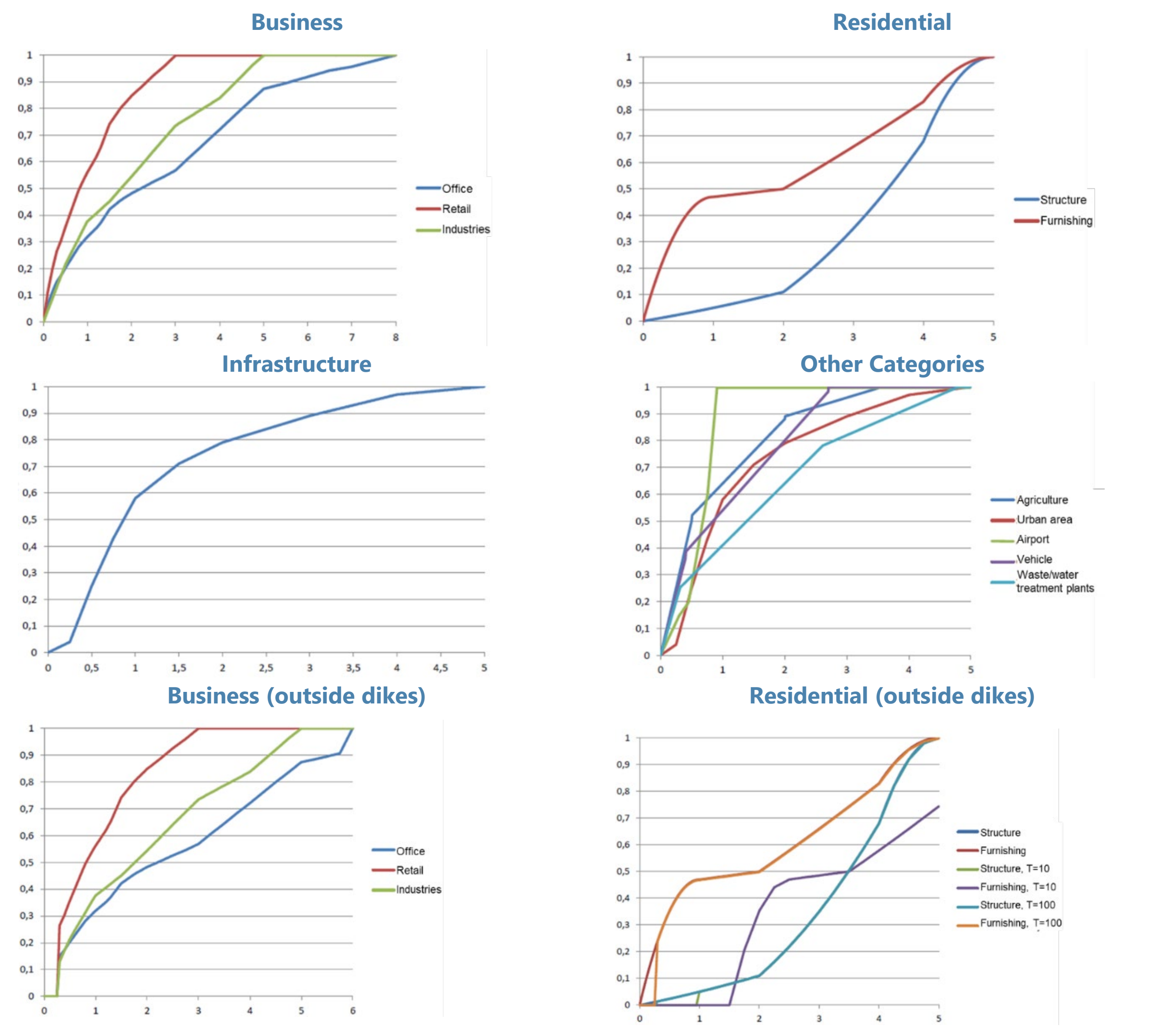
[6] For business and residences, the source data is the Basic Registration of Addresses and Buildings (BAG) 2022 and buildings and residence objects (ESRI file geodatabase, www.esri.nl). For infrastructure, road data is from the National Road File (NWB-Wegen 2022) via the national georegister Netherlands (www.nationaalgeoregister.nl), and railway data is from the Top10NL (2022) files which also take into account various light-rail connections, metro and tram tracks. A full description of the software and data source can be found at https://iplo.nl/thema/water/applicaties-modellen/waterveiligheidsmodellen/schade-slachtoffer-module/.

[7] In addition, the SSM software also considers some special objects. There are 4 main categories of special objects: vulnerable objects, national monuments, IED installations and protected areas according to the Water Framework Directive (WFD). For these objects and areas, only affected numbers or areas are reported and no damage is calculated.

[8] The SMM software also calculates the expected casualty caused by floods, using a mortality function with water depth, water flow rate, rate of ascent, inhabitant data as inputs.

27. The damage factor α_i is determined from damage functions that vary across categories (and subcategories), calibrated specifically for the Netherlands. With increasing water depth, the damage factor increases from 0 to 1. Some examples of damage functions for each category and subcategory are presented in Figure 5. The consequences of floods outside the dikes differ from the floods that occur within the dike. This is mainly due to the limited size (both area and water depth) and the expectation that objects and inhabitants are adapted to flooding to a certain extent (Slager et al. 2013). That is why some adjustments, mainly in terms of damage functions, have been made to the outside dike method. For instance, for houses outside dikes it is assumed that a number of structural measures, such as no basement, laying stone floors, have been taken in the outer dike area where high water occurs with some regularity.

Figure 5. The Netherlands: Damage Function for Direct Damage



Note: The horizontal axis is water depth(m) and the vertical axis is damage factor. The damage functions for residential real estate outside dikes are differenciated by return periods (T=10 and T=100).

Source: Butcher and Wagenaar (2017).

28. Each category has a maximum damage S_i, calibrated based on the CBS macro data at national level. Table 5 displays the amount of maximum direct damage per unit and corresponding units for each category. These values are periodically updated to reflect changes in property values and the number of properties.

Table 5. The Netherlands: Categories and Maximum Damage in SSM2017

Categories		Direct damage	Indirect damage	Maximum Direct damage (€/unit)	Unit
Business	Meeting facilities	X	X	194	m^2
	Office	X	X	1,607	m^2
	Health services	X	X	2,689	m^2
	Industries	X	X	1,420	m^2
	Education facilities	X	X	1,228	m^2
	Sport facilities	X	X	113	m^2
	Retail and Commerce	X	X	1,796	m^2
Residential	Single family houses - Structure	X	X	1,295	m^2
	Single family houses - Furnishing	X		81,985	obj.
	Ground floor apartments - Structure	X	X	1,295	m^2
	Ground floor apartments – Furnishing	X		81,985	obj.
	First floor apartments – Structure	X	X	1,295	m^2
	First floor apartments – Furnishing	X		81,985	obj.
	Higher floor apartments - Structure	X	X	1,295	m^2
	Higher floor apartments – Furnishing	X		81,985	obj.
Infrastructure	Regional roads	X		2,243	m
	Motorways	X		1,520	m
	Other roads	X		414	m
	Railroads – electrified	X		1,710	m
	Railroads – unelectrified	X		6,842	m
Other Categories	Agriculture	X		2.36	m^2
	Green house	X		63.1	m^2
	Recreation intensive	X		17.22	m^2
	Recreation extensive	X		13.98	m^2
	Urban area	X		76	m^2
	Airport	X		185	m^2
	Vehicle	X		10,491	obj.
	Pumping stations	X		1,177,853	obj.
	Waste/water treatment plants	X		17,107,030	obj.

Note: Maximum direct damage in this table is damage from floods within dikes only.

Source: De Bruijn et al. (2015) and SSM2017 v4.1 (2023).

29. The capital shock, or damage rate, is computed as the percentage of estimated direct physical damage to the (pre- damage) total capital value. Estimating the total capital value in the Netherlands is challenging, so a proxy is devised. First, a hypothetical flood map is generated with 10 meters of water depth, assuming that the entire surface of the Netherlands is submerged. Then, the damage from this hypothetical flood can be calculated using SSM. This damage amount can be interpreted as a proxy for the total capital value in the Netherlands.

30. Damages from floods in Belgium and Germany are estimated using IMF internal methodology. The methodology draws from the IMF working paper "A multi-country study of forward-looking economic losses from floods and tropical cyclones". Specifically, flood depths and fraction flooded data are retrieved from Jupiter Intelligence for a 1-in-100 return period under SSP5 RCP 8.5 scenario in 2050. The methodology uses the damage functions for floods in Europe calibrated by Huizinga et al. (2017) and the gridded GDP data from Murakami et al. (2021) as economic exposures.

31. The aggregate country-level damage rate of country c (D_c) is calculated as:

$$D_c = \sum_{i=1}^{n} d_{i,c} * \frac{GDP_{i,c}}{GDP_c}$$

where

- $d_{i,c}$: the damage rate for location i[9] in country c, as $d_{i,c} = frac_{i,c} \times df_{floods}(depth_{i,c})$
- df_{floods}: damage function in Europe from Huizinga et al. (2017)
- $frac_{i,c}$: fraction of flooded area within location i from Jupiter
- $depth_{i,c}$: flood depth in location i from Jupiter
- $GDP_{i,c}$: gridded GDP in location i from Murakami et al. (2021)
- GDP_c: the total GDP of country c

32. For each grid, the exposure into built-up and non-built-up are divided, using the land cover data Copernicus Global Land Operations "Vegetation and Energy" (CGLOPS-1) for 2019 from Buchhorn et al. (2020). Built-up areas refer to the land used for human habitation, such as buildings and other manmade structures, while non-built-up areas include forest, water, and other nature. For built-up areas, the residential, commercial, and industrial damage functions are combined, by equally weighting each function, while for non-built-up agriculture and infrastructure damage functions are considered.

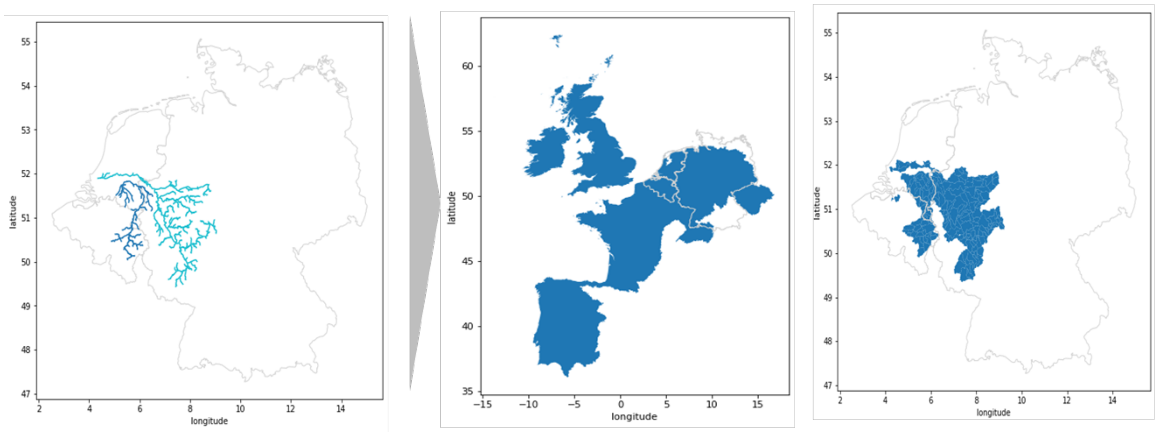
33. Due to the lack of flood data in Germany and Belgium, the inundated locations are selected as follows (Figure 6). First, the subbasins along the Rhine and Meuse rivers are divided into different levels of granularity. Then, the flood depth and the gridded GDP within each subbasin (level 9) are used as inputs for damage functions to calculate the flood damage rate for each subbasin. While the damage rates across subbasins are obtained, it is unrealistic to assume that floods occur simultaneously in all subbasins. Hence, a damage rate is selected from the distribution of damages across subbasins, considering the size of damages from historical events.

[9] Location i refers to an area where both flood depths and gridded GDP data are available at a certain level of granularity. For example, in para 33, each subbasin is treated as a location.

