



December 2023

Bermuda Monetary Authority

Catastrophe Risk Modelling

2022 Report



Foreword

Bermuda is predominantly an insurance-based international financial centre, specialising in catastrophe reinsurance alongside a broad range of other insurance risks and is host to one of the largest reinsurance markets in the world.

With a relatively high concentration of catastrophe risk underwritten in Bermuda, a broad understanding of catastrophe modelling practices is central to the Bermuda Monetary Authority's (Authority or BMA) supervisory framework. As insurers rely significantly upon internally built and external vendor models to assess catastrophe exposures, this information is also important to Bermuda insurers, other stakeholders and insurance markets around the globe.

Realising Bermuda's significant role as a leader in the regulation of the catastrophe market, the Authority produces this report annually to provide a high-level overview of the catastrophe modelling practice in Bermuda to continue to re-emphasise our commitment to high standards of transparency.

Ricardo Garcia
Managing Director

Modelling Practices Report

This is the fourth stand-alone annual *Catastrophe Risk Modelling Report* published by the Authority. The content of this report is the result of analyses carried out by the BMA staff and includes data from both insurers and (re)insurers.

About the Authority

The Authority was established by statute in 1969. Its role has evolved over the years to meet the changing needs in Bermuda's financial services sector. Today, it supervises, regulates and inspects financial institutions operating in the jurisdiction. It also issues Bermuda's national currency, manages exchange control transactions, assists other authorities with detecting and preventing financial crime and advises the Government on banking and other financial and monetary matters.

The Authority develops risk-based financial regulations that apply to the supervision of Bermuda's banks, trust companies, investment businesses, investment funds, fund administrators, money service businesses, corporate service providers, insurance companies, digital asset issuances and digital asset businesses. It also regulates the Bermuda Stock Exchange and the Bermuda Credit Union.

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ACRONYMS

AAL	Average Annual Loss
AIR	AIR Worldwide
AMO	Atlantic Multi-decadal Oscillation
BMA/Authority	Bermuda Monetary Authority
BSCR	Bermuda Solvency Capital Requirement
Cat	Catastrophe
Cat Return	Catastrophe Risk Return and Schedule of Risk Management
CSR	Capital and Solvency Return
EQECAT	Catastrophe Risk Management (CoreLogic)
EP	Exceedance Probability
IFC	International Financial Centre
Mph	Miles per hour
PML	Probable Maximum Loss
RMS	Risk Management Solutions
RDS	Realistic Disaster Scenarios
SPI	Special Purpose Insurer
SST	Sea Surface Temperatures
TVaR	Tail Value at Risk

I. EXECUTIVE SUMMARY

This report highlights the Catastrophe (Cat) modelling practices of Bermuda (re)insurers. (Re)insurers rely substantially on models to project losses and assist them in risk and solvency calculations. In its prudential supervisory work, the Authority tracks trends in the usage of models to form views and supervisory responses in managing Cat risk.

In 2022, Bermuda legal entities' average loading factor in the accumulation process increased to 10.57% compared to 9.3% in 2021. The increase in the loading factor within the last two years can be attributed to an increase in social inflation and the impact of climate change that might not yet be fully reflected in the models. The average loading factor for groups stood at 9.10% in 2022, compared to 8.8% in 2021. In 2022, more legal entities and groups had assumed the Atlantic Multi-decadal Oscillation (AMO) near-term view of exposure compared to 2021.

AIR and RMS are the most frequently used modelling software tools (together or stand-alone), with AIR being the leading model for legal entities and groups. In-house modelling¹ was utilised by 37.5% of legal entities and 28.6% of groups in 2022. Additionally, 16.7% of legal entities and 21.1% of groups reported using more than one model in their accumulations. Legal entities mostly use their models on a quarterly basis, with 54.2% of insurers doing so, while 38.1% of groups accumulate on a quarterly basis.

¹ An in-house model is a proprietary model built by an insurer.

II. INTRODUCTION

Bermuda's insurance sector is regulated and supervised by the Authority. As part of its regulatory and supervisory measures, the Authority requires all Class 3B and Class 4 insurers to submit a Capital and Solvency Return, which includes a Catastrophe Risk Return and Schedule of Risk Management (together 'Cat Return'), as part of their annual statutory filing, detailing the insurers' Cat risk management practices.

