Research Paper Series

Insurance Risk Management: Overview of Solvency Framework and Comparative Insights on Standard and Internal Models

Gianmarco Mori

Matteo Bazzucchi

Francesco Bertonati

Daniel Bruttomesso

Amina Cavazzana

September 2026

iason

ESSENTIAL SERVICES FOR FINANCIAL INSTITUTIONS

iason

Research Paper Series

Year 2026 - Issue Number 88

Last published issues are available online:
http://www.iasonltd.com/research

Front Cover: **Umberto Boccioni**, *Dinamismo di un ciclista*, 1913.

Executive Summary

This paper examines the evolution of European insurance regulation from the basic, volume-based Solvency I framework to the sophisticated and risk-sensitive Solvency II regime. It highlights how modern prudential standards increasingly align capital requirements with insurers' actual risk profiles, supported by market-consistent valuation, advanced modelling tools, and enhanced governance and disclosure expectations. A key focus is the comparison between the Standard Formula and Internal Models used to calculate the Solvency Capital Requirement (SCR). While the Standard Formula provides a harmonised and broadly applicable approach, Internal Models allow companies to reflect their specific portfolios, capturing diversification benefits, tail behaviour, and company-specific risk drivers. The paper analyses their calibration methods, underlying assumptions, and strategic implications for capital efficiency and risk management. The discussion also considers the ongoing regulatory evolution, including recent Solvency II Review proposals aimed at refining long-term guarantee measures, strengthening proportionality, and incorporating sustainability and macroprudential risks. These developments illustrate a prudential framework that continues to adapt to a changing risk environment and to insurers' role as long-term, stabilising investors. Overall, the paper offers an integrated perspective on how solvency regulation, capital models, and supervisory expectations shape modern insurance risk management and contribute to the resilience of the European insurance sector.

About the Authors

Gianmarco Mori:
Head of Insurance
He holds a Bachelor in Banking and Finance and a Master degree in Statistics and Actuarial science. He obtained a specialization in Quantitative Finance at Politecnico di Milano and he had worked in a consulting firm for two year focused in Credit and Liquidity Risk Management. After these years, he moved to banking sector in Risk Management area and currently he has been working in iason as financial engineer for some of the major italian players.

Matteo Bazzucchi:
Business Analyst
He holds a Master's degree in Finance and Quantitative Methods from the University of Perugia. He has over two years of experience in risk management across interest rate, credit, and operational risk domains. He has worked on projects involving IRRBB/CSRBB modelling and validation, credit risk mitigation under CRR3 and IT solutions for operational risk.

Francesco Bertonati:
Financial Engineer
Graduated in Quantitative Finance and Insurance and holding a Master's degree in Statistics and Applied Mathematics, he worked as a Financial Engineer with the Risk Management team of one of the leading Italian insurance companies, contributing to the development of the internal model. His work focused in particular on modeling dependencies between different risk factors, preparing the related technical documentation, and assessing underwriting risks in the Life insurance sector. He is currently collaborating with the Financial Risk team of one of the major Italian banks, where he focuses on risk pricing analysis and the development of models for financial products.

Daniel Bruttomesso:
Financial Engineer
He holds an MSc in Mathematical Engineering. He collaborated as a Financial Engineer with the Risk Management team of one of the leading Italian insurance companies, contributing to the development of the internal model. His work focused in particular on modeling dependencies between risk factors, preparing the related technical documentation, and assessing underwriting risks related to Life insurance. He is currently working, within the Financial Risk team of a major Italian bank, on the risk metrics engine and the pricing analysis of financial products.

Amina Cavazzana:
Credit Risk Quant
She holds a degree in Statistics for Economics and Business and currently works as a Credit Risk Analyst. She collaborates with the Risk Management team of one of Italy's leading banking groups, contributing to the development and monitoring of Probability of Default (PD) models within the Internal Ratings-Based (IRB) framework. Her main activities include credit risk model development and calibration, performance metrics and sensitivity analyses, as well as supporting model validation and methodological documentation.

Table of Content

This paper provides a structured overview of the evolution from the traditional Solvency I framework to the modern and risk-based Solvency II regime, exploring its quantitative and qualitative pillars, its market-consistent valuation principles, and the tools that shape today's prudential environment. Building on this foundation, the paper examines the differences and strategic implications of the two principal methods used under Solvency II to determine capital requirements: the Standard Formula and Internal Models, with particular attention to their calibration, underlying assumptions, and impact on risk management practices. The analysis also considers the ongoing regulatory evolution, including recent reviews aimed at refining long-term guarantee measures, enhancing proportionality, and incorporating emerging risks such as sustainability and macroprudential concerns. By integrating historical context, actuarial concepts, and supervisory developments. The paper aims to offer a comprehensive perspective on how solvency regulation continues to adapt to support both policyholder protection and the resilience of the European insurance market. Readers already familiar with insurance regulation may want to proceed directly to Section *"Solvency II: Framework Evolution"*, where the Solvency II Review is introduced.

1. Regulatory Framework: From Solvency I to Solvency II

1.1 Introduction to Solvency and Preparatory Studies

The concept of solvency in the insurance sector refers to the ability of an insurance company to meet its obligations toward policyholders over time. It embodies the degree of assurance that an insurer can withstand adverse fluctuations in claims experience and still honour commitments. The protection of policyholders stands at the centre of solvency regulation, ensuring that insurance contracts maintain their economic and social function. From an economic perspective, solvency represents a dynamic balance between risks and the capital available to absorb them, with a specific emphasis on the time horizon over which those risks might materialise. Its importance goes beyond the safeguard of individual policyholders, since adequate solvency levels contribute to market stability, investor confidence and the effectiveness of prudential supervision in the financial system as a whole.