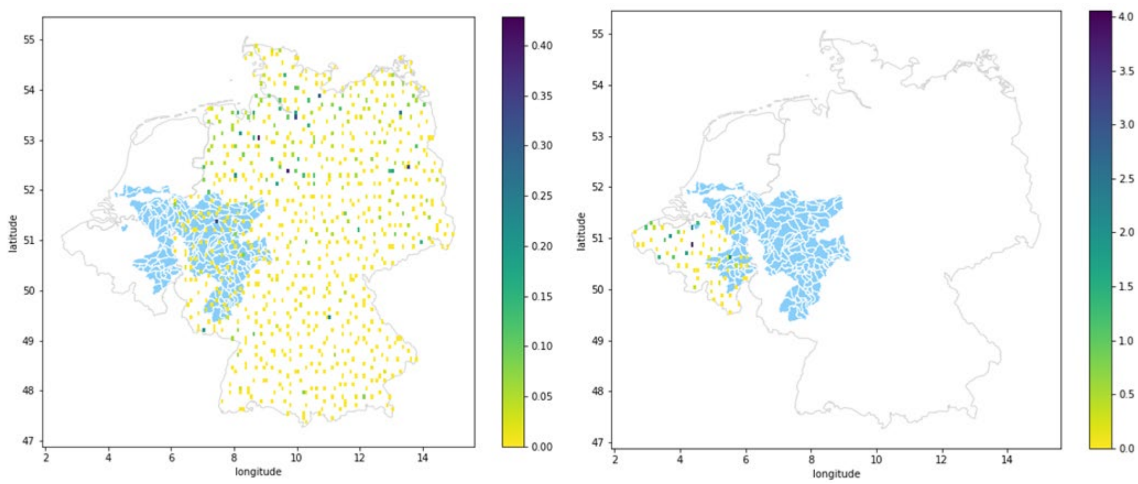
Figure 6. The Netherlands: Damage from Germany and Belgium

Subbasins along Rivers

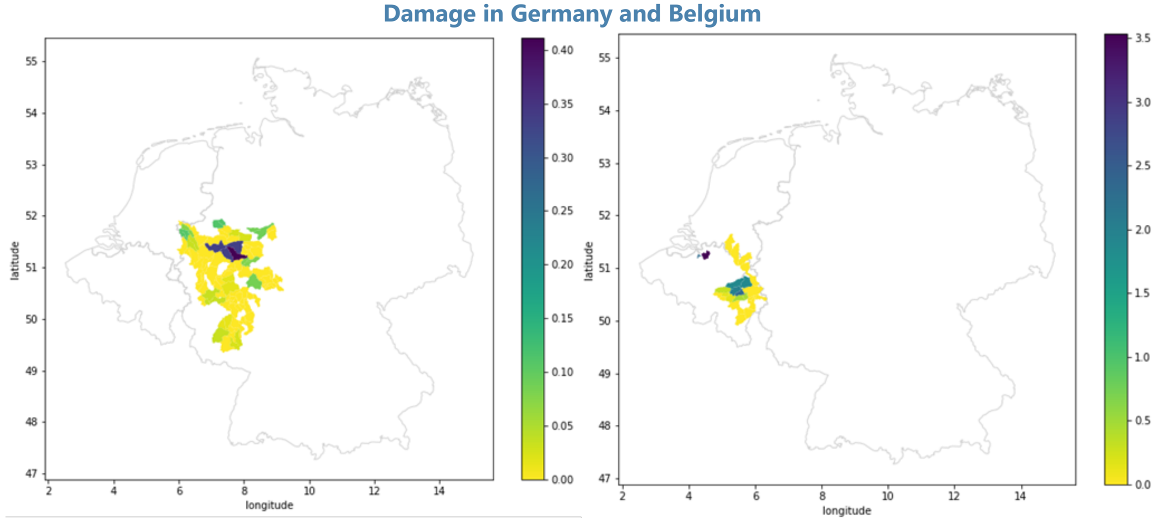
Rivers	Subbasins Level 2	Subbasins Level 9



Subbasins and Gridded GDP (Level 9, in percent of country GDP)



Damage in Germany and Belgium



Source: FAO, HydroSHEDS, WB, and IMF Staff Calculation.

34. While this approach allows for the calculation of damage rates from flood scenario, there is a caveat concerning the consistency of GDP and capital stock shock. The damage rate is calculated in terms of GDP losses, even though the macro model uses a damage rate of capital stock as an input for a non-linear production function. This implies that the GDP loss rate might differ from the capital damage rate unless the production function is a perfect linear function. This limitation could result in an underestimation of impacts on macro variables.

D. Macro-Approach Stress Test

35. This analysis takes a macro-approach stress test to examine the impact of the aggregated flood damages on the banking sector at the country level. Given the regional nature of floods, credit risks from floods are closely related to bank exposure to geolocational portfolio. However, the unavailability of bank loan-level data hampers the analysis from delving into the probability of default (PD) and the loss given default (LGD) for residential real estate (RRE) or commercial real estate (CRE) loans. Instead, the macro-approach is employed, relying on aggregated flood damages at the country level and aggregated PD and LGD at the bank level.

36. The IMF Global Macro-financial Model (GMM) generates macro scenarios spanning three-year horizons[10] by using shocks calibrated from the flood scenarios. Similar to the previous Philippines and Mexico FSAPs[11], the following three shocks are considered:

- **Direct destruction of physical capital.** The total damage rate from floods, aggregated at country level for the Netherlands, Belgium, and Germany, serves as an immediate direct shock to the capital stock.
- **Impact on total factor productivity (TFP).** The shock to TFP arises from the direct damages to the capital stock. This is calibrated at twice the total damage rate and assumed to be persistent, aligning with evidence from the literature.
- **House prices shock.** The shock to house prices is calibrated using the ratio of direct damages for all residences relative to the maximum damages for residences multiplied by the number of residences. Given the regional nature of floods, the house damage rate is adjusted by multiplying the elasticity of regional house prices changes to overall house price changes. Due to the data limitation of the regional house damage estimates in Germany and Belgium, the house price shock is only imposed on the Netherlands.

37. The analysis focuses on bank exposure to loan portfolios and the associated credit risks under the simulated macro scenarios. The stress test methodology, which is also used in the

[10] Although the damage rates from flood scenarios are estimated based on flood risks in year 2050 or 2100, the damages can be materialized within the short horizon, albeit with a substantially low probability. While this is a strong assumption, the FSAP bank solvency stress test and the climate stress testing exercises by central banks and regulators adopt similar approaches.

[11] The technical notes for the Philippines and Mexico FSAP can be found at Philippines FSAP Technical Note on Bank Stress Test for Climate Risk, and Mexico FSAP Technical Note on Climate Risk Analysis, respectively.

FSAP bank solvency stress test[12], considers the following loans categories of six Dutch Systemically Important Institutions (SIs): mortgage, corporates, other retails, financial institutions, government, and qualifying loans. For the purposes of the physical risk analysis, particular emphasis is placed on mortgage and corporate loans.

38. Additionally, the simulated macro scenarios are used to stress PDs and LGDs of each bank (Appendix II). Leveraging the historical relationship between PDs and macro variables, future trajectories of PDs of each loan category in each macro scenario are projected. House price shocks are used to project LGDs for collateralized loans, while LGDs for uncollateralized loans are expressed as a function of PDs.

39. The analysis specifically focuses on the credit risk channel of the flood scenarios. While acknowledging that other risk channels, such as interest rate risks and market risks, also contribute to transmitting shocks, this analysis narrows its focus on the credit risk channel, recognizing it as a main driver of the overall impact of shocks on bank capital. This approach allows for assessing the first-order impact of damages on bank credit losses, emphasizing the perspective of physical capital damages. However, it is important to note that this approach may have a caveat of possible underestimation of impacts due to the exclusion of other channels.

E. Results

40. Out of the 77 flood scenarios, 12 scenarios that cover each flood type, region, and climate condition are selected to evaluate their impacts on bank capital.[13,14] Using these selected 12 scenarios, the following stress test exercises are considered:

- Impact of climate changes in the unembanked area;
- Impact of climate changes and reinforcement (adaptation) in the embanked area;
- Impact of extreme flood scenarios (EDOs);
- Impact of floods in the neighboring countries.

41. Overall, the banking sector is resilient to flood events, with no banks expected to fall below capital requirements under all flood scenarios considered. The local nature of floods limits the overall damage to physical capital compared to the country's total capital stock. While the banking sector remains resilient, the aggregate result masks heterogeneity across banks and

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[12] The details of the stress test methodology can be found in the FSAP technical note on systemic risk analysis.

[13] All results are reported as the capital loss, or credit loss, deviation from the baseline scenario of the FSAP bank solvency stress, unless specifically stated.

[14] The macro approach, which adopts country-level damages (aggregated from granular location specific damages), ignores regional macro dynamics and the regional distribution of banks' loans. However, it is challenging to estimate different macro impacts on flooded and non-flooded regions without granular loan-level data and a dedicated regional model.

vulnerabilities at the individual institution level. Furthermore, the lack of access to bank LLD restricts the team's analysis to a macro-level approach that underestimates damages to collateral at the localized and firm levels.

Impact of Climate Changes in the Unembanked Area

42. This exercise assesses the impact of climate changes when a 1-in-1000 year flood occurs in the unembanked area of the lower river courses (Region IV). Region IV is selected as a representative case because of its higher damages incurred compared to other regions. While floods in Region I and II occur due to storm surges in the sea, floods in Region III and IV typically occur due to both storm surge and river floods. Consequently, the flood duration in Region III and IV is longer, resulting in higher damages (Figure 7).

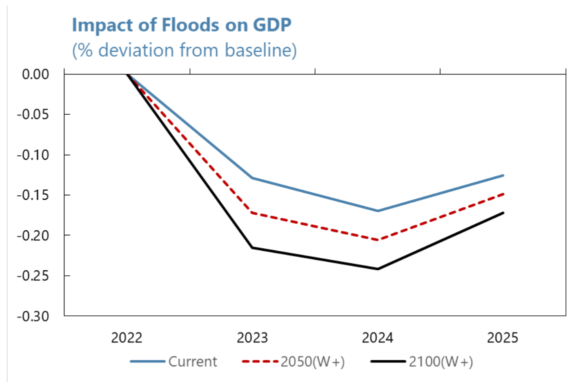
Figure 7. The Netherlands: Impact of Climate Changes in the Unembanked Area

Climate changes magnify capital and house price shocks…

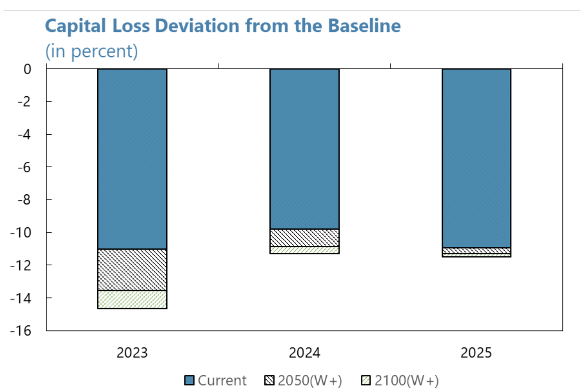
Capital and House Price Shock by Scenario

Return Period: 1000 years			
Scenario		Capital Shock	House Price Shock
A1	Current	0.020	1.26
A2	2050(W+)	0.032	1.48
A3	2100(W+)	0.044	1.70

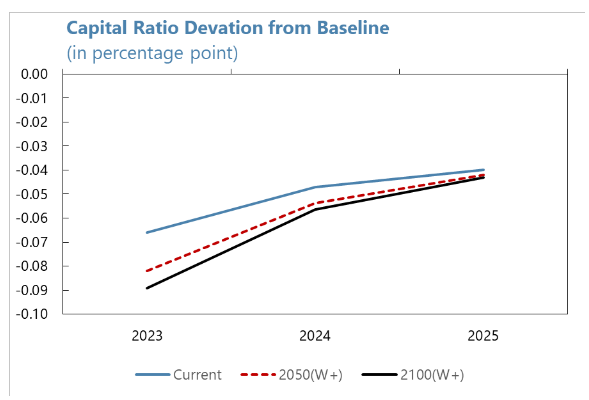
… as well as the adverse impacts on GDP.



The reduction rate of bank capital loss increases under the future scenarios.



The bank capital ratio drops but stands above the capital requirement.



Source: HKV, LIVO, and IMF Staff Estimates.

43. With the rise in hydraulic loads due to climate change, the adverse impact of floods on capital stocks and house prices are stronger. The flood under the current climate condition causes an additional 11 percent credit losses compared to the baseline scenario in 2023, and the magnitude of losses increases in the future climate scenarios. In the 2100(W+) scenario, the flood reduces the bank capital ratio by 0.09 percentage points in 2023. No bank's capital ratio falls below the capital requirement in all scenarios.