The global insurance market, particularly, the Bermuda market, significantly relies upon vendor models to assess Cat exposures. If the vendor models underestimate potential losses arising from events, the entire industry may have their capital levels impacted. Therefore, a comprehensive understanding of the modelling practices in Bermuda is a key aspect of the Authority's supervisory framework.

This report contributes to the understanding of Bermuda as an insurance-based International Financial Centre (IFC) and a leader in regulating the Cat (re)insurance market. This report ultimately demonstrates the contribution of Bermuda's natural Cat risk mitigation to the global capacity for risk-taking while also emphasising the Authority's commitment to high standards of transparency.

III. METHODOLOGY

This report was produced using aggregated and non-aggregated data from the Bermuda Capital and Solvency Return (CSR) filings of Class 3B and Class 4 legal entities and insurance groups for the period ending 31 December 2022². Specifically, the following schedules from the CSR were used as data sources:

- Schedule X(e) – Cat Risk Return: Accumulations Overview
- Schedule X(f) – Cat Risk Return: Data Analysis

The exclusion of other insurer classes, such as Special Purpose Insurers (SPI)³, limits the conclusions that can be made from the results of this survey. Therefore, the results reflect one industry segment and not the entire exposure of the Bermuda insurance market⁴. This report also does not consider mortality catastrophic risk as the long-term (life) insurers are not included in the analysis.

The analysis of the accumulation process is based on responses from insurers in 2022 and previous years' CSR filings. The accumulation process provides insights into the relationship between the modelling practices of insurers and the actual management of those risks from an operational point of view.

The analyses in this report were based only on original CSR data input. Although other documents are separately required for the CSR filing, no reference was made to them for the purposes of this report. The

² Not all insurers have 31 December year ends; therefore, the data used in the report may not fully reconcile with the BMA Annual Report, which will include fall-end underwriting data.

³ SPIs are significant contributors to Cat risks underwritten in Bermuda with these details included in the BMA's annually published Alternative Capital Report.

⁴ The Bermuda insurance market includes the Bermuda (re)insurance market.

Authority's supervisory team reviews these additional documents at the micro level in the context of individual insurers. However, the analyses for this report did not reflect the subtle nuances provided by an insurer's full return that might otherwise impact these results.

Information Box

Class 3B and Class 4 insurers are the largest property and casualty commercial insurers in Bermuda’s market, and are required to maintain statutory capital and surplus of at least 99% Tail Value at Risk (TVaR) over a one-year time horizon.

Aggregate Statistics for Classes 3B and 4, 2022 (In US\$ billions)

Net written premiums	66.1
Net earned premiums	62.2
Net income	3.8
Total claims	39.5
Total assets	283.4