The first systematic efforts to define solvency standards in Europe emerged in the postwar years, when regulators and academics recognised the necessity of calibrating capital requirements for insurers. A landmark contribution came from the Belgian actuary Campagne, who, under the mandate of the OECD, analysed loss experience data to establish a framework for minimum solvency margins. His studies initially relied on Swiss non-life insurance data from 1945 to 1954 and assumed that expenses were a stable proportion of premiums. The empirical findings suggested that loss ratios could be modelled with a Beta distribution, while the number of claims could be represented by a Poisson distribution under assumptions of independence. Using these statistical tools, Campagne estimated the probability distribution of the combined ratio and identified a capital buffer capable of absorbing extreme but plausible adverse outcomes. At a confidence level of 99.97%, the extreme combined ratio was calculated at 125%, leading to a solvency margin equal to 25% of premiums, which was interpreted as a "safety buffer" between expected results and potential ruin.

The conceptual innovation lay in treating solvency as a probabilistic measure of ruin, aligning capital with risk through quantitative methods. This approach introduced the logic of Value at Risk to insurance long before it became standard in financial regulation. The balance between protecting policyholders and preserving insurer profitability was

already evident: while a larger safety buffer enhanced security, it also constrained capital available for growth and return. Subsequent extensions of the Campagne study across eight European countries confirmed the robustness of the 25% margin, though with national variations ranging from as low as 3% in Germany to as high as 35% in France. Campagne also suggested an additional loading for reinsurance credit risk, amounting to 2.5% of ceded premiums, highlighting the interconnection between primary insurers and reinsurers in safeguarding solvency.
These preparatory studies had clear regulatory implications. They provided the first indicative coefficients that would later influence European Solvency frameworks, starting with the so-called Solvency 0 introduced in the 1970s and then inspiring parallel developments in other jurisdictions, such as the Risk-Based Capital system in the United States and the Swiss Solvency Test. By integrating statistical modelling with supervisory policy, these early contributions laid the groundwork for a progressive alignment of capital requirements with the actual risk profile of insurance undertakings, thereby initiating the gradual transition from static solvency margins to risk-sensitive approaches.

1.2 The Regulatory Framework and Solvency I (Directive 2002)

The first attempts to establish a coherent European Solvency framework date back to the 1970s, when the First Directives on non-life and life insurance introduced the concept of a minimum solvency margin, known as Solvency 0. These rules marked a significant departure from the earlier system, in which insurers were only required to hold a minimum share capital that did not depend on either premium volumes or portfolio composition. With Solvency 0, companies were required to maintain available capital at least equal to a calculated margin, derived from premiums and claims for non-life business and from mathematical reserves and sums at risk for life business. This laid the foundation for a risk-sensitive solvency regime, albeit in a still rudimentary form.
The regulatory framework was updated with Directive 2002/12/EC [10], which represented the formalisation of Solvency I. This directive, later implemented in Italy through Legislative Decree 307/2003 [4], introduced only limited adjustments compared with the Solvency 0 system, such as a slight increase in the minimum solvency margin and in the guarantee fund thresholds, together with stronger intervention powers for the supervisory authority. The essential structure, however, remained unchanged, preserving the principle that the available solvency margin must not fall below the required solvency margin.
The architecture of Solvency I was defined through three main elements:

- **Minimum Solvency Margin (MSM)**: the required capital calculated according to fixed rules based on business volume;
- **Guaranteed Fund (GF)**: equal to one third of the MSM but not less than an absolute floor depending on the lines of business exercised, ensuring that companies maintained a stable minimum of available resources;
- **Available Solvency Margin (ASM, or MSD)**: defined by the admissible own funds recognised under accounting and regulatory principles.

Supervisory authorities such as ISVAP, later IVASS, were responsible for verifying the compliance of insurers with these requirements and could intervene if either the MSM or the QG was breached. The solvency condition was expressed in the inequality $ASM \geq MSM$ which became the cornerstone of the system, reflecting the principle that the resources available to an insurer had always to be at least equal to the required solvency capital.

1.2.1 Solvency I Calculation Formulas

Within the Solvency I regime, the calculation of the Minimum Solvency Margin (MSM) was carried out through formulas that were deliberately simple but intended to reflect the main underwriting exposures of insurers.
For non-life business the requirement was determined using two alternative bases: premiums and claims. On the premium basis, the margin was linked to the volume of gross written premiums, adjusted by a retention factor to account for reinsurance. On the claims basis, the margin was computed on the average claims burden of the past three years, again adjusted for reinsurance. The formula required the higher of the two results, thereby avoiding the possibility that an unusually favourable claims history or a temporary decline in premiums could reduce the requirement excessively. An additional surcharge of 50% was applied to liability lines other than motor, reflecting the higher volatility and tail risk associated with these classes. Formally, if P denotes premiums, S the average claims burden, and α the retention factor, the required margin could be represented schematically as:

$$MSM_{NL} = \max\{\alpha \cdot k_1 \cdot P,\ \alpha \cdot k_2 \cdot S\},$$

where the coefficients k_1 and k_2 were defined by the directive and the surcharge applied in case of non-motor liability business. This construction made the formula only partially sensitive to risk, since it captured volume but not diversification or reserve risk.
For life business, the calculation was based on two components. The first was 4% of the gross mathematical reserves, adjusted by a minimum retention factor of 85%, reflecting the possibility that reinsurance could reduce but not eliminate the exposure. The second was 0.3% of the sums at risk, defined as the insured capital minus the reserves, again adjusted by a minimum retention factor of 50%. In symbolic form:

$$MSM_L = 0.04 \cdot V \cdot c_1 + 0.003 \cdot CR^+ \cdot c_2,$$

where V denotes the mathematical reserves, CR^+ the positive sums at risk, $c_1 \geq 0.85$ the retention coefficient for reserves, and $c_2 \geq 0.50$ the retention coefficient for sums at risk. This design aimed to capture both the long-term accumulation of obligations (through reserves) and the immediate exposure to mortality or similar risks (through sums at risk). A further safeguard was provided by the Guarantee Fund, equal to one third of the MSM and subject to absolute minimum thresholds expressed in euro amounts depending on the type of business authorised. This mechanism ensured that even small or newly established companies would not operate with insufficient capital. The overall solvency condition remained expressed by the inequality:

$$ASM \geq MSM,$$

where ASM represented the available solvency margin, defined by admissible own funds such as paid-up capital, reserves, and certain subordinated instruments. Only resources of sufficient permanence and loss-absorption capacity could be recognised as eligible.