Impact of Climate Changes and Reinforcement (Adaptation) in the Embanked Area

44. This analysis evaluates the impact of floods under both current and future conditions in the embanked area and disentangles it into the effects of climate change and adaptation. The transition from B1 to B2 scenarios quantifies the difference in impacts between the current and future conditions. During these periods, hydraulic loads increase due to climate changes, and the government reinforces the flood defense system to adapt to climate changes. Keeping the climate condition constant, the difference between B2 and B3 scenarios measures the effect of a lower failure probability due to the dike reinforcement. Similarly, the climate change effect is measured by comparing losses under B1 and B3 scenarios (Figure 8).[15]

Figure 8. The Netherlands: Impact of Climate Changes and Adaptation in the Embanked Area

The reinforcement of flood defenses reduces physical capital damage from floods.

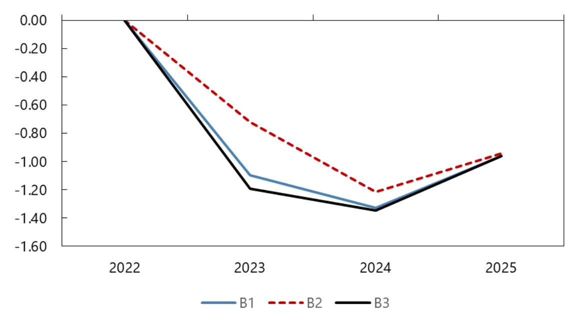
Capital and House Price Shock by Scenario

Return Period: 10,000 years

Scenario			Capital Shock	House Price Shock
	Climate	Failure Probability		
B1	Current	Current	0.200	9.6
B2	2050(W+)	2050	0.062	10.5
B3	2050(W+)	Current	0.241	9.5

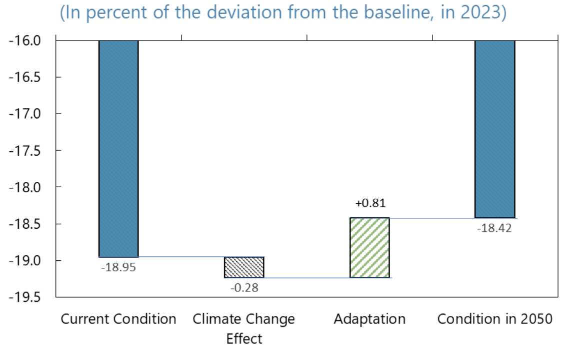
The adaptation plan serves as an absorber of the adverse impact on the economy.

Impact of Floods on GDP
(% deviation from baseline)



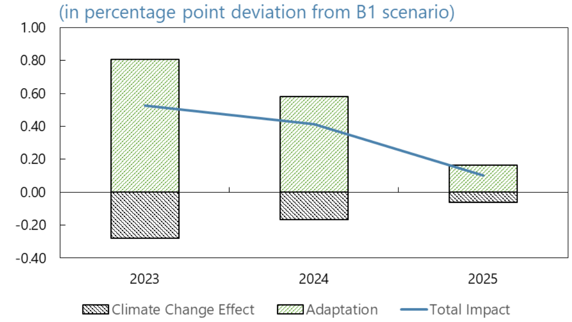
Climate changes and the adaptation plan have the opposite impacts on bank capital loss.

Climate Change and Adaptation on Bank Capital
(In percent of the deviation from the baseline, in 2023)



Lower probability of defense failure mitigates bank credit risks.

Impact of Climate Change and Adaptation on Bank Capital Loss Rate
(in percentage point deviation from B1 scenario)



Source: HKV, LIVO, and IMF Staff Estimates.

[15] According to Table 4, these scenarios assume 4 simultaneous breaches. As the B2 scenario involves different hydraulic loads, the breach locations differ from B1 and B3, contributing to more pronounced house price shocks.

45. While climate change events have negative impacts on the bank capital, the government's current reinforcement plan is strong enough to absorb the capital losses from climate changes. A 1-in-10,000-year flood in Region II under the current conditions generates 0.2 percent destruction in capital stocks. Despite higher hydraulic loads, the damage rate is expected to decrease by 0.138 percentage point under the conditions in 2050. In B1 scenario, bank capital losses increase by 18.95 percent relative to losses in the baseline in 2023. While higher hydraulic loads add losses of 0.28 percentage points, the lower defense failure probability in 2050 absorbs the losses by 0.81 percentage points, leading to lower the capital loss rate by 0.53 percentage point in total.

Impact of Extreme Flood Scenarios

46. The extreme scenarios (EDO scenarios) consider exceptionally rare flood cases, assuming simultaneous breaches of multiple dikes in the region. In the coastal storm surges scenarios in both Southwest and central coast area (Region I) and Wadden sea area (Region II), the dike breaches also cause a devastating surge on the lake districts. These two scenarios impact the widest area approximately 4,300 km^2 and 4,600 km^2, respectively, which adds up to nearly 26 percent of total land area in the Netherlands. However, the damage is significantly greater in the Region I due to its denser population, leading to substantial decline in GDP. On the other hand, despite a smaller inundated area, the flood water depths in Rhine and Meuses (Region III) and Lower river courses (Region IV) area are higher than other regions on average. (Figure A-1)

47. In all extreme flood scenarios, a severe flood can still cause a small, but nonnegligible capital ratio reduction in the first year (Figure 9). The bank capital ratio drops by 0.3-0.6 percentage points, standing above the requirement. While the reduction in GDP is larger in EDO-I scenario than in other scenarios, the magnitude of reduction in the capital ratio is not as large as the difference in GDP reductions. This can be attributed to three main factors: first, the significant heterogeneity in the size of the impact across banks, in part due to incorrectly-reported data in some banks[16]; second, our probability of default (PD) model for the Netherlands suggests a relatively smaller impact of GDP changes on future PD trajectories; and lastly, the absence of other risk channels (interest risk and market risk) in this analysis is another caveat to this analysis.

48. An additional sensitivity analysis with higher house price shocks adds 0.1 percentage point decline in the bank capital ratio. In this case, the loss rate in house value due to regional flood applies to the national-wide house value in the Netherlands, without consideration of the elasticity of regional price to overall house price. Higher house price shock amplifies the adverse impact on the capital ratio, especially in the first year.

[16] See the section of SI Solvency Stress Test in Technical Note on Systemic Risk Analysis for details.

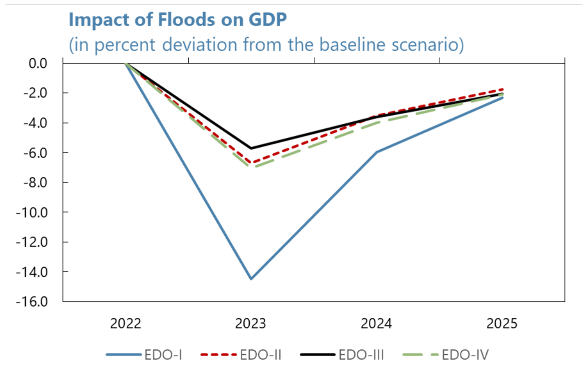
Figure 9. The Netherlands: Impact of Extreme Flood Scenarios

The extreme flood scenarios have negative impacts on the capital stock and house prices…

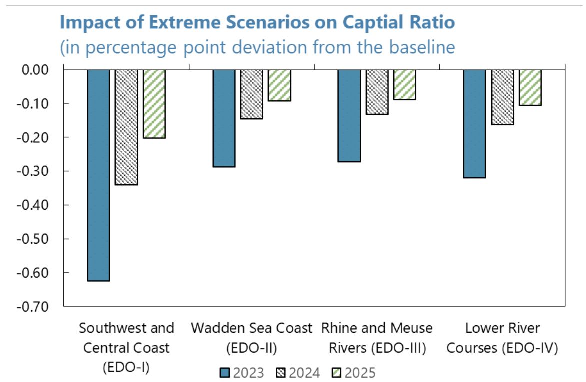
Capital and House Price Shock by Scenario

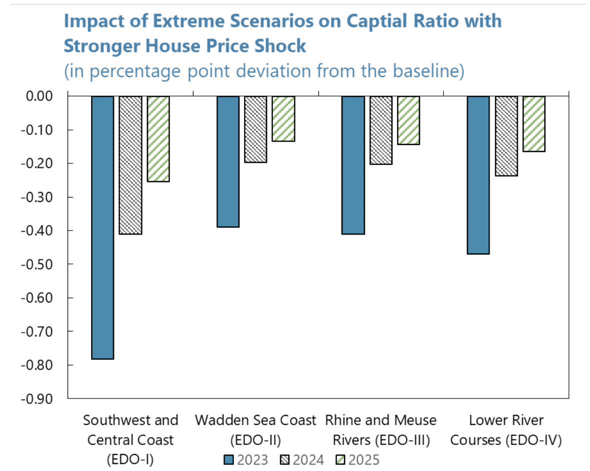
Scenario	Capital Shock	House Price Shock
EDO-I	5.4	13.9
EDO-II	2.4	13.9
EDO-III	1.9	17.7
EDO-IV	2.4	17.4

… and GDP, especially in Region I.



Severe floods can cause small but nonnegilible capital ratio reductions.





Source: HKV, LIVO, and IMF Staff Estimates.

Impact of Floods in the Neighboring Countries

49. **In July 2021, heavy rains across Belgium, Germany, the Netherlands, and many other western European countries, caused streams and rivers to overflow their banks in many locations.** Some of the affected regions experienced rainfall of this magnitude not seen in the last 1,000 years.[17] The floods are estimated to have caused a minimum of 10 billion euros in total damage, with particularly severe damage to infrastructure in Belgium and Germany.[18] According to the international disaster database (EM-DAT), the damage per GDP in Germany was approximately three times larger than that in Belgium.

50. **Floods along Rhine and Meuse River area in Germany and Belgium have minimal spillover impacts to Dutch banks despite the latter's exposure to those countries.** As described

[17] https://www.nytimes.com/2021/07/16/world/europe/germany-floods-climate-change.html

[18] https://www.wsj.com/articles/germany-flooding-bernd-whats-happening-11626446298

in the paragraph 33, damage rates, or capital shocks, of Germany and Belgium are selected based on the evidence from the 2021 flood event. While floods in the neighboring countries have negative impacts to bank capital in the first year, the impact is very small, increasing the capital loss rate only by 0.06 percentage point. The impacts of floods on Germany and Belgium are not large enough to transmit additional credit risks to Dutch banks. However, depending on their exposure to those countries, the impacts on banks vary significantly. Acquiring more granular flood and collateral data from Germany and Belgium would help refining assessments of damage and spillover impacts on the banks.

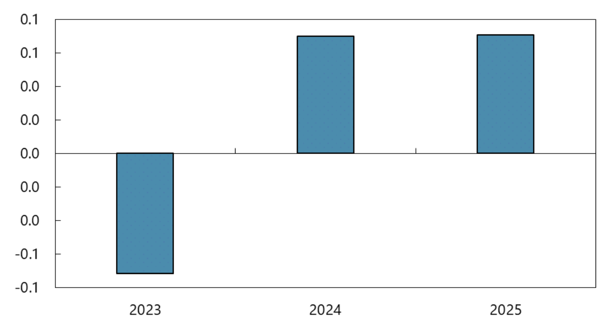
Figure 10. The Netherlands: Impact of Floods in the Neighboring Countries

Floods from the neighboring countries adds bank capital losses, but with limited impacts.

Capital and House Price Shock by Scenario

Return Period: 100 years		
Scenario	**Capital Shock**	**House Price Shock**
NLD	0.124	10.5
DEU	0.041	-
BEL	0.13	-

Impact of Floods in BEL/DEU on Bank Capital Loss
(in percentage point deviation from NLD only Flood)



Source: HKV, LIVO, and IMF Staff Estimates.

F. Recommendations

51. Although the impacts of floods on the Dutch banking sector is limited, climate change can intensify the losses from floods, putting downward pressure on capital ratios. A comparative analysis of current and future climate conditions and different failure probabilities suggests that the Dutch government's current reinforcement plan, which encompasses measures to strengthen dikes and enhance flood warning systems, could help mitigate some of the anticipated losses from climate change.[19]

52. The analysis and results should be regarded as provisional and interpreted with caution, given the uncertainty associated with the scenarios and models. The stress test models are subject to various simplifying assumptions due to the constraints in data and the model's scope. In particular, this analysis only considers the credit risk module of the standard bank solvency stress test model with short horizons. Also, the flood damage estimates at the regional level are applied to the macro-level, assuming that the impacts of these damages are evenly distributed across all regions. A more comprehensive examination is needed to understand the complete impacts of

[19] The 2022 Article IV Consultation and Chen et al. (2023) assessed the impact of adaptation initiatives on macroeconomy, suggesting further efforts to mainstream climate change adaptation at all government levels and provides guiding principles for efficient adaptation strategies.

floods through alternative channels to banks. Furthermore, the analysis of the impact from Belgium and Germany requires more specific flood information and micro data from these countries.