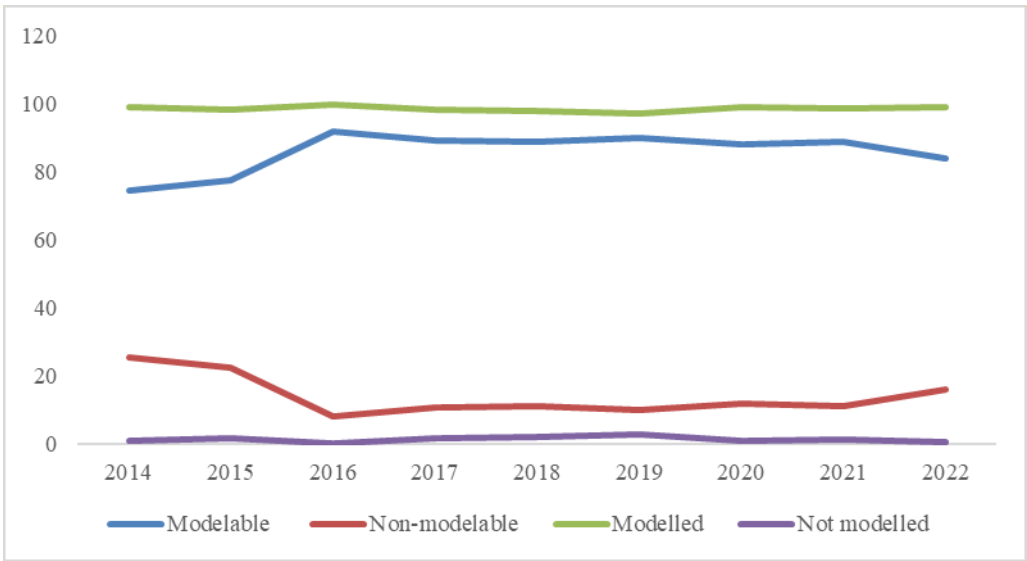
Source: BMA

IV. PROBABLE MAXIMUM LOSS AND ACCUMULATION PROCESS

The accumulation process is an important component of the modelling process and is integral to the insurer's risk management framework. In Bermuda, the accumulation of catastrophe risks is a multifaceted risk management process. A portion of this accumulation process is the modelling practices of insurers. As part of the CSR filing, the Authority annually collects information about the accumulation process from the prudential filings of companies.

The 2022 CSR filing showed that 83.83% of the Cat risk exposure underwritten in Bermuda is modelable⁵ using vendor Cat models and that 99.15% of Cat risks were modelled⁶. While the percentage of modelable exposure has dropped compared to 2021, the percentage of modelled exposure has slightly increased⁷.

Figure 1. Modelable and Modelled Exposure (In per cent)



Source: BMA staff calculations

⁵ Modelable exposure refers to the exposure that can be simulated through a vendor Cat model; non-modelable exposure refers to exposure that cannot be simulated through a vendor Cat model or when there are no Cat models that assess the risk of the region peril under consideration; modelled exposure refers to risks that the insurer modelled. When exposures are not modelable through the use of vendor Cat models (i.e., non-modelable exposure), insurers often use models developed in-house to evaluate risk. As such, very few exposures are ‘not modelled’.

⁶ Reasons for non-modelled risk may include data limitations that prevent the exposure from being run through a vendor or in-house Cat model. This may be due to: 1) lack of resolution of the data or lack of completeness of the data, which renders the data insufficient to produce credible modelled results; 2) model deficiency, where the model is deemed to be inadequate to produce credible results; and/or 3) there is no accessible model to assess the peril under consideration.

⁷ The 2021 CSR filing showed that 88.72% of the Cat risk exposure underwritten in Bermuda is modelable using vendor Cat models and that 99.15% of Cat risks were modelled.

A. PROBABLE MAXIMUM LOSSES AND ACCUMULATION PROCESS - LEGAL ENTITIES

This section presents aggregated results from the statutory filings of insurers for 2022. Bermuda Class 3B and Class 4 insurers are required to file the Catastrophe Risk Schedule, a questionnaire addressing modelling practices. The Catastrophe Risk Schedule also includes quantitative information about catastrophe exposures. With respect to quantitative metrics, Bermuda insurers report metrics on the Average Annual Loss (AAL), Probable Maximum Loss (PML) and factor loadings. The latest data is displayed in the following figures and tables. The PML is defined as the 99% TVaR on an aggregate basis.

Figure 2. Gross and Net Average Industry PML (In US\$ millions)