1.2.2 Structural Limitations of Solvency I

The Solvency I regime, despite introducing a more formalised prudential framework, revealed several structural limitations that progressively reduced its effectiveness as insurance markets evolved. One of the most evident shortcomings was the absence of risk differentiation in the non-life formula. The required margin was calculated on the overall portfolio without distinguishing among lines of business and with only limited recognition of volatility differences. Reserve risk was not explicitly considered, even though it represents one of the major sources of uncertainty in non-life insurance. The fixed coefficients applied to premiums and claims were based on outdated empirical studies and failed to reflect the true heterogeneity of risk profiles across markets.

In life insurance the same rigidity emerged. The 4% factor on reserves and the 0.3% factor on sums at risk were applied uniformly, irrespective of product complexity or market conditions. Although reinsurance adjustments were included, they were only partial and often distorted by minimum retention thresholds, favouring proportional treaties over non-proportional ones. Moreover, negative sums at risk, such as those arising from annuity portfolios, were not considered, resulting in an underestimation of biometric risks linked to longevity.

Another fundamental limitation was the neglect of financial and market risks. Asset allocation was not captured in the calculation of the minimum solvency margin, which implicitly assumed a homogeneous and low-risk investment structure. Credit risk, liquidity risk, asset-liability mismatch and operational risk were completely absent from the framework. The system therefore provided no incentive for insurers to manage these exposures actively, nor did it penalise excessive concentration in risky assets.

Finally, the design of the formulas implied that the relative capital burden decreased as company size increased, due to concavity in the relationship between MSM and business volume. This created an implicit advantage for larger insurers without any explicit consideration of diversification or correlation effects. The overall result was a system that was simple to administer and easy to verify from an accounting perspective, but one that lacked sensitivity to the actual risk profile of insurers. These limitations highlighted the need for a more comprehensive and market-consistent approach, setting the stage for the development of Solvency II.

1.3 The New Solvency II System

The rationale for the reform of the solvency regime in Europe arose from the recognition that Solvency I, while functional as a first prudential framework, was no longer able to capture the complexity of modern insurance risks. The uniform coefficients applied to premiums, claims, and reserves proved insufficient in light of financial innovation, the growing integration of capital markets, and the emergence of new biometric and operational risks. Furthermore, the lack of a true risk-based approach and the absence of incentives for proper asset-liability management meant that the solvency requirements under the old system could not guarantee either comparability across companies or resilience under stress scenarios. Against this background, regulators sought a framework capable of aligning capital requirements with the actual risk profile of each insurer, thereby strengthening both policyholder protection and the stability of the European insurance sector.

1.3.1 Three-Pillar Architecture and Market-Consistent Valuation

The architecture of Solvency II (Directive 2009/138/EC [11]) was conceived on the basis of a three-pillar framework, inspired by the Basel II structure for banks but adapted to the specificities of the insurance sector. The reform aimed to create a prudential regime that is not only quantitatively robust but also qualitatively sound and transparent, capable of reflecting the true economic position of insurance undertakings.

The innovations introduced by Solvency II transformed both methodological frameworks and operational processes. On the methodological side, the shift to market-consistent

valuation replaced traditional conservative accounting principles, making insurers' balance sheets a closer representation of economic reality. Assets and liabilities are valued in line with observable market data and risk-adjusted assumptions, ensuring consistency with financial markets. Capital requirements were recalibrated to rely on probabilistic measures of risk, aligning the solvency assessment with modern risk theory.
On the operational side, the new framework embedded corporate governance, risk management, and transparency into the core of prudential regulation. This approach recognizes that solvency depends not only on capital levels but also on how risks are actively identified, measured, and controlled through daily business processes.
The system was structured around three interdependent pillars, each addressing a key dimension of prudential supervision:

- **Pillar I – Quantitative requirements**
  This pillar sets the capital standards, notably the Solvency Capital Requirement (SCR) and the Minimum Capital Requirement (MCR). These are designed to capture the full spectrum of risks affecting insurers, including underwriting, market, credit, and operational risks, through probabilistic models and market-consistent valuation principles. Pillar I therefore represents the quantitative foundation of the regime, ensuring that capital levels are commensurate with the underlying risk profile.

- **Pillar II – Governance and supervisory review**
  This pillar introduces qualitative requirements centred on the system of governance, risk management, and the supervisory review process (SRP). It emphasises that capital adequacy alone does not guarantee solvency; the stability of an insurer also depends on the quality of its internal controls, decision-making processes, and overall risk culture. The Own Risk and Solvency Assessment (ORSA) is a key component, requiring firms to assess their solvency position in a forward-looking and holistic manner.

- **Pillar III – Disclosure and market discipline**
  Transparency is elevated to a core principle. Insurers must disclose both quantitative and qualitative information regarding their solvency position, risk exposures, and governance systems through the Solvency and Financial Condition Report (SFCR) and the Regular Supervisory Report (RSR). These disclosures aim to strengthen market discipline and external monitoring, allowing supervisors, investors, and policyholders to form a clear view of the insurer's financial soundness.

The three-pillar architecture was intended to balance numerical rigour with supervisory judgement and market discipline, creating a holistic prudential system rather than a purely formulaic one.
A central methodological innovation within Pillar I is the market-consistent valuation of assets and liabilities. For liabilities, this required moving away from the conservative technical provisions of the past and introducing a two-part structure: the Best Estimate and the Risk Margin, which will be described in detail in Section *"Valuation of Technical Provisions"*.
The Best Estimate represents the probability-weighted present value of all future cash flows, discounted at the risk-free rate and based on realistic assumptions. The Risk Margin is an additional allowance, calculated using a cost-of-capital approach, designed to ensure that the transfer value of the liabilities would be sufficient even in the presence of non-hedgeable risks.