53. Flood scenarios designed with detailed flood maps under future climate conditions would provide a more accurate assessment of both climate change impact and adaptation measures. It is recommended to integrate the recently published climate scenarios (KNMI'23) into these flood scenarios, which can then be applied for medium and long-term physical risk analysis. For this purpose, strengthening data sharing and collaboration with floods and climate experts is warranted. Moreover, the access to the bank-loan level data will enhance the analysis, particularly in estimating damages to collateral at the local and firm levels.[20]

PHYSICAL RISK ANALYSIS – INSURERS

A. Insurers' Exposures to Physical Risks

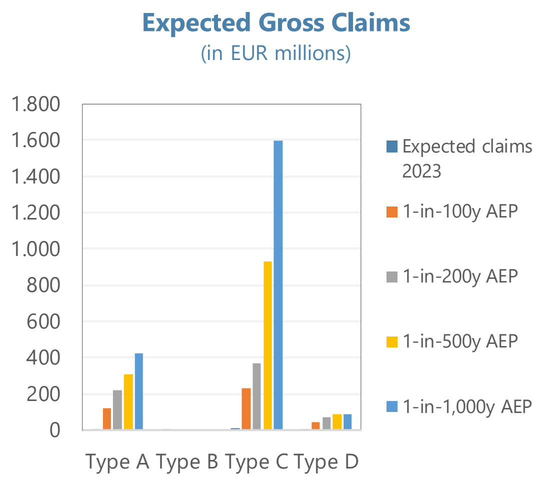
54. The insurance sector is exposed to physical climate risks mainly through its non-life underwriting. Domestically, the most important natural perils are windstorms, hail, and floods—some of which are expected to become more frequent and/or severe with climate change. While the scientific evidence for a higher future frequency or severity of European windstorms is not clear-cut, hailstorms are expected to occur more often and are difficult to model given their very local nature. More precipitation and a rise in sea levels increase the risk of floods.

55. Flood risks in the Netherlands need to be differentiated, and not all flood risks can be insured in the private market. While properties or area's behind primary flood defenses ("Type B") are not insured by private insurers, those behind non-primary defenses ("Type C")—in particular along rivers— form the largest exposure of the P&C insurers. Additionally, inundation of regional water systems ("Type D") can be insured. Expected loss distributions are different for these flood types, with particularly fat tails for Type C (Figure 11). For all three flood types covered, Dutch primary insurers retain very limited exposure to events with lower occurrence probabilities and are instead covered by reinsurance. Hence the expected net claims (after reinsurance) of a 1-in-1,000 years Type C flood would be only around EUR 200m for the P&C insurers in the sample, considerably lower than the EUR 1.6bn gross claims. Outside the Netherlands, Dutch insurers hardly underwrite any risks in lines of business which could be vulnerable to flood risks—however, foreign entities within Dutch insurance groups could certainly have local exposures.

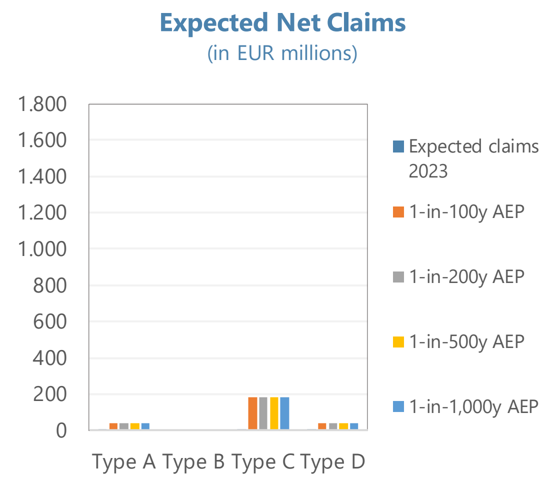
[20] See also Caloia and Jansen (2021) and Caloia et al. (2023) for an exploration of how flood-related property damages would impact credit risk.

Figure 11. The Netherlands: Insurers' Physical Climate Risks—Natural Catastrophes

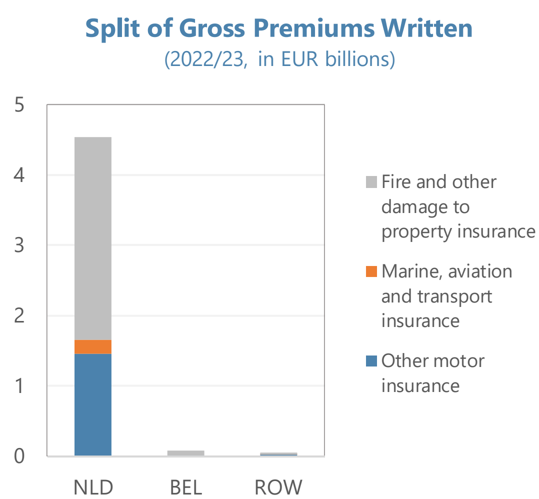
Non-primary flood coverage (Type C) would cause the highest losses (which increase substantially for lower occurrence probabilities)…



… but the use of reinsurance limits the net claims for the Dutch primary insurers significantly.



Exposures of solo P&C insurers in vulnerable lines of business are almost exclusively domestic.



Source: IMF staff calculations based on company submissions.

B. Approach and Scope of the Physical Risk Analysis

56. Physical flood risks were assessed BU in collaboration with five large P&C insurers. The P&C insurers were requested to provide exposure data, the solvency impact of historic and hypothetic flood disasters, and the impact of a permanent increase in the frequency and severity of weather-related loss events on claims and insurance liabilities.

57. Two historic flood events were tested in addition to hypothetical events which assume higher maximum precipitation levels. For the historic events, insurers were asked to assume these would occur again, with their impact being simulated based on current exposures and at current prices. Both events rank amongst the flood events which have caused the highest insured losses in the Netherlands over the last decades:

- River flood event in the Limburg province (July 2021);
- Cloudburst event (28 July 2014).

For the two hypothetical events, the modelled maximum precipitation levels of both historic events were multiplied by 1.25 ("scaling-up"[21]) as an additional layer of prudence and incorporating the effect of a warming atmosphere. Insurers were asked to report, for each peril, gross and net claims, the impact on EOF and the resulting SCR, the occurrence probability, as well as information on the model used for producing the estimates. In addition, information on the five largest reinsurers' recoverable (on a group basis) was collected.

58. The parametric approach assumed an overall, permanent increase in the frequency and severity of all weather-related events by 10, 30 and 50 percent, respectively. Insurers were requested to apply these increases to all insurance liabilities across all lines of business.

C. Results of the Physical Risk Analysis

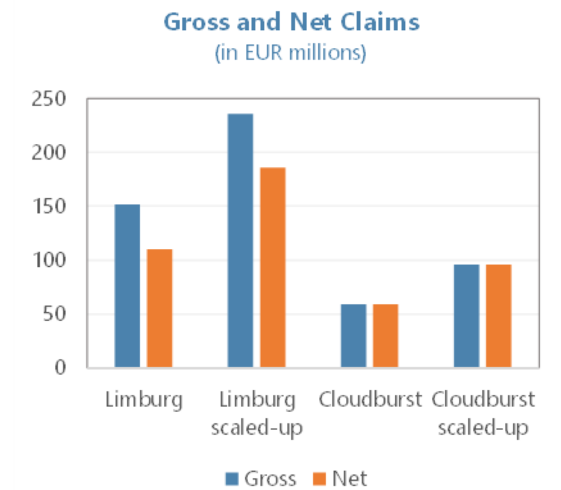
59. The net claims effect—after reinsurance—of a non-primary regional flood event on Dutch insurers is limited (Figure 12). A repetition of the 2021 flood in Limburg, based on today's exposures and assuming a 25 percent increase in maximum precipitation during the event, would result in net claims of EUR 180m for the sample. The SCR for the median insurer would drop by less than 5 percentage points to 153 percent. The impact of the cloudburst event (even with the scaling up of the precipitation levels) would be even lower, resulting in a decline of the median SCR of only 2 percentage points.

60. However, modeling approaches used by insurers vary markedly, in particular for the likelihood of the hypothetic flood events. While one insurer considered the historic Limburg flood to be a 1-in-70 years event, another insurer estimated it to be a 1-in-400 years event. Scaling up the precipitation led to even larger dispersions of estimates: while for one insurer the return period of Limburg flood increases by 1.3 times, for another insurer it increases by a factor of 10. These differences highlight some modeling uncertainties and potentially the absence of certain data inputs critical for accurate modeling. Dutch insurers use different flood models, offered by large risk model vendors, reinsurance brokers, and local providers. DNB is recommended to intensify discussions with P&C insurers on their flood-risk modeling, and relate these insights to the planned development of dashboards for physical climate risk and—more generally—climate risk supervision.

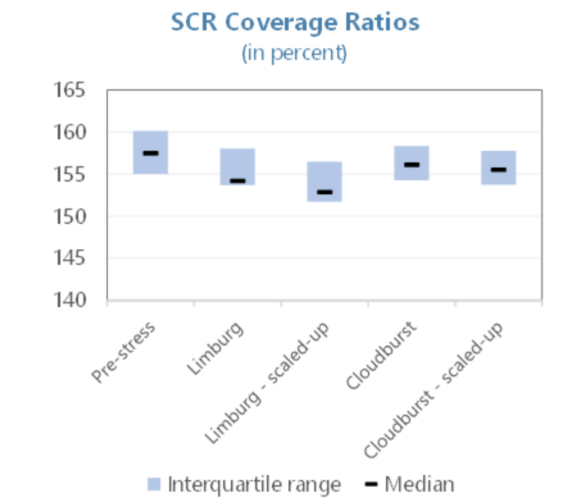
[21] "Scaling up" refers to a proportional increase in the amount of hourly/daily precipitation. As an example, the maximum daily precipitation recorded in the Netherlands on 28 July 2014 was 131.6mm (at Deelen airfield)—in this exercise, this was assumed to be 164.5mm.

Figure 12. The Netherlands: Insurers' Physical Climate Risks—Flood Events

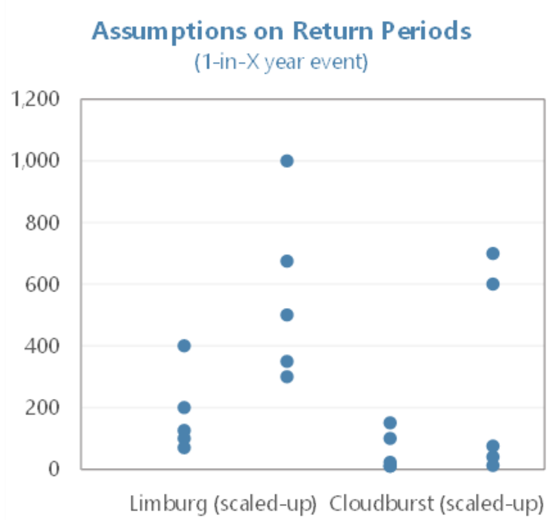
A repetition of the 2021 Limburg flood with 25 percent higher maximum precipitation would cause net claims of around EUR 190m for insurers in the sample…



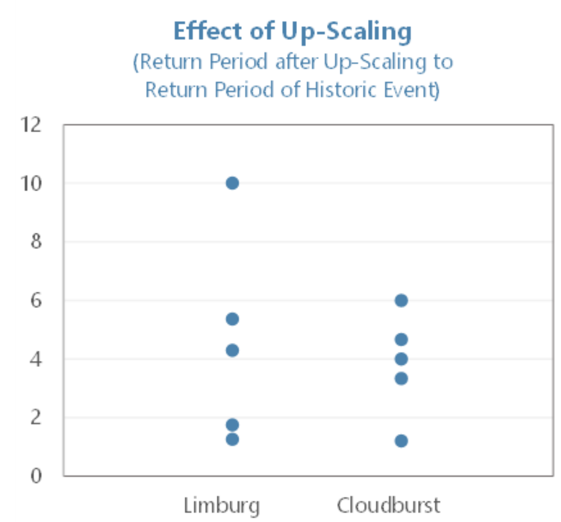
… resulting in a rather minor reduction of the SCR of less than 5 percentage points for the median insurer.



P&C insurers have rather different views on the likelihood of each flood scenario, e.g., the return period for the Limburg flood event ranges between 1-in-70 years and 1-in-400 years.



Assuming a 25 percent increase in the maximum precipitation in each of the two historic flood scenarios gives a particularly wide dispersion of estimates of the return period, depending on the flood risk model used.