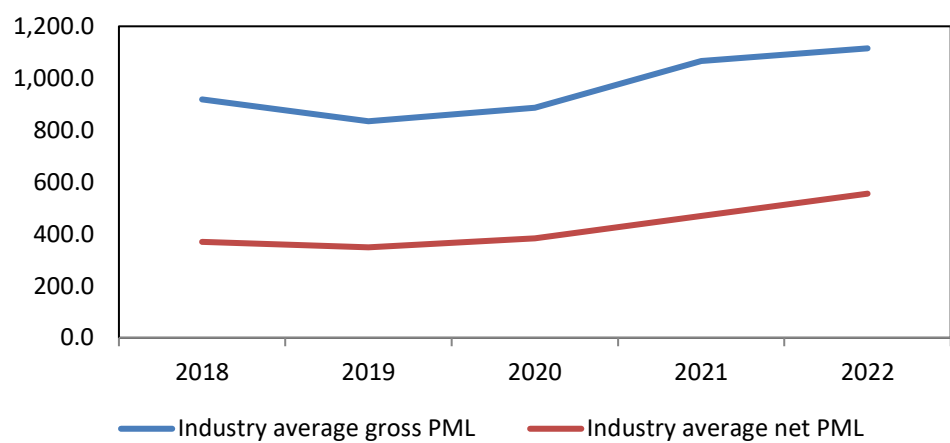
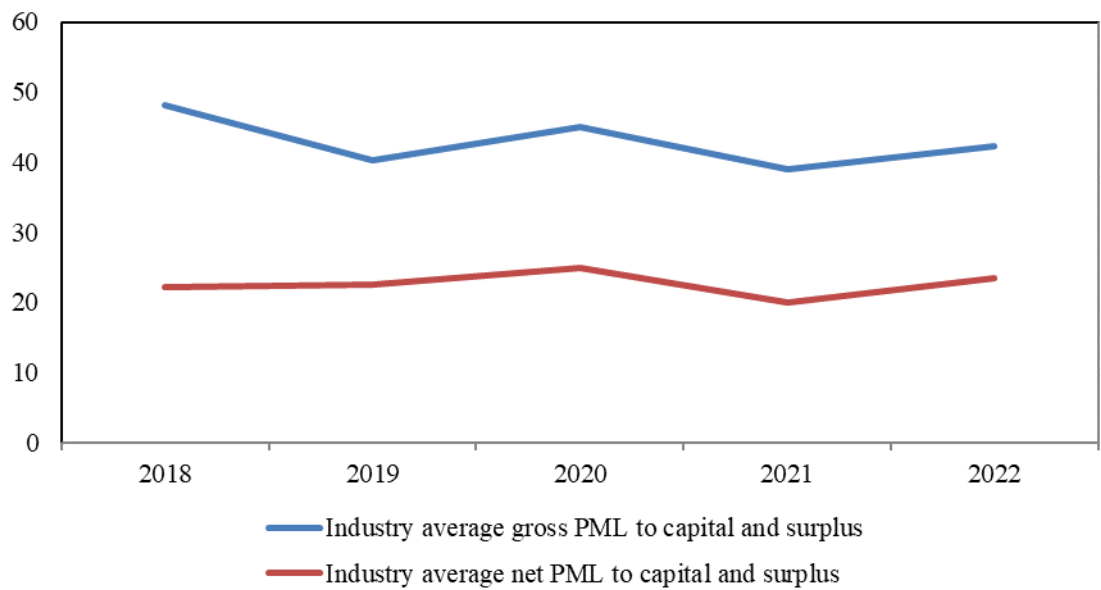


Table 1: PML (In US\$ millions)

	2022	2021	2020	2019	2018
Industry average gross PML	1,115.1	1,066.4	885.8	834.2	918.7
Industry average net PML	555.2	469.6	382.7	348.5	369.6

Source: BMA

Figure 3. Gross and Net Industry PML to Capital and Surplus (In per cent)



Source: BMA staff calculations

Table 2: PML Ratios (In per cent)

	2022	2021	2020	2019	2018
Industry average gross PML to capital and surplus	42.3	38.9	44.9	40.2	49.9
Industry average net PML to capital and surplus	23.4	20.0	24.9	22.5	22.8

Source: BMA. The sample removes certain outliers that distort the ratios.

Table 1 represents the average PML for legal entities in dollar amounts. The average PML for 2022 experienced an increase on both a gross and net basis compared to 2021.

Table 2 presents ratios of the gross and net PML to capital and surplus. This ratio expresses whether the available capital and surplus can withstand a loss equal to 99% TVaR. On a gross basis, in 2022, a 99% TVaR aggregate loss was expected to consume 42.3% of available capital and surplus. On a net basis, this ratio also went up compared to last year, at 23.4%.

Table 3 presents the loading factors used as add-ons to the output of catastrophe modelling. These factors compensate for model error and conservatism in the modelling process and they are applied to the PML. For example, if the Cat model yields a PML of US\$100, a 5% factor would raise the PML to US\$105.

Table 3: Loading Factors⁸ (In per cent)

	2022	2021	2020	2019	2018
Average loading factor	10.6	9.3	6.6	6.1	8.3

Source: BMA

In 2022, the average loading factor reached 10.6%, representing an increase compared to 2021. Over time, vendor models strive to become more accurate while also becoming more conservative, thus reducing the need for higher safety buffers. However, the 2022 average loading factor increase reflects the risk of pricing challenges derived from the high inflation (real and social) environment and the increase in severity and frequency of Cat events, among other related climate change developments that might not yet be reflected in the models.