Together, these two components established a valuation framework that is both economically grounded and risk-sensitive, fully consistent with market principles and with the overall prudential objectives of Solvency II.

1.3.2 Quantitative Requirements

The quantitative requirements of Solvency II were designed to create a more risk-sensitive capital framework, capable of aligning prudential standards with the true exposure of each insurance undertaking. At the core of this system lies the Solvency Capital Requirement (SCR), calibrated as the Value-at-Risk of basic own funds over a one-year time horizon with a confidence level of 99.5%. This definition implies that an insurer holding capital equal to the SCR should, under normal conditions, have less than a 0.5% probability of insolvency within a year. The SCR is comprehensive in scope, covering underwriting risk for both life and non-life business, market risk, counterparty default risk, and operational risk. It can be calculated through the standard formula, which applies prescribed parameters and correlation structures, or through internal models approved by supervisors, provided that these models demonstrate statistical quality, robust calibration, and integration into the company's risk management processes.
Alongside the SCR, the directive introduced the Minimum Capital Requirement (MCR), defined as a lower threshold calibrated to a Value-at-Risk at the 85% confidence level over one year. The MCR represents the minimum amount of capital that an insurer must always hold in order to continue operating. Falling below the SCR triggers supervisory intervention and the requirement to restore capital within a specified period, whereas a breach of the MCR leads to immediate and more severe supervisory action, including potential withdrawal of the license. The relationship between SCR and MCR (Section "*The Minimum Capital Requirement*") was designed to ensure a ladder of intervention, with the SCR functioning as an early warning level and the MCR as an absolute floor, thereby safeguarding both policyholders and financial stability.

1.4 Supervisory Authorities

At the European level, the European Insurance and Occupational Pensions Authority (EIOPA) plays a central role in ensuring the consistent application of the Solvency II regime across Member States. As one of the three European Supervisory Authorities (ESAs), EIOPA's mandate is to safeguard financial stability, protect policyholders and beneficiaries, and promote supervisory convergence throughout the EU insurance market.
EIOPA fulfils these responsibilities through a broad set of tools aimed at enhancing uniformity and quality of supervision. It issues binding Technical Standards, Guidelines, and Opinions, which complement the Solvency II Directive, Delegated Acts (Delegated Regulation (EU) 2015/35 [13]) and Omnibus (2014) [12] by providing detailed, harmonised interpretations of prudential rules. National competent authorities, such as IVASS in Italy, are required to comply with EIOPA's Guidelines, ensuring a high degree of supervisory consistency.
A core element of EIOPA's mandate is the promotion of supervisory convergence. Through peer reviews, onsite visits to supervisory authorities and participation in Colleges of Supervisors, EIOPA supports the adoption of best practices across jurisdictions. This reduces the risk of regulatory arbitrage and strengthens the Single Market for insurance services. EIOPA also develops common methodologies for risk assessments, including the design and coordination of EU-wide stress tests, which are presented in the next section.
In addition to supervisory convergence, EIOPA has a substantial role in market monitoring

and risk analysis. It publishes regular reports, such as the Financial Stability Report, the Consumer Trends Report, and the Insurance Risk Dashboard, which inform policymakers, supervisors and stakeholders of emerging vulnerabilities and structural trends. EIOPA also contributes to the enhancement of disclosures by setting guidelines on public reporting and by monitoring the quality of Solvency II data submitted by national authorities.

Ultimately, EIOPA's role under Solvency II is instrumental in maintaining a stable, transparent and integrated European insurance market. By fostering harmonisation, enhancing risk sensitivity and promoting high-quality supervision, EIOPA complements the work of national authorities such as IVASS and reinforces policyholder protection across the EU.

Within the Solvency II framework, IVASS plays a pivotal role as Italy's national supervisory authority, entrusted with ensuring the full and consistent implementation of the prudential regime across the domestic insurance and reinsurance market. IVASS acts as the competent authority for Italy, responsible for enforcing compliance with the quantitative, qualitative and disclosure requirements set out in the three Pillars of Solvency II.

From a prudential perspective, IVASS is charged with monitoring the financial soundness of supervised entities. This includes verifying the adequacy of Solvency Capital Requirement (SCR) and Minimum Capital Requirement (MCR) coverage, assessing the availability and quality of Own Funds, and ensuring that capital instruments meet the criteria defined under the Tier system. Beyond pure capital metrics, IVASS evaluates the effectiveness of insurers' governance structures, internal control systems and risk management frameworks, with particular attention to the ORSA (Own Risk and Solvency Assessment), which constitutes a key element of Pillar 2 supervision.

Regarding reporting and transparency, IVASS ensures the accuracy, completeness and timely submission of all regulatory disclosures, including the Quantitative Reporting Templates (QRT), the Regular Supervisory Report (RSR) and the Solvency and Financial Condition Report (SFCR). These instruments allow the supervisor to maintain a comprehensive and forward-looking view of the risk profile of individual undertakings and of the market as a whole.

In its supervisory role, during both off-site activities and on-site inspections, IVASS naturally focuses on the areas that can most affect an undertaking's soundness: the evolution of its risk profile, the robustness of its governance and organisational safeguards, and the alignment of day-to-day practices with regulatory expectations. Off-site monitoring helps detect early signs of deterioration or unusual trends, while on-site work enables a more structured deep dive into specific domains such as underwriting practices, reserving methodologies, governance, asset-liability management or IT infrastructures. When these activities reveal material weaknesses or practices that fall short of requirements, IVASS activates its progressive ladder of intervention, asking undertakings to implement proportionate remedial measures and, in the most severe circumstances, resorting to more intrusive actions.