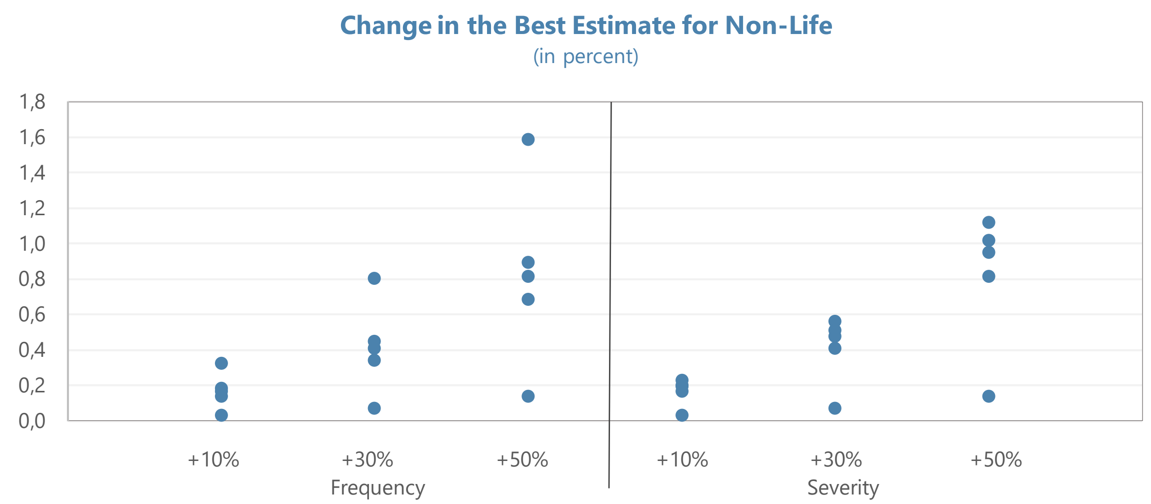
Source: IMF staff calculations based on company submissions.

61. **A higher frequency or severity of weather-related loss events would result in only marginally higher liabilities for P&C insurers** (Figure 13). Even when assuming a 50 percent increase in frequency, the best estimate of non-life insurance liabilities would increase by only 0.8 percent for the median firm. Assuming a permanent 50 percent increase in severity would result in a best estimate which is less than 1 percent higher than in the baseline. It should be noted,

however, that any increase in the best estimate (and hence in future expected claims) would very likely—at least over a medium-term horizon—result in an increase in the premiums charged to policyholders and/or cover design changes as insurers aim to keep their underwriting business profitable.

Figure 13. The Netherlands: Insurers' Physical Climate Risks—Natural Catastrophes

Assuming a higher frequency or severity of weather-related loss events would result in marginal increases in the best estimate of non-life insurance liabilities, but the variation across the sample is large.



Source: IMF staff calculations based on company submissions.

TRANSITION RISK ANALYSIS – NITROGEN

A. Nitrogen in the Netherlands

62. Nitrogen serves as a vital nutrient for plants and crops growth, but high levels of concentration pose risks to both humans and nature. Although nitrogen itself is not directly harmful, nitrogen oxides (NOx, a compound of nitrogen and oxygen) and ammonia (NH3, a compound of nitrogen and hydrogen) can be detrimental.[22] The combustion of fuels and animal manure are the main source of nitrogen emissions. Excessive depositions of these substances can contribute to significant problems to nature, such as acid rain, soil degradation, contamination of groundwater, and loss of biodiversity.

[22] When nitrogen in fertilizers is exposed to soil, microbes transform it into nitrous oxide, which is 300 times more potent at warming the atmosphere than carbon dioxide. Algal blooms in lakes and waterways, often caused by fertilizer run-off, also emit greenhouse gases. Ammonia, emitted from the housing, storage facilities, livestock manure, and fertilizers, itself is not a greenhouse gas, but it acts as a base for emissions of nitrous oxide (UNEP).

63. The gross nitrogen balance[23] in the Netherlands is notably higher than that in neighboring countries, and the exceedance above the critical value based on international research[24] is substantial. The Netherlands has the highest nitrogen balance (or surplus) in Europe as of 2019. On average, European countries had 68 kilograms of nitrogen per hectare between 2010 and 2015. The Netherlands had an average gross nitrogen balance of more than two times as much. Risks could arise from exposures to sectors responsible for nitrogen deposition, given the current level of exceedance in the Netherlands.[25] When critical values of nitrogen deposition[26] are exceeded, an ecosystem is considered at risk of eutrophication (a chain reaction, starting with an overabundance of algae and plants in bodies of water) and biodiversity loss. (Figure 14).

64. NOx emissions have been steadily declining since the 1980s, but the reduction in NH3 emissions plateaued around 2010. The share of NH3 emissions in the total nitrogen emission is on the rise, underscoring the importance of giving greater attention to NH3 emissions. 70 percent of NOx emissions originate from the traffic and transportation sector, while the agriculture sector accounts for 88 percent of NH3 emissions. These proportions have remained constant over the past decade (Figure 15).

65. In order to promote the conservation of biodiversity and protect natural habitats and species, the EU established the Birds and Habitats Directive. This directive urges member states to designate a network of protected areas known as Natura 2000 areas to avoid deterioration and improve the conservation status. In the Netherlands, out of the 161 designated Natura 2000 areas, nitrogen deposition exceeds acceptable levels in 118 of them (Figure 15).

66. The Dutch government therefore initiated the Nitrogen Approach Program (PAS, *Programma Aanpak Stikstof*) in 2015 to further reduce nitrogen emissions and mitigate their adverse effects. This program established measures, including permit requirements for certain projects or activities, to prevent significant harm to Natura 2000 sites from increased nitrogen deposition. However, a ruling by the Council of State determined that PAS did not comply with the EU regulations, emphasizing the need for a more robust approach to nitrogen management. The ruling emphasized that projects contributing to additional nitrogen emissions, such as the construction of motorways and residential areas, could not proceed without adequate

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[23] The gross nitrogen balance is an agri-environmental indicator calculated from the total inputs minus total outputs to the soil. The inputs of the gross nitrogen balance include fertilizer and animal manure, atmospheric nitrogen deposition. The outputs include total removal of nitrogen with the harvest of crops and the harvest and grazing of fodder (Eurostat).

[24] National Emission Reduction Commitments Directive (2016/2284/EU) sets national emission reduction commitments for EU member states and Nitrates Directive (91/676/EEC) requires the member states to monitor the quality of waters at risk of nitrogen pollution.

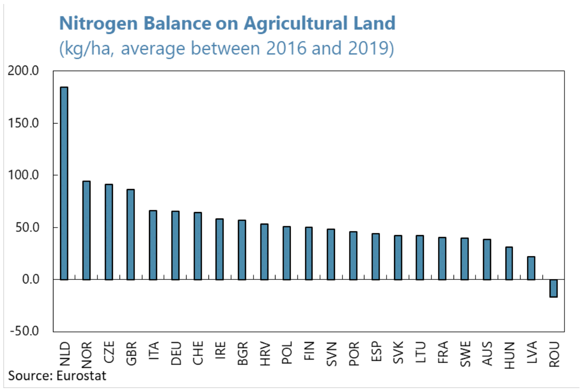
[25] One of the targets of the European Commission's zero pollution action plan is to reduce the area of ecosystems in the EU at risk of eutrophication caused by atmospheric nitrogen deposition by 25 percent by 2030, compared with 2005. (European Environment Agency).

[26] Refer the paragraph 10 for the definition of nitrogen deposition.

compensation for the environmental impact on nitrogen-sensitive areas.[27] This led to a reevaluation of nitrogen management policies in the Netherlands.

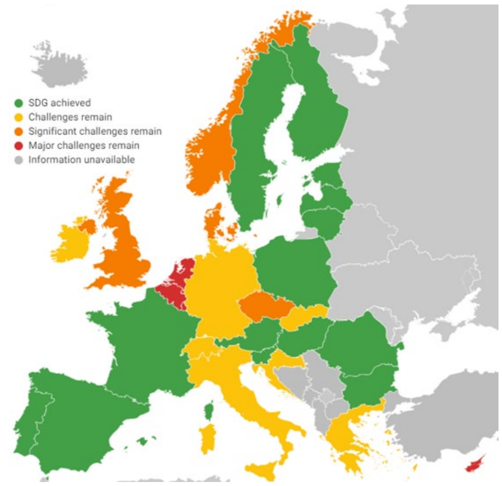
Figure 14. The Netherlands: Nitrogen in the Netherlands

The Netherlands has the highest nitrogen balance in Europe



Note: In 2015, the nitrogen balance in Cyprus exceeded that of the Netherlands in 2015; however, recent data is not available.

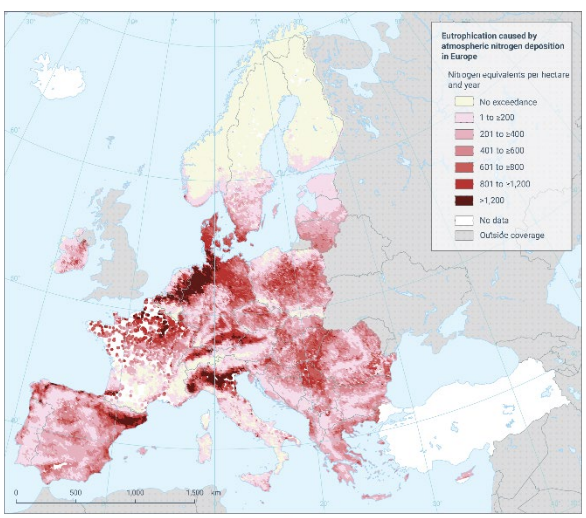
The Europe Sustainable Development Report placed the Netherlands in the category of "major challenges remain".



Source: Europe Sustainable Development Report (2022)

Many parts of the Netherlands are under eutrophication due to the atmospheric nitrogen deposition.

Exceedance of critical loads of atmospheric nitrogen depositon in Europe in 2021

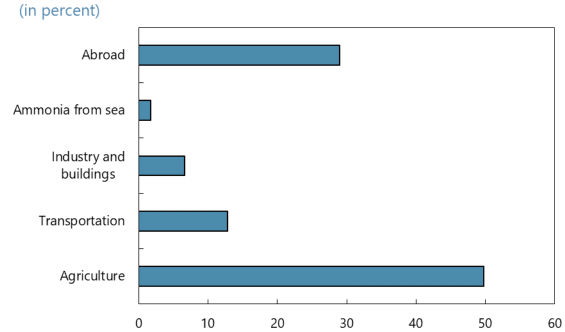


Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO

Source: European Environment Agency.

A large share of nitrogen deposition comes not only from domestic agriculture and transportation but also from abroad.

Share of Nitrogen Deposition by Source in 2021
(in percent)



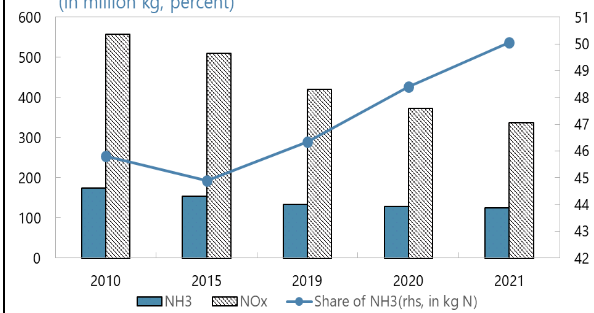
Source: RIMV (National Institute for Public Health and the Environment)

[27] According to research conducted by a real estate consulting company, without the rule of Council of State, about 23,000 more homes would have been built since mid-2019. (https://nltimes.nl/2024/01/09/nitrogen-crisis-prevented-construction-23000-homes-since-2019)

Figure 15. The Netherlands: Nitrogen Emission in the Netherlands

While NOx emissions have been steadily declining, the reduction in NH3 emissions has plateaued since 2010.