The loading factor is estimated using variations of either an analytical portfolio approach, where insurers analyse the model's total output and back-test the results according to the total loss experience, or a per-risk view that blends the experience of single lines of business into the total portfolio. PML. The responses can be found in Table 4.

Table 4: Loading Factor Estimation Methods (In per cent of respondents)

	2022	2021	2020	2019	2018
Determined analytically	40.5	41.0	35.7	43.6	42.1
Estimated	59.5	59.0	64.3	56.4	57.9

Source: BMA

In 2022, 59.5% of insurers estimated the loading factor, while 40.5% determined it analytically through modelling.

Another interesting modelling practice is the usage of AMO. AMO refers to the alteration of Sea Surface Temperatures (SST) in the Northern Atlantic Ocean from cool to warm phases, which lasts for several years. Since the mid-1990s, a warm phase has existed. A correlation has been observed between warm SSTs, more

⁸ The loadings reflect the cumulative loading regardless of the level applied (i.e., within the accumulation process or post the accumulation process/applied to the PML). The same applies for legal entities and groups.

frequent severe hurricanes and other destructive weather phenomena B based on near-term or long-term views, Bermuda insurers responded to whether they consider loadings for this risk factor.

Table 5. AMO Factor Consideration (In percent of respondents)

	2022	2021	2020	2019	2018
Near-term frequency	73.5	68.9	64.6	61.7	65.9
Long-term frequency	26.5	31.1	35.4	38.3	34.1

Source: BMA

In 2022, 73.5% of insurers utilised the near-term AMO factor to model Atlantic hurricane exposures, while 26.5% utilised the long-term factor. The AMO factor relates to trends in hurricane frequencies taken into account in modelling Atlantic hurricane exposures and the financial losses that stem from hurricane activity.

The questionnaire inquired about the vendors used to determine whether insurers base their modelling opinions on one or multiple models. This question allows the identification of the more prevalent Cat model vendors in the market. In addition, the questionnaire also asks how frequently insurers perform portfolio modelling (or, as the BMA refers to it, 'accumulations') and whether insurers develop their own models separately from vendor models. The following table summarises the responses.

Table 6: Vendor Model Usage and Licensing (In per cent of respondents)

Model Usage	2022	2021	2020	2019	2018
AIR only	46.7	37.5	37.1	20.9	24.4
EQECAT only	0.0	0.0	0.0	0.0	0.0
RMS only	36.7	28.1	34.3	32.6	31.7
AIR and RMS	16.7	34.4	28.6	46.5	43.9
AIR and EQECAT	0.0	0.0	0.0	0.0	0.0
EQECAT and RMS	0.0	0.0	0.0	0.0	0.0
AIR, EQECAT and RMS	0.0	0.0	0.0	0.0	0.0
Model Licensing	2022	2021	2020	2019	2018
AIR only	37.5	29.5	21.7	14.9	20.0
EQECAT only	0.0	0.0	0.0	0.0	0.0
RMS only	25.0	20.5	21.7	21.3	24.4
AIR and RMS	35.4	50.0	54.3	61.7	55.6
AIR and EQECAT	0.0	0.0	0.0	0.0	0.0
EQECAT and RMS	2.1	0.0	2.2	2.1	0.0
AIR, EQECAT and RMS	0.0	0.0	0.0	0.0	0.0

Source: BMA

AIR is the most commonly used stand-alone model. Moreover, the use of three models in tandem is the exception, with EQECAT receiving no share of use within the last five years for the category of insurers in this report. Additionally, the findings show that no single insurer has used all three models within the last five years to perform their accumulations.