Under Solvency II, the role of IVASS evolves significantly compared with the Solvency I environment. Rather than focusing primarily on compliance with static rules and formula-based margins, the supervisory approach becomes prospective, risk-based and deeply integrated with the internal processes of undertakings. This shift requires supervisors to assess not only the numerical adequacy of capital but also the robustness of risk culture, the consistency of strategic decisions with the risk appetite, and the ability of the company to withstand adverse scenarios. As a result, the IVASS supervisory model under Solvency II strengthens policyholder protection, enhances transparency and contributes to the resilience and orderly functioning of the Italian insurance market.

1.5 Quantitative Impact Studies (CEIOPS/EIOPA)

Since its inception, the development of the Solvency II framework has relied heavily on empirical testing and data-driven policy design. To ensure that regulatory standards were appropriately calibrated, the European Insurance and Occupational Pensions Authority (EIOPA) coordinated a series of Quantitative Impact Studies (QIS) and related field exercises. These studies were conducted in cooperation with national supervisory authorities and the insurance industry to assess how proposed rules would affect firms' solvency positions, risk sensitivity, and market behavior. Through this evidence-based approach, EIOPA aimed to strike a balance between prudential soundness and economic relevance, ensuring that Solvency II could strengthen policyholder protection and financial stability while supporting insurers' ability to provide long-term investment and protection products. Specifically, the QIS objectives are to measure the financial impact of reforms, check the calibration of regulatory parameters, assess operational feasibility, and provide a structured dialogue between supervisors and industry. Their scope typically spans a broad range of insurers and business lines, combining quantitative data templates with qualitative feedback. Methodologically, they have evolved from simple stress tests into iterative exercises involving scenario analysis, calibration adjustments, and refinements based on real-world data. The most recent example, the UK Prudential Regulation Authority's QIS conducted as part of the Solvency II review (2021-22), examined reforms to the matching adjustment, risk margin, and technical provisions. Its findings showed significant potential shifts in solvency ratios and liability valuations, underlining how QIS not only quantify numerical impacts but also highlight trade-offs between prudence, competitiveness, and proportionality in regulatory design.

The Long-Term Guarantees Assessment (LTGA), launched by EIOPA in 2013, was a major field study designed to evaluate the impact and suitability of measures intended to address volatility in insurers' balance sheets under Solvency II. The exercise focused on "anti-volatility measures" such as the matching adjustment, volatility adjustment, extrapolation of the risk-free curve, and transitional provisions, all of which were aimed at smoothing short-term market fluctuations and ensuring that the regulation reflected the long-term nature of insurance liabilities. The LTGA tested how these mechanisms would influence solvency positions, capital requirements, and the availability of long-term products, especially annuities and other guaranteed savings contracts. Results showed that while such measures could mitigate artificial volatility and reduce pro-cyclicality, they also raised concerns about complexity, comparability across jurisdictions, and the risk of masking underlying financial weakness. Ultimately, the LTGA informed the final calibration of the Solvency II framework, balancing the need to preserve prudential soundness with the policy objective of supporting insurers' role as providers of long-term financial products and institutional investors in the broader economy.

European insurance stress tests, coordinated by EIOPA since 2011, are designed to assess the resilience of the sector to adverse but plausible shocks, such as sudden interest rate movements, sharp declines in asset values, or extreme natural catastrophe scenarios. Their objectives are not only to measure potential vulnerabilities at individual and sectoral levels, but also to enhance transparency and market discipline by publishing aggregate results, and to provide supervisors with insights for macroprudential oversight. Methodologically, stress tests combine bottom-up calculations by insurers with top-down consistency checks by EIOPA, covering both capital adequacy and liquidity aspects. In addition to these periodic exercises, the EIOPA Risk Dashboard offers a more frequent, real-time overview of risks facing the insurance sector. Based on a set of risk indicators covering solvency, profitability, market, liquidity, and macroeconomic exposures, the dashboard tracks trends across the industry and signals emerging vulnerabilities. Together, the stress tests and the Risk Dashboard provide complementary tools: the former offering deep, scenario-based assessments, and the latter ensuring continuous monitoring, both essential to the stability and supervisory effectiveness of the European insurance market.

Taken together, the QIS exercises, the LTGA, the European stress tests, and the EIOPA Risk Dashboard were fundamental in shaping the final calibration of Solvency II. QIS provided the empirical foundation for testing different capital and valuation approaches, ensuring that regulatory parameters were not only theoretically sound but also workable for a diverse industry. The LTGA specifically addressed the treatment of long-term guarantees, leading to the introduction and fine-tuning of anti-volatility measures such as the matching and volatility adjustments. Stress tests added a forward-looking, systemic dimension, demonstrating how insurers would cope under severe shocks and highlighting vulnerabilities that informed supervisory priorities. Finally, the Risk Dashboard established an ongoing monitoring framework, giving regulators and markets greater visibility of emerging risks. Together, these tools helped calibrate Solvency II in a way that balances prudential soundness with proportionality, supports the provision of long-term products, and strengthens the resilience and transparency of the European insurance sector.

In recent years, EIOPA has continued to deepen its empirical and supervisory work beyond classic QIS and stress-test exercises, reflecting new priorities and evolving risks in the European insurance sector. Notably, its Peer Review Work Plan 2023-2024 includes a dedicated review of stochastic valuation practices, especially in life insurers with significant options and guarantees, signaling a shift toward more sophisticated liability modeling [7]. Moreover, in 2024 EIOPA published a comparative study on diversification in internal models, highlighting large heterogeneity in how insurers capture diversification effects, a topic with direct implications for capital calibration [8]. On the risk-monitoring side, the Insurance Risk Dashboard remains a key tool: its most recent editions (e.g. April 2025) show that overall risk levels in the sector remain at medium levels, but with increasing concern around geopolitical instability, market volatility, and digital/cyber risks [6]. These newer studies complement the earlier QIS, LTGA, and stress test exercises by providing granular insights into internal model practices and continuous, real-time risk surveillance, informing regulatory calibration and supervisory priorities.