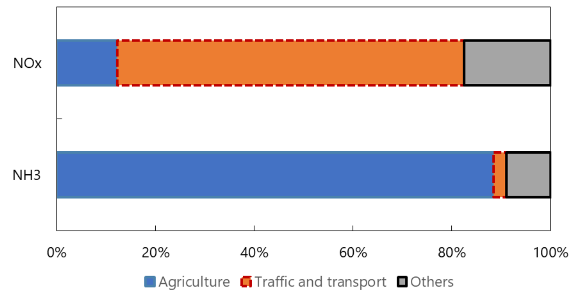
Nitrogen Emission in the Netherlands
(in million kg, percent)



Source: Emissieregistratie and IMF Staff calculation

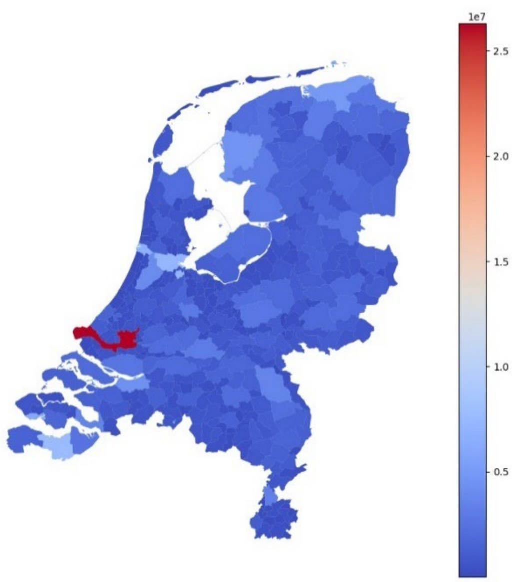
Emissions from agriculture and transportation account for a large share of total emissions.

Nitrogen Emission by Sector
(in percent, 2021)



Source: Emissieregistratie and IMF Staff calculation

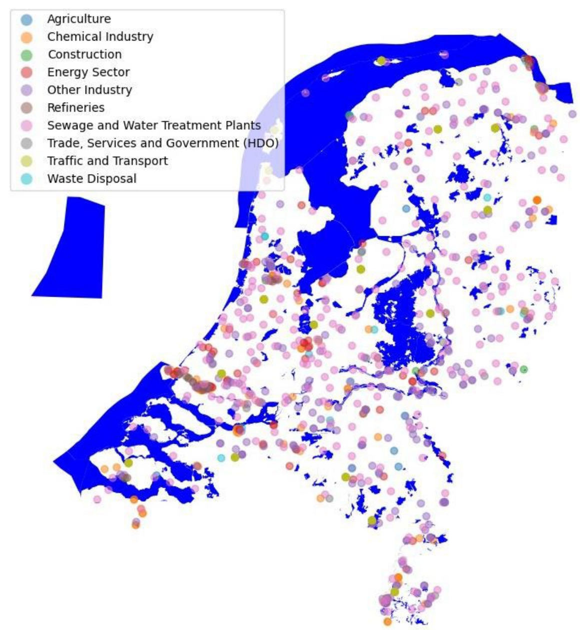
Nitrogen Emission by region and Natura 2000 Area in 2020
(in kgs)



Source: Emissieregistratie and IMF staff calculation

Note: The level of emissions is the sum of NH3 and NOx emissions.

Nitrogen Emitting Firms by sector around Natura 2000 Area in 2020



Source: Emissieregistratie

Note: The map presents firms which reported their emissions to Emissieregistratie. It does not represent emissions by all firms in the Netherlands. The blue area shows Natura 2000 areas.

67. **In 2022, the government announced the Nitrogen Reduction and Nature Improvement Program, backed by the Nitrogen Reduction and Nature Improvement Act (*Wet stikstofreductie en natuurverbetering*).** This program aims to achieve that, in 50 percent of the area with high nitrogen deposition within nitrogen sensitive and Natura 2000 areas, the internationally adopted critical deposition load will no longer be exceeded by 2030 (74 percent by 2035). While excessive nitrogen is a global concern, the Netherlands together with Belgium are where the legal ruling has prompted additional measures for limiting nitrogen emission (DNB and PBL, 2020).

68. This program entails multiple ongoing measures with a budget of 24.3 billion euros, including measures on agriculture in rural areas and Natura 2000 Area. The measures include targeted purchases and termination of livestock farms, and a national cessation scheme for livestock and others. Currently, provincial programs which include a variety of additional measures are drawn up and subsequently assessed by central Government to be eligible for funding. In addition, a budget of 7 billion euros has been allocated to mitigate nitrogen emissions in all sectors (agriculture, mobility, and industry).[28] In addition to nitrogen reduction measures, part of this budget is allocated to a broadening of the nature restoration program.

69. However, this program faced substantial opposition from farmers who are concerned about the impact it will have on their livelihoods. To achieve the set of objectives, a number of measures is aimed at a one-third reduction of livestock by 2030. While certain measures within the program are currently being implemented, the future trajectory of policy implementation and the extent of subsidies remain unclear due to the change in government, contributing to overall policy uncertainty.

70. Against this background, the analysis aims to examine the banking sector's exposure to industries emitting nitrogen. This examination is crucial, as policy changes might significantly impact banks' credit risks and their overall portfolio. However, unlike a standard transition risk stress test, this analysis will not assess the impact of specific transition policies on the Dutch economy or the solvency and liquidity of banks. Instead, its focus is on providing a descriptive overview of the level of exposure banks have to nitrogen emitting sectors. This corresponds to the first stage in the IMF climate risk analysis framework (IMF climate note[29]), while the second stage (scenario design) and third stage (mapping of scenario into banks' resilience) are out of the scope of the transition risk analysis.

71. Before delving into the analysis, it is worth clarifying three different concepts that describe various aspects of how nitrogen compounds move and interact in the environment. First, nitrogen *emission* denotes the release of nitrogen compounds into the atmosphere or into the environment from various sources, such as human activities and natural processes. Second, nitrogen *concentration* refers to the amount of nitrogen present in a specific volume or weight of a substance in water or in air. Lastly, nitrogen *deposition* refers to the process by which nitrogen compounds from the atmosphere are deposited onto the Earth's surface, such as land or water bodies. While the ultimate policy objectives are the reduction in deposition, the practical policy tool involves controlling emissions from economic activities.

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[28] For example, following the annulment of the temporary exemption for nitrogen limits in the construction project in 2022 by a ruling by the Council of State, each project requires a stricter assessment of its nitrogen impact throughout both the construction and operational phases. To prevent construction project from coming to a halt, the government provides subsidies and incentives to encourage construction companies to use clean and emission-free equipment.

[29] Approaches-to-Climate-Risk-Analysis-in-FSAPs

72. Given the limited scope of this study, the subsequent analysis will concentrate on the following approaches. Firstly, the bank loan exposure to high nitrogen emitting sectors will be presented. Then, the analysis will examine the nitrogen emission intensity across the sectors, taking into account banks' exposure to each sector, and extend the analysis to the future nitrogen trajectory. Finally, it will conclude by examining the corporate characteristics of the high nitrogen emitting sectors.

B. Analysis of Bank Exposure to Nitrogen

73. The banking sector's exposure to high nitrogen-emitting sectors amounts to 34 billion euros in domestic loans, constituting 6.5 percent of total loans and 1.5 percent of total assets. Economic sectors are categorized into three groups based on the ratio of sector emissions to total emissions. A group is classified as high if the ratio exceeds 10, mid if it falls between 1 and 10, and low if it is below 1. While the total amount of loans to nitrogen-emitting sectors did not vary significantly, the proportion of loans to high-emitting sectors as share of total domestic loans decreased by 0.3 percentage point from 2018 to 2023 (Figure 16).

74. The nitrogen emission intensity metric, which measures the amount of nitrogen emission per unit of value-added, serves as an indicator of a bank's involvement in nitrogen emitting sectors, particularly when weighted by the bank' exposure to these sectors. The (weighted) nitrogen emission intensity of bank k in year t can be computed using the following formula:

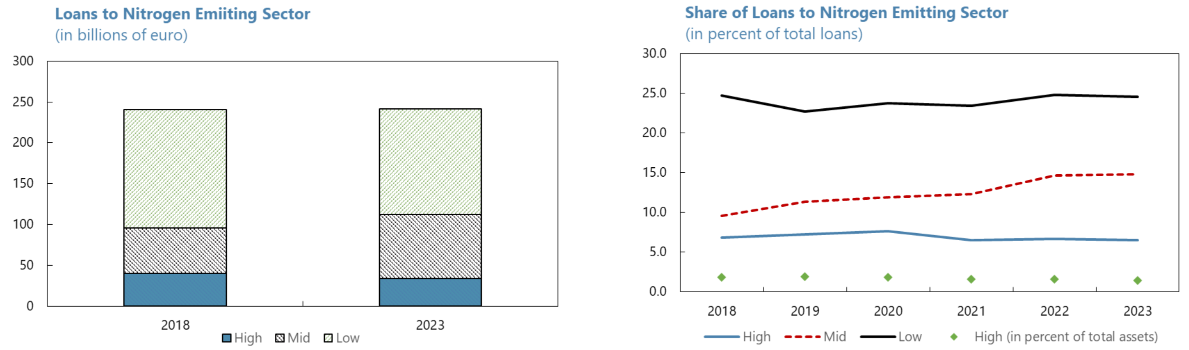
$$Intensity_t^k = \sum_{i=1}^{I} \frac{(Emission\ from\ sector\ i)_t}{(Value\ Added\ from\ sector\ i)_t} \times \frac{(Loans\ to\ Sector\ i)_t^k}{(Total\ Loans)_t^k}$$

where the first term denotes the nitrogen emission per unit of value-added (kg/euro) from sector i and the second term represents bank k's contribution to the emissions from sector i. Changes in emission intensity can occur through two channels: a reduction in nitrogen emission driven by policies or voluntary actions, and a reallocation of bank loans to sectors with lower nitrogen emission. If a bank maintains the same portfolio, a higher intensity implies a greater susceptibility to transition risks.

75. Both NH3 and NOx emission intensities in the banking sector declined between 2018Q1 and 2021Q4. Figure 17 illustrates this trend of the whole banking sector. Bars (I) and (III) represent the NH3 and NOx emission intensities in 2018Q1 and 2021Q4, respectively. Bars (II) represent the emission intensities in 2021Q4 but with the loan exposure as it was in 2018Q1. This arrangement allows us to decompose the reduction in the intensities into two components: the difference between bars (I) and (II) shows the decrease in nitrogen emission per the unit of value-added, and the difference between bars (II) and (III) represents the impact of the shift in the bank loan portfolio across sectors.

Figure 16. The Netherlands: Nitrogen Concentration and Deposition Intensities

The banking sector's exposure to high nitrogen-emitting sectors amounts to 34 billion euros in domestic loans... *... which account for about 1.5 percent of total assets.*

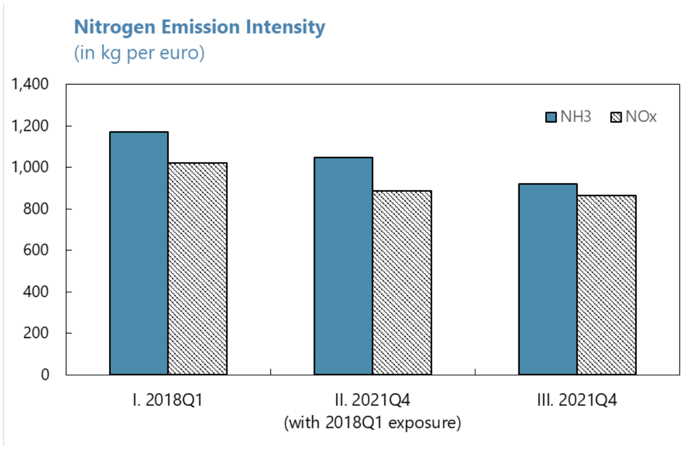


Source: CBS, DNB, and IMF Staff calculation

Source: CBS, DNB, and IMF Staff calculation

Figure 17. The Netherlands: Nitrogen Emission Intensity

The reduction in nitrogen emission intensities is primarily attributable to policy interventions and economic agents' efforts to reduce nitrogen rather than a shift in banks' portfolio toward less nitrogen emitting sectors.



Source: CBS, DNB, and IMF Staff Calculation.

76. **While the nitrogen emission intensity has exhibited a decline, this reduction is primarily attributable to policy interventions and economic agents' efforts to reduce nitrogen, rather than a shift in banks' portfolio toward less nitrogen emitting sectors.** The decrease in NOx emission per the unit of value-added (from (I) to (II)) is seven times larger than the impact of banks shifting their loan portfolio across sectors (from (II) to (III)) for NOx emission, and almost the same for NH3 emission. At the individual bank level, these distinctions are more pronounced for banks with higher intensities.