Table 7: Model Frequency Usage (In per cent of respondents)

	2022	2021	2020	2019	2018
Ad-hoc	0.0	0.0	0.0	0.0	2.2
Annual	4.2	2.3	4.3	4.2	2.2
Semi-annual	2.1	0.0	4.3	6.3	2.2
Quarterly	54.2	56.8	41.3	43.8	44.4
Monthly	22.9	20.5	23.9	22.9	24.4
Weekly	0.0	0.0	0.0	0.0	0.0
Daily	10.4	13.6	17.4	14.6	15.6
Real-time	6.3	6.8	8.7	8.3	8.9

Source: BMA

Insurers use and update Cat modelling in fixed periods, usually quarterly and monthly. Each quarter, renewals or supervisory reporting are the most common reasons to run the catastrophe models, with 54.2% of insurers reporting quarterly use in 2022, down from 56.8% in 2021. In addition, real-time use dropped to 6.3% of insurers in 2022, compared to 6.8% in 2021.

Table 8: Model Frequency and Business Unit Differences
(In per cent of respondents)

	2022	2021	2020	2019	2018
Yes	32.6	39.5	36.6	40.0	37.8
No	67.4	60.5	63.4	60.0	62.2

Source: BMA

Insurers were asked whether different business units use Cat models at different frequencies. In 2022, 67.4% of respondents said they do not perform accumulations at different frequencies, compared to 60.5% in 2021.

Table 9: Internal Model Usage (In per cent of respondents)

	2022	2021	2020	2019	2018
Yes	37.5	36.4	41.3	39.6	33.3
No	62.5	63.6	58.7	60.4	66.7

Source: BMA

In 2022, 37.5% of insurers developed their own stochastic model. Insurers with specialised lines of business outside the cover of traditional vendors are more likely to develop such in-house models to capture their unique risks.

The BMA also asked insurers how their Cat risk modelling reflects their reinsurance and retrocessional purchases. The responses are shown in Table 10.

Table 10: External Reinsurance Model Usage (In per cent of respondents)

	2022	2021	2020	2019	2018
The company has minimal Cat exposure protection; therefore, gross is effectively net	4.2	2.3	6.8	6.4	6.7
The accumulations are calculated on a gross basis with reinsurance protections calculated approximately outside of the system	2.1	0.0	2.3	4.3	4.4
The accumulations are calculated on a gross basis, with reinsurance protections calculated explicitly outside of the system	4.2	4.7	0.0	2.1	2.2
The accumulations are calculated on a gross basis with the effect of reinsurance protections calculated explicitly for some types of protection within the system	50.0	48.8	45.5	34.0	40.0
The accumulations are calculated on a gross basis with the effect of reinsurance protections calculated explicitly for each type of protection within the system	39.6	44.2	45.5	53.2	46.7

Source: BMA

The number of insurers purchasing little or no external Cat reinsurance increased to 4.2% of respondents in 2022 compared to 2.3% in 2021. The vast majority of insurers model Cat risk by considering external reinsurance explicitly, either for some treaties or separately. In 2022, 93.7% of respondents explicitly calculated either some external reinsurance or all reinsurance treaties in their Cat modelling.

B. PROBABLE MAXIMUM LOSSES AND ACCUMULATION PROCESS - INSURANCE GROUPS

The same data collected for legal entities is also collected from insurance groups.

Figure 4. Gross and Net Average Industry PML (In US\$ millions)

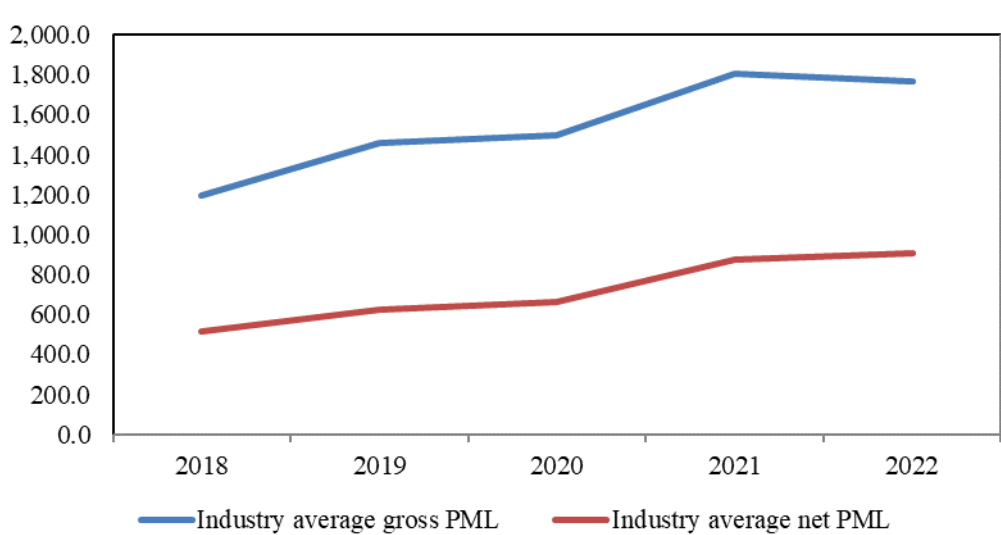


Table 11: PML (In US\$ millions)