Together, these continuing initiatives illustrate EIOPA's commitment to maintaining Solvency II as a living framework, responsive to emerging risks and grounded in quantitative evidence.

2. Solvency II: Principles and Tools

2.1 The Solvency Capital Requirement (SCR)

The Solvency Capital Requirement (SCR) is the cornerstone of the Solvency II quantitative framework and represents the main solvency requirement for insurers. Its purpose is to ensure that insurance undertakings hold sufficient capital to withstand severe but plausible adverse conditions over a one-year horizon. To compute this requirement, the directive allows undertakings to choose between two primary regulatory approaches, subject to supervisory approval: the Standard Formula, which is a predefined, modular framework designed by EIOPA to capture the risk profile of an average insurer, and Internal Models (either full or partial), which are custom risk assessment frameworks developed by the company itself to better reflect its specific and complex risk characteristics.

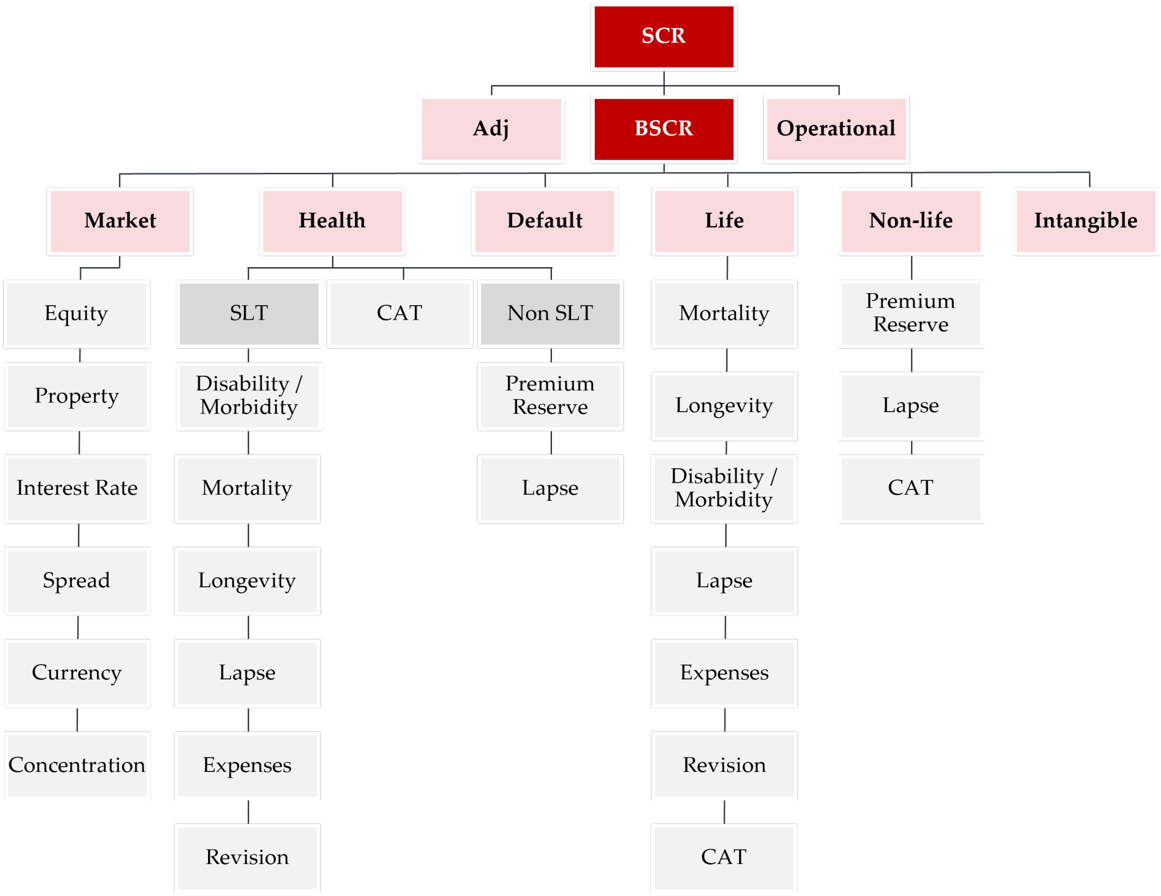

FIGURE 1: Risk aggregation tree under the Standard Formula from "Study on Diversification in Internal Models" (EIOPA) [8].

Under the standard framework, the SCR has a modular structure (see Figure 1), composed of the Basic SCR (BSCR), operational risk, and adjustments reflecting the loss-absorbing capacity of technical provisions and deferred taxes. The general aggregation formula is:

$$SCR = \sqrt{\sum_i \sum_j SCR_i \cdot \rho_{ij} \cdot SCR_j} \; + \; SCR_{\text{oper}} \; - \; Adj,$$

where:

- SCR_i and SCR_j represent the capital requirements of risk modules and sub-modules;
- ρ_{ij} are correlation coefficients defined by the directive;
- SCR_{oper} is the capital requirement for operational risk;
- Adj reflects the loss-absorbing capacity of technical provisions and deferred taxes.

The risk modules considered in the BSCR are:

- **Market risk**, covering:
  - Interest rate risk;
  - Equity risk;
  - Spread risk;

  - Currency risk;
  - Concentration risk;
  - Property risk.

- **Counterparty default risk**, addressing exposures to reinsurers, intermediaries, and other counterparties.

- **Life underwriting risk**, including:
  - Mortality;
  - Longevity;
  - Disability-morbidity;
  - Lapse;
  - Expense;
  - Revision;
  - Catastrophe risks.

- **Non-life underwriting risk**, covering:
  - Premium risk;
  - Reserve risk;
  - Lapse risk;
  - Catastrophe risks.

- **Health underwriting risk**, addressing analogous risks for health insurance products.