77. **However, banks' efforts to promote low emissions might be obscured in this metric due to the limitations imposed by the high-level sector classification.** Due to the unavailability of granular data, the only available classification, NACE Level 1 with alphabetical letters, represents the highest level of sector classification. With such a broad classification, there can be substantial

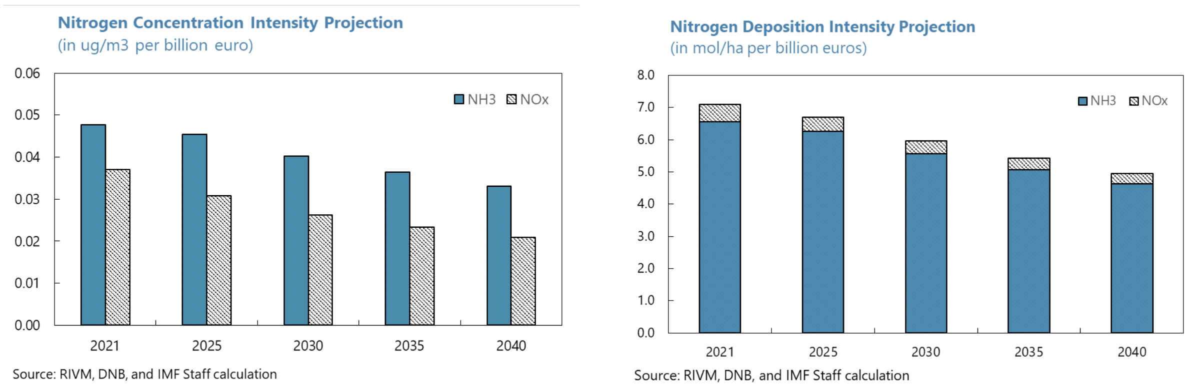
variations in both the level of emissions and the proportion of bank loans within a sector. This constraint underscores the necessity of gathering detailed nitrogen emission data through more granular classifications based on economic activities.

78. In addition to the emission intensity, the intensities of nitrogen concentration and deposition can be also calculated. RIVM (National Institute for Public Health and the Environment) provided maps of large-scale nitrogen concentrations and depositions (GCN and GDN) in the Netherlands for past years and future years (2025, 2030, 2035, 2040).[30] The estimates of the GCN and GDN rely on the air pollutants scenario in KEV (Climate and Energy Outlook (PBL, 2022)), accounting for the expected economic growth, historical emission data from Emission Registry (*Emissieregistratie*), the Operational Priority Substances (OPS) dispersion model, and various other data sources. The forecast, while accounting for Dutch and European environmental policies, does not include crucial updates to nitrogen regulations implemented after May 1, 2022. This omission hinders examining the impact of recent and future policy changes.

79. While the currently implemented policy is expected to reduce both concentration and deposition intensities in the future, the recent RIVM report predicts that by 2030, 43 percent of nitrogen deposition area will still fall below the standard. Figure 18 illustrates the declines of the concentration and deposition intensities for both NH3 and NOx. As forecast data for bank loan portfolios across sectors and the growth of value-added from 2021 to 2040 are unavailable, it is assumed that the loan portfolios remain constant, and the value-added grows at the historical average GDP growth rate. Consequently, the caveat of this analysis is that it does not reflect the expected changes in banks shifting loan allocation toward greener sectors.

Figure 18. The Netherlands: Nitrogen Concentration and Deposition Intensities

The current nitrogen policy is expected to reduce both concentration and deposition intensities in the future.



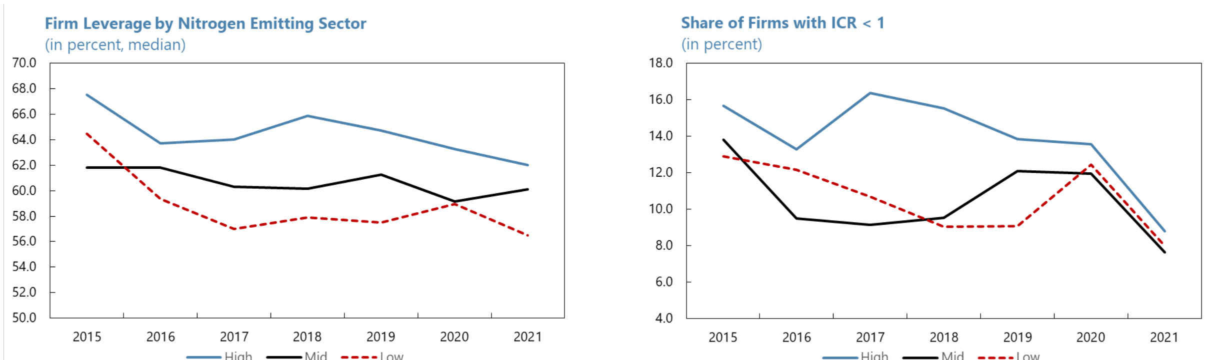
[30] RIVM's GCN and GDN use a sectoral classification system different from NACE. The GCN classification offers a highly detailed categorization based on nitrogen emission activities, whereas the NACE classification is more general categorization for production. Since the value-added data based on GCN classification is unavailable, manual matching of the GCN classification to the NACE classification is performed to calculate the intensities.

80. The banking sector could face transition risks through the credit channel, especially if loans are extended to financially vulnerable firms in high nitrogen-emitting sectors. Orbis firm-level data is used to calculate the leverage (debt-to-asset ratios) and interest rate coverage ratio (ICR). Leverage measures the extent to which a firm depends on external financing, while the ICR assesses a firm's capacity to service its debt obligations using current earnings without resorting to asset sales. The ICR is computed by dividing earnings before interest and taxes (EBIT) by interest payment expenses on liabilities.[31]

81. Firms in the high nitrogen emitting sectors often exhibit higher leverage and financial constraints compared to companies in other sectors, making them more susceptible to the economic impacts of nitrogen emission reduction policies. Figure 19 illustrates that the median values of firm leverage and the proportion of ICR lower than 1 in the high emitting sectors have been consistently higher than those in other sectors. While significant heterogeneity may exist within each group, the results indicate that the policy-induced adverse effects on financially vulnerable firms could pose credit risks to banks. However, the credit risks can be mitigated by some other policies, such as voluntary buyouts.

Figure 19. The Netherlands: Financial Indicator of Firms by Nitrogen Emitting Sector

Firms in the high nitrogen emitting sector appears to be vulnerable to transition risks due to their high leverage and financial constraints.



Source: Orbis, Emissieregistratie, and IMF Staff Calculation

Source: Orbis, Emissieregistratie, and IMF Staff Calculation

C. Recommendations

82. From the perspective of financial stability, understanding the extent of nitrogen exposure in the banking sector would provide an initial indication of the relevance and potential materiality of transition to lower nitrogen emissions. However, due to data constraints and the ongoing process of policy implementation, the analysis could not incorporate firm-level analysis based on spatial nitrogen data and government policy measures into the assessment.

[31] Although earnings before interest, taxes, depreciation, and amortization (EBITDA) offers a more comprehensive measure of profitability, EBIT is employed in this analysis due to the limited availability of EBITDA data. However, it is worth noting that for many firms, EBIT and EBITDA are identical, indicating that the selection of metric is not critical.

83. To assist banks in mitigating potential losses, clarity on the policy transition path towards reducing nitrogen deposition is an essential input to banks' decision-making.[32] In the interim, banks can proactively incorporate environmental disclosure information into their credit risk assessments in anticipation of the potential impact of new policies.

84. Strengthening data sharing and collaboration with climate and environment experts would facilitate the development of a comprehensive transition risk analysis model to assess the impact of a transition to lower nitrogen emissions on the banking sector. For example, DNB can contribute its macro forecasts and scenarios for the projection of nitrogen deposition and concentration, supplementing the current PBL's scenario. Additionally, RIVM can provide detailed geographical nitrogen data, allowing DNB to align them with bank-firm loan-level data, if accessible, for more granular stress tests.

[32] Prodani et al. (2023) conduct a transition risk analysis under the scenario of the inadequate agriculture measures with the consideration of weakened construction activities to meet the nitrogen reduction targets. Despite non-negligible economic damages due to the large share of construction in Dutch GDP, the analysis shows limited impacts on bank capital.

Appendix I. Climate Risk Analysis by DNB

1. De Nederlandsche Bank (DNB) has been one of the first central banks to perform climate stress testing. In 2018 DNB developed a top-down framework to assess transition risks on the Dutch financial system (Vermeulen et al., 2018). The results of the exercise revealed that financial institutions would face sizeable, but manageable, losses in the event of a disruptive energy transition, while timely implementation of climate policies would help to avoid unnecessary losses.

2. DNB developed four energy-transition scenarios, with a horizon of five years, to encompass the impact of government policy, technological advances as well as a decline in consumer confidence if the transition was postponed and technological breakthroughs were absent. The analysis was performed at a sectoral level, covering the majority of bond and equity holdings of Dutch banks, insurers and pension funds, as well as corporate loans (excluding commercial real estate) for the largest Dutch banks.

3. More recently, DNB has conducted a research study on physical risk reverse stress test focusing on flood risk in the banking sector (Caloia and Jansen 2021). The results show that the banking sector is sufficiently capitalized to withstand floods in areas where there is little real estate. However, severe floods in more densely-populated areas would cause significant capital impacts on banks.

4. First, they estimate damages from floods to real estate (both residential and commercial) using flood maps and geocoded data (latitude and longitude) of banks' real-estate exposures under six different scenarios (i.e. flood types and levels of water stress, focusing on floods not covered by insurers). However, the scenario has only a one-year horizon, hence, does not account for climate change. Further, the same level of flood depth is applied to every location, not accounting for differences in flood risks in different locations. Second, they calibrate macro-financial scenarios accounting for flood damages. Third, they use their top-down stress test framework to analyze the financial implications of the various scenarios for banks (credit risk, market risk, and profitability).

5. A special focus has been devoted to climate-related risks of financial institutions through their exposures to real estate (which represents more than a quarter than their combined assets). The 2021 Financial Stability Report includes an in-depth analysis on both transition risks (from transitioning to a climate-neutral built environment) and physical risks (from floods) for the real estate sector, and the resulting impact for banks, insurers and pension funds. It should also be noted that the AFM has recently released publications regarding the impact of climate risks on the pricing and valuation of homes (AFM, 2024).[1] When this impact becomes transparent, individual homeowners and buyers can act on that and valuators can incorporate these risks into their valuations. This contributes to financial stability.

[1] AFM: https://www.afm.nl/~/profmedia/files/afm/trendzicht-2024/klimaatrisicos--woningmarkt.pdf

6. On transition risk the authorities shared the DNB Occasional Studies Vol. 19-4 "Real estate and climate transition risk". The study focuses on real estate exposures for banks, insurers and pension funds both domestically and abroad.

7. For domestic exposures they quantify the retrofitting costs of the underlying properties that are exposed to transition risk (exposures at risk), i.e. the investment needed to meet energy efficiency or carbon emissions standards accounting for various building characteristics between now and 2030 under two scenarios. In the first scenario, the minimum standard of energy efficiency for all houses is label C by 2030 and label B for other buildings (based on the Dutch Climate Agreement). In the second more ambitious scenario all buildings need label B by 2030. The also make different assumptions about municipalities heating/energy systems/networks (green gas vs heat pumps). They then look at the ability for owners to cover the cost (the impact on LTV, LTI, loan amount, collateral value) and then PD and LGD of mortgages and CRE loans.

8. For international exposures, the study analyzes risks for Dutch pension funds and insurers (not banks) under two scenarios (2 and 1.5 degree) up to 2030 and 2050 using different decarbonization pathways (based on CRREM data). They compute the emission reduction requirements for residential, office, retail and industrial properties. Exposures are considered at risk when their current energy use intensity is higher than the level implied by the decarbonization pathway in the country they are located in. They cover 11 percent of tot exposures in 30 countries. Data availability is limited for countries outside Europe though, particularly in the US. Transition risk is then quantified by multiplying properties' excess carbon (exceeding the reduction requirement) by the country's carbon price in the scenario (from the NGFS).

Appendix II. Credit Risk Module[1]

1. The credit risk module of the bank solvency stress test projects credit impairment of banks' loan portfolios under the baseline and adverse scenarios. It is built on the future trajectories of probability of default (PD), loss given default (LGD), and provisioning rules prescribed by International Financial Reporting Standard 9 (IFRS 9). The authorities provided the historical PD and LGD data of the banking system by portfolio and country of exposure. Staff did not consider the credit losses of securities at amortized cost.

2. The team estimated the historical relationship between PDs and macrofinancial variables by portfolio and country of exposure, using a panel regression model with system-wide PDs by portfolio and country of exposure. It then projected the future PD paths conditional on the macroeconomic evolution. Portfolios in this exercise include mortgage, other retail, qualifying revolving, corporate, government, and financial institution. Countries of exposure include the Netherlands, Germany, Belgium, UK, United States, Australia, and the rest of the world.