	2022	2021	2020	2019	2018
Industry average gross PML	1,769.9	1,805.1	1,497.6	1,461.7	1,193.9
Industry average net PML	906.8	871.9	665.1	626.6	513.5

Source: BMA

In 2022, the industry average gross exposure slightly decreased compared to 2021, but the net exposure increased, showing a reduction in reliance on reinsurance.

Figure 5. Gross and Net Industry PML to Capital and Surplus (In per cent)

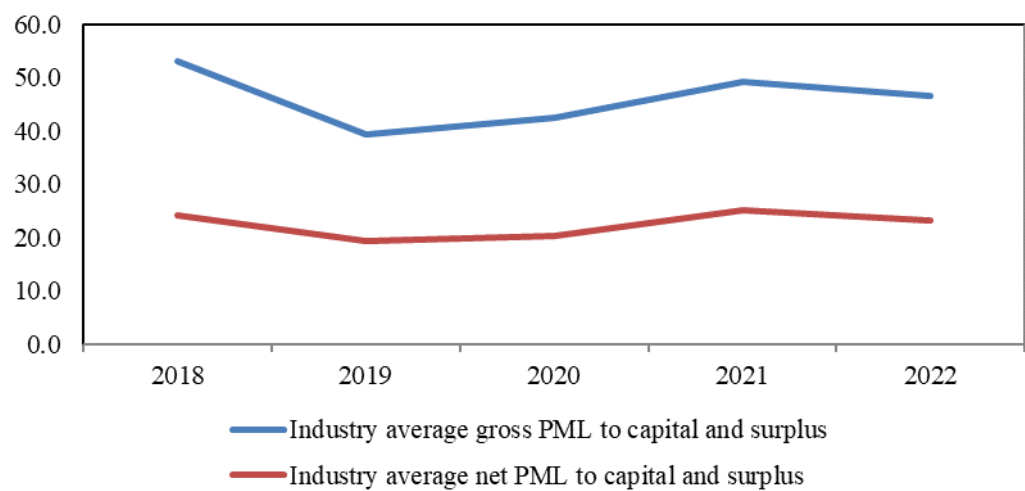


Table 12: PML Ratios (In percent)

	2022	2021	2020	2019	2018
Industry average gross PML to capital and surplus	46.5	49.2	42.4	39.3	53.0
Industry average net PML to capital and surplus	23.3	25.2	20.3	19.3	24.2

Source: BMA

As in the case of legal entities, the BMA reports the average loading factors for groups in Table 13.

Table 13: Loading Factors (In per cent)

	2022	2021	2020	2019	2018
Average loading factor	9.1	8.8	4.6	5.5	8.4

Source: BMA

The loading factor for groups has increased for 2022 compared to 2021. In 2021, the average loading factor was 8.8%, compared to 9.1% in 2022. The increase in the average loading factor in the last two years can be attributed to social inflation and the impact of climate change that are not yet reflected in the models.

Table 14 displays how groups establish loading factors, either estimated or analytically determined. In 2022, 57.9% of groups established their factors non-analytically by relying on expert judgement.

Table 14: Loading Factor Estimation Methods (In per cent of respondents)

	2022	2021	2020	2019	2018
Determined analytically	42.1	41.2	35.3	37.5	33.3
Estimated	57.9	58.8	64.7	62.5	66.7

Source: BMA

In 2022, 71.4% of groups used near-term frequency of the AMO compared to 68.4% in 2021. Model results are converging based on either the near-term or long-term frequency of the AMO factor.