The Basic Solvency Capital Requirement (BSCR) is obtained by aggregating the individual risk modules using a correlation matrix that captures the statistical dependencies between them. This approach recognises that not all risks materialise simultaneously or perfectly correlate, thereby introducing diversification effects that reduce the overall capital requirement. However, these effects are limited by regulatory constraints to avoid excessive capital relief. The use of a linear correlation framework assumes elliptical joint distributions and may underestimate extreme co-movements, particularly during market stress.
To address this limitation, internal model approaches often employ copulas or non-linear dependence structures, providing a more realistic representation of tail correlations between risk drivers such as market and underwriting risk. Alternative approaches include multi-factor models, where dependencies arise through common underlying risk drivers, and scenario-based frameworks, which reflect joint risk materialisation through coherent adverse economic and insurance stress scenarios. Each module is subdivided into submodules, calibrated individually and then aggregated through an appropriate dependency structure. This structure introduces diversification effects in a controlled way: companies can benefit from the reduction of overall capital requirements when risks are imperfectly correlated, but only within the bounds defined by the regulation.
The Solvency Capital Requirement (SCR) is defined as the level of own funds corresponding to the Value-at-Risk (VaR) of basic own funds over a one-year time horizon with a confidence level of 99.5%. This calibration means that an insurer holding capital equal to the SCR should have a probability of insolvency of less than 0.5% within a year. Formally:

$$SCR = VaR_{99.5\%}(\Delta \text{Own Funds}, \ 1 \text{ year}),$$

where the variation in own funds (ΔOwn Funds) is driven by market, credit, underwriting, and operational risks.

2.2 Value-at-Risk (VaR)

The Value-at-Risk (VaR) is a quantile-based statistical measure that estimates the maximum loss an institution may experience over a given time horizon, at a specified confidence level, under normal market conditions. Formally, for a random variable L representing losses, the Value-at-Risk at confidence level α is defined as:

$$VaR_\alpha(L) = \inf\{\, l \in \mathbb{R} \mid \mathbb{P}(L \le l) \ge \alpha \,\}.$$

Intuitively, $VaR_{99.5\%}(L)$ corresponds to the loss level that will not be exceeded with 99.5% probability over the chosen time horizon. Thus, only 0.5% of outcomes are expected to result in a greater loss. The rationale behind using VaR in the Solvency II framework lies in its clarity and interpretability: it provides a single, easily communicable number representing the capital amount needed to cover unexpected losses up to a given confidence level. Moreover, VaR is directly compatible with the balance sheet structure, as it measures potential variations in own funds based on the joint distribution of underlying risks.

2.3 Tail-Value-at-Risk (TVaR)

While the Value-at-Risk (VaR) at the 99.5% confidence level represents the official risk measure under Solvency II, it differs conceptually from the Tail-Value-at-Risk (TVaR), also known as Expected Shortfall (ES). The TVaR captures the expected loss beyond the VaR threshold, providing a more conservative and comprehensive measure of tail risk. Formally, it can be expressed as:

$$TVaR_\alpha(L) = \mathbb{E}[\, L \mid L > VaR_\alpha(L) \,].$$

Although both are percentile-based measures, TVaR averages the extreme outcomes in the tail of the loss distribution, rather than setting a fixed quantile cut-off.

2.4 Capital-at-Risk (CaR)

A complementary interpretation of the regulatory capital measure comes from the notion of Capital-at-Risk (CaR), widely used in actuarial risk theory. While the Solvency II Directive defines the SCR as the 99.5% Value-at-Risk of the one-year change in own funds, the CaR expresses the same concept by decomposing total losses into their expected and unexpected components.

Let L denote the random variable describing one-year losses. Then the Capital-at-Risk is defined as:

$$CaR_\alpha(L) = VaR_\alpha(L) - \mathbb{E}[L].$$

In this formulation, the CaR isolates the portion of losses corresponding to unexpected deviations from the mean, i.e. the economic capital required to protect the insurer against adverse outcomes occurring with probability 1-α. At the 99.5% confidence level used for the SCR, the CaR therefore represents the capital buffer needed to absorb extreme but plausible losses, consistent with the "one-in-200-year" event underlying Solvency II calibration. Accordingly, the CaR reinforces the idea that the SCR is not a measure of average performance but a quantile-based capital buffer designed to ensure policyholder protection under severe but credible stress scenarios.

2.5 Comparison with Banking Regulation

Solvency II favours the VaR approach due to its interpretability and computational simplicity, as well as its consistency with accounting data and reporting requirements. In contrast, the

Basel II and Basel III frameworks for banking supervision often rely on Expected Shortfall (ES), which is sub-additive and therefore more coherent for aggregating risks in portfolios with fat-tailed loss distributions. The choice of VaR in Solvency II ultimately reflects a compromise between statistical rigor and practical implementation, ensuring consistency and comparability across insurers while maintaining computational tractability.

2.5.1 Solvency Capital Requirement in the CRM

The calculation of the Solvency Capital Requirement (SCR) is grounded in the actuarial theory of collective risk, known as the Collective Risk Model (CRM).
In this framework, the insurance risk is represented by a random variable describing the aggregate cost of claims over a specified time horizon (typically one year). This cost is defined as the sum of individual claim amounts $Z_1, Z_2, \dots, Z_N$, where N is a random variable denoting the number of claims, generally assumed to follow a Poisson distribution or a Mixed Poisson distribution to account for portfolio heterogeneity.
An important generalisation of the Poisson model is the Negative Binomial distribution, which arises when the Poisson parameter itself is considered a random variable following a Gamma distribution. This mixture captures the overdispersion typically observed in real insurance portfolios, where the variance of the number of claims exceeds the mean due to portfolio heterogeneity, contagion effects, or varying exposure levels.
By allowing for additional variance, the Negative Binomial model provides a more flexible and realistic representation of claim frequency and improves the calibration of the risk modules under Solvency II. It is especially useful for large, diversified portfolios where risk pooling does not completely eliminate volatility in claim counts.
Modeling risk through the CRM allows for a consistent estimation of the mean, variance, and skewness of the loss distribution, parameters that are essential for calibrating the risk modules within the Standard Formula or Internal Models. A key feature of this framework is the distinction between frequency and severity of claims:

- Frequency is described by discrete distributions (e.g., Poisson, Negative Binomial);
- Severity by continuous positive distributions (e.g., Lognormal, Gamma, Pareto).