3. First, for mortgage, other retail, qualifying revolving, and corporate portfolios, a Panel Autoregressive Distributed Lag (ARDL) model in equation (1) is deployed. The logit-transformed probability of default is explained by its 1-period lag, a group of exogenous variables and their lags z_{t-s} (Equation (1)). z_t include the standard explanatory variables, e.g., economic growth, interest rate, housing price growth, and real wage growth underpinning the scenarios. A fixed effect α_i captures the unobserved country-specific characteristics. The selection of explanatory variables may differ across portfolios depending on statistical performance and economic intuition.

$$ln\left(\frac{PD_{i,t}}{1-PD_{i,t}}\right) = \alpha_i + \lambda \cdot ln\left(\frac{PD_{i,t-1}}{1-PD_{i,t-1}}\right) + \sum_{s=0}^{P} \beta_{i,s}\, z_{t-s} + u_{i,t} \qquad (1)$$

4. The econometric analyses reveal that economic growth is an important factor to explain the PD variation. Housing price growth affects mortgage portfolios and to some extent the retail portfolios through wealth effect. Interest rate rises are only felt with a lag, more so for mortgage loans which tend to be long-term and with fixed rates in the Netherlands. Wage growth is a positive for sustaining retail borrowers' credit quality, but CPI inflation erodes their purchasing power. CPI inflation outpaces wage growth in the adverse scenario, thus eroding household's debt service capability. Corporate portfolio benefits from a positive export growth. Credit spread is a significant predictor for corporate creditworthiness.

5. The PDs of government and financial institution are computed by equation (2). The choice of this structural model is due to the low occurrence of default events and significant impact by idiosyncratic factors in the two sectors.

[1] This appendix is written based on the description of bank solvency stress test model in the FSAP technical note on systemic risk analysis.

$$PD_{i,t} = \left(\frac{Credit\ spread_{i,t}}{1 - Recovery\ Rate}\right) \qquad (2)$$

6. The PD projections from the "satellite models" above are by portfolio and economy. They are transformed to bank-specific level by assuming constant differential of riskiness between the system aggregate and a bank holding the same portfolio. Specifically, by computing the distance-to-default of both aggregate (from "satellite models") and bank-specific PDs (from credit risk module, STE) as of 2022. This is through taking the inverse normal of the two values. The difference of the two was taken and assumed to stay unchanged throughout the stress testing horizon. The bank-level can be implied accordingly. A suite of "satellite models" above projected 216 future PD paths for six banks, six portfolios, and six economies.

7. The team estimated LGDs using two structural models. For the secured portfolio, it derived the LGD trajectories with bank-specific LTV projections and several other cost factors (Gross et al., 2020). For the unsecured loans, the LGDs were modelled as a function of future PDs (Frye and Jacobs, 2012; Frye, 2013).

8. The IFRS 9 accounting rule requires banks to provision for expected credit losses by loan stage. The team first estimated the bank-specific transition matrices by sector, i.e., household, corporate, government and institution, using historical information on loan movements across stages supplemented by statistics directly provided by the authorities. It then adjusted the transition probabilities with scenario-conditional PDs from the "satellite models" ("beta-linking", Gross et al., 2020) and inferred the outstanding loan amount by stage over the stress-testing horizon. It finally computed the 12-month provision for stage 1 loans, and lifelong provision for stage 2 and 3 loans. Write-off rate is assumed to be zero.

Annex I. Capital and House Price Shocks under Flood Scenarios

Annex I. Table 1. The Netherlands: Region I - Capital and House Price Shocks
(in percent)

Capital Shocks	Scenario Name	Climate Condition	Failure Probability	Return Period 10	100	1000	10000
Unembanked Area	A1	Current	-	0.001	0.002	0.006	0.020
	A2	2050 (W+)	-	0.002	0.004	0.013	-
	A3	2100 (W+)	-	0.002	0.006	0.020	-
Embanked Area	B1	Current	Current	-	-	0.025	0.053
	B2	2050 (W+)	2050	-	-	0.032	0.047
	B3	Current	2050	-	-	0.028	0.065
House Price Shocks	**Scenario Name**	**Climate Condition**	**Failure Probability**	**Return Period 10**	**100**	**1000**	**10000**
Unembanked Area	A1	Current	-	1.46	2.84	2.69	3.55
	A2	2050 (W+)	-	2.15	2.77	3.12	-
	A3	2100 (W+)	-	2.84	2.69	3.55	-
Embanked Area	B1	Current	Current	-	-	17.4	13.8
	B2	2050 (W+)	2050	-	-	8.9	6.7
	B3	Current	2050	-	-	17.0	15.8

Note: The return period of EDO scenario is larger than 10000 years.
Source: HKV, LIWO, IMF Staff Calculation.

Annex I. Table 2. The Netherlands: Region II - Capital and House Price Shocks
(in percent)

Capital Shocks	Scenario Name	Climate Condition	Failure Probability	Return Period 10	100	1000	10000
Unembanked Area	A1	Current	-	0.001	0.003	0.006	0.012
	A2	2050 (W+)	-	0.002	0.004	0.009	-
	A3	2100 (W+)	-	0.003	0.006	0.012	-
Embanked Area	B1	Current	Current	-	-	0.032	0.200
	B2	2050 (W+)	2050	-	-	0.024	0.062
	B3	Current	2050	-	-	0.035	0.241
House Price Shocks	**Scenario Name**	**Climate Condition**	**Failure Probability**	**Return Period 10**	**100**	**1000**	**10000**
Unembanked Area	A1	Current	-	12.00	10.96	7.49	8.48
	A2	2050 (W+)	-	11.48	9.22	7.99	-
	A3	2100 (W+)	-	10.96	7.49	8.48	-
Embanked Area	B1	Current	Current	-	-	8.9	9.6
	B2	2050 (W+)	2050	-	-	10.3	10.5
	B3	Current	2050	-	-	9.0	9.5

Note: The return period of EDO scenario is larger than 10000 years.
Source: HKV, LIWO, IMF Staff Calculation.

Annex I. Table 3. The Netherlands: Region III - Capital and House Price Shocks
(in percent)

Capital Shocks	Scenario Name	Climate Condition	Failure Probability	Return Period			
				10	100	1000	10000
Unembanked Area	A1	Current	-	0.009	0.012	0.025	0.024
	A2	2050 (W+)	-	0.011	0.019	0.030	0.040
	A3	2100 (W+)	-	0.012	0.025	0.032	0.043
Embanked Area	B1	Current	Current	-	0.029	0.150	0.912
	B2	2050 (W+)	2050	-	0.000	0.200	0.529
	B3	Current	2050	-	0.124	0.150	0.912

House Price Shocks	Scenario Name	Climate Condition	Failure Probability	Return Period			
				10	100	1000	10000
Unembanked Area	A1	Current	-	24.71	21.97	17.94	7.43
	A2	2050 (W+)	-	23.69	16.97	16.20	16.56
	A3	2100 (W+)	-	21.97	17.94	7.43	21.38
Embanked Area	B1	Current	Current	-	7.9	9.7	7.9
	B2	2050 (W+)	2050	-	16.6	14.4	13.6
	B3	Current	2050	-	10.5	11.1	7.9

Note: The return period of EDO scenario is larger than 10000 years.
Source: HKV, LIWO, IMF Staff Calculation.

Annex I. Table 4. The Netherlands: Region IV - Capital and House Price Shocks
(in percent)

Capital Shocks	Scenario Name	Climate Condition	Failure Probability	Return Period			
				10	100	1000	10000
Unembanked Area	A1	Current	-	0.005	0.008	0.020	0.044
	A2	2050 (W+)	-	0.007	0.014	0.032	
	A3	2100 (W+)	-	0.008	0.020	0.044	
Embanked Area	B1	Current	Current	-	0.003	0.353	0.353
	B2	2050 (W+)	2050	-	0.001	0.001	0.001
	B3	Current	2050	-	0.002	0.353	0.382

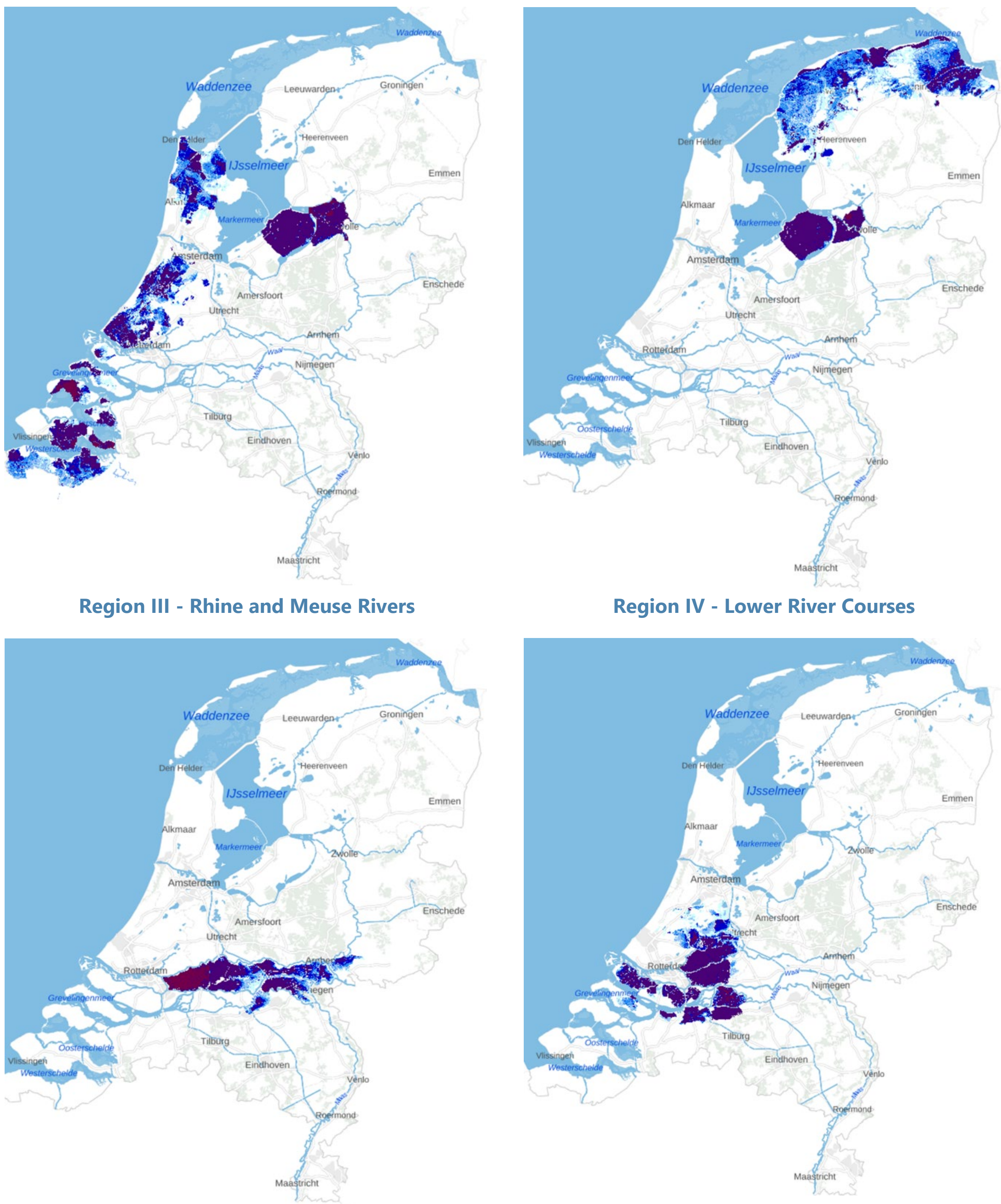
House Price Shocks	Scenario Name	Climate Condition	Failure Probability	Return Period			
				10	100	1000	10000
Unembanked Area	A1	Current	-	0.91	0.57	1.26	1.70
	A2	2050 (W+)	-	0.74	0.92	1.48	-
	A3	2100 (W+)	-	0.57	1.26	1.70	-
Embanked Area	B1	Current	Current	-	2.7	15.7	15.6
	B2	2050 (W+)	2050	-	4.0	4.1	5.1
	B3	Current	2050	-	3.7	15.6	15.5

Note: The return period of EDO scenario is larger than 10000 years.
Source: HKV, LIWO, IMF Staff Calculation.

Annex II. Flood Map of the Extreme Scenarios

Annex II. Figure 1. The Netherlands: Flood Map of EDO Scenarios

Region I - Southwest and Central Coast **Region II - Wadden Sea Coast**



Source: LIWO.

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