Table 15: AMO Factor Consideration (In per cent of respondents)

	2022	2021	2020	2019	2018
Near-term frequency	71.4	68.4	55.6	47.4	53.3
Long-term frequency	28.6	31.6	44.4	52.6	46.7

Source: BMA

Table 16 displays the model vendor licensing and usage statistics for groups.

Table 16: Vendor Model Usage (In per cent of respondents)

Model Usage	2022	2021	2020	2019	2018
AIR only	47.4	38.9	31.3	17.6	30.8
EQECAT only	0.0	0.0	0.0	0.0	0.0
RMS only	26.3	38.9	43.8	35.3	23.1
AIR and RMS	21.1	22.2	18.8	41.2	46.2
AIR and EQECAT	0.0	0.0	0.0	0.0	0.0
EQECAT and RMS	5.3	0.0	6.3	5.9	0.0
AIR, EQECAT and RMS	0.0	0.0	0.0	0.0	0.0
Model Licensing	2022	2021	2020	2019	2018
AIR only	42.9	26.3	21.1	5.9	15.4
EQECAT only	0.0	0.0	0.0	0.0	0.0
RMS only	23.8	31.6	31.6	23.5	23.1
AIR and RMS	28.6	42.1	42.1	64.7	61.5
AIR and EQECAT	0.0	0.0	0.0	0.0	0.0
EQECAT and RMS	4.8	0.0	5.3	5.9	0.0
AIR, EQECAT and RMS	0.0	0.0	0.0	0.0	0.0

Source: BMA

AIR usage is now taking the largest share in groups, either stand-alone or in combination with other models. Nevertheless, the market remains concentrated between two vendors.

Table 17: Model Frequency Usage (In per cent of respondents)

	2022	2021	2020	2019	2018
Ad-hoc	0.0	0.0	0.0	0.0	6.7
Annual	14.3	10.5	10.5	10.5	6.7
Semi-annual	4.8	5.3	5.3	10.5	6.7
Quarterly	38.1	42.1	42.1	42.1	53.3
Monthly	28.6	26.3	26.3	21.1	13.3
Weekly	0.0	0.0	0.0	0.0	0.0
Daily	9.5	15.8	15.8	15.8	13.3
Real-time	4.8	0.0	0.0	0.0	0.0

Source: BMA

Accumulation frequency follows a similar pattern for groups and legal entities as well. Most groups perform accumulations quarterly, as 38.1% of respondents did in 2022 compared to 42.1% in 2021. However, annual accumulations continue to be completed by some groups, with 14.3% of respondents doing so in 2022.

Table 18: Model Frequency and Business Units Differences
(In per cent of respondents)

	2022	2021	2020	2019	2018
Yes	42.9	47.4	52.6	47.4	61.5
No	57.1	52.6	47.4	52.6	38.5

Source: BMA

With regards to the utilisation of different frequencies of accumulations, 42.9% of groups have frequency differences compared to 32.6% of legal entities.

Table 19: Internal Model Usage (In per cent of respondents)

	2022	2021	2020	2019	2018
Yes	28.6	31.6	31.6	42.1	46.7
No	71.4	68.4	68.4	57.9	53.3

Source: BMA

The BMA also surveyed groups on the use of internal models. As of 2022, 71.4% of groups do not use internally developed models compared to the 28.6% of groups that do.

Table 20: External Reinsurance Model Usage (In per cent of respondents)

	2022	2021	2020	2019	2018
The company has minimal Cat exposure protection, and as such, gross is effectively net	0.0	0.0	5.6	5.3	6.7
The accumulations are calculated on a gross basis with reinsurance protections calculated approximately outside of the system	0.0	0.0	0.0	5.3	0.0
The accumulations are calculated on a gross basis, with reinsurance protections calculated explicitly outside of the system	0.0	0.0	0.0	0.0	6.7
The accumulations are calculated on a gross basis with the effect of reinsurance protections calculated explicitly for some types of protection within the system	52.4	63.2	50.0	31.6	20.0
The accumulations are calculated on a gross basis with the effect of reinsurance protections calculated explicitly for each type of protection within the system	47.6	36.8	44.4	57.9	66.7

Source: BMA

On the group level, models are used for their outward reinsurance treaties. In 2022, all groups had external reinsurance treaties due to minimal Cat exposure. The percentage of groups modelling explicitly for all treaties within the Cat model was 47.6%.