The choice of the severity distribution plays a crucial role in determining the overall variability of the aggregate claims cost. Distributions such as the Lognormal and Pareto exhibit heavy tails, meaning that a small proportion of claims can contribute disproportionately to total losses. This feature has a direct impact on the tail of the aggregate loss distribution and therefore on the Solvency Capital Requirement, which is calibrated to extreme quantiles. Selecting an appropriate severity model, supported by empirical data and statistical fitting, is therefore essential for realistic capital estimation and effective risk management.
The aggregation of the two components, claim frequency and claim severity, produces the total loss distribution, enabling the estimation of the Value-at-Risk at a 99.5% confidence level, as required under Solvency II. This approach bridges risk-management practice with statistical and actuarial theory, providing a quantitative foundation for determining both economic and regulatory capital.
Since the exact convolution of frequency and severity distributions is analytically complex, approximation methods are commonly used to estimate the distribution of aggregate losses. Classical approaches include the Normal approximation (based on the Central Limit Theorem) and refinements such as the Normal-Power and Wilson-Hilferty transformations, which improve accuracy for skewed and positively bounded data. These methods allow for the practical computation of percentiles and Value-at-Risk estimates without requiring

extensive simulation.
When loss distributions are strongly asymmetric or heavy-tailed, more robust numerical techniques are recommended. The Panjer recursion formula provides a recursive algorithm to determine the probability distribution of total losses when both claim frequency and severity follow specific classes of distributions (such as the $(a, b, 0)$ class). This method is particularly suitable for portfolios with discrete claim amounts and is frequently used in actuarial practice for its speed and numerical stability.
Alternatively, Monte Carlo simulations offer a flexible approach for modelling more complex or heavy-tailed loss distributions. By repeatedly sampling both the number and the size of claims, these simulations generate an empirical loss distribution from which quantiles such as the Value-at-Risk or Tail-Value-at-Risk can be estimated directly. While computationally intensive, Monte Carlo techniques allow actuaries to incorporate dependencies, reinsurance structures, and non-linear effects that cannot be captured by closed-form formulas, providing a robust foundation for the calculation of the Solvency Capital Requirement. A more detailed discussion of analytical approximations for compound frequency-severity processes, including the Single Loss Approximation developed in the Operational Risk literature, is provided in Section *"Advanced Modelling Techniques"*.

2.5.2 Technical and Actuarial Insights into Non-life Underwriting Risk

Within the Solvency II framework, two key components of the non-life underwriting module are the Premium Risk and the Reserve Risk, both of which capture the uncertainty in future claims development over a one-year horizon.
From a mathematical perspective, Premium Risk relates to claims that will arise from policies not yet fully earned at the valuation date. It is typically modelled as the variability of the aggregate loss ratio over the forthcoming year. Denoting the expected number of claims by λ and the average claim size by c_z, the total claims amount can be expressed as $S = \sum_{i=1}^{N} Z_i$, with $N \sim Poisson(\lambda)$ and Z_i representing independent and identically distributed claim severities. The volatility of this risk arises from both the frequency ($Var[N]$) and the severity ($Var[Z]$) components. The Reserve Risk, by contrast, reflects the potential for deviation between the best estimate of outstanding claims and their actual ultimate cost. It is often assessed through a one-year re-reserving model, in which the uncertainty of prior accident years' liabilities is re-evaluated after one year. This dynamic perspective aligns the actuarial process with the Solvency II one-year horizon assumption for the SCR.
In stochastic formulations, the variability of Premium and Reserve Risk is parameterised through the expected frequency λ, the mean claim cost c_z, and the associated variances. The total variance of claims can be decomposed as:

$$Var(S) = \mathbb{E}[N] \cdot Var(Z) + Var(N) \cdot (\mathbb{E}[Z])^2.$$

This relationship highlights how uncertainty in both the number and size of claims contributes to overall volatility. Within the Solvency II standard formula, these risks are captured through volume measures (premiums and provisions) scaled by standard deviations calibrated by EIOPA to reflect the 99.5% Value-at-Risk confidence level. In internal model frameworks, actuaries often estimate these variances empirically, incorporating dependencies across lines of business via copulas or correlation matrices. The resulting capital requirement for underwriting risk is thus directly linked to the stochastic structure of N and Z, ensuring consistency between empirical observation and regulatory calibration.
A complementary source of uncertainty within the underwriting module is the volatility

of the expense ratio, which influences both Premium and Reserve Risk. Fluctuations in administrative and acquisition expenses affect the total cost structure and therefore the insurer's combined ratio. Empirical studies show that variations in expenses can amplify the overall loss ratio, particularly when expense assumptions are based on fixed overheads rather than scalable costs. Under Solvency II, the interaction between loss ratio and expense volatility is reflected in the calibration of the standard deviation parameters for Premium Risk. Higher variability in expense ratios translates into increased volatility of technical results and therefore higher capital charges. Proper modelling of expense dynamics, especially when using internal models, is crucial for accurately assessing the Solvency Capital Requirement and avoiding systematic underestimation of underwriting volatility.

2.6 The Minimum Capital Requirement

The Minimum Capital Requirement (MCR) represents the absolute floor of the Solvency system. Its function is to ensure that insurance undertakings maintain a basic amount of own funds below which they cannot legally continue operating. While the SCR provides a comprehensive and risk-sensitive benchmark, the MCR is intentionally simpler, relying on linear formulas applied to volume measures such as written premiums, technical provisions, and sums at risk.
Formally, the directive defines the MCR as a linear function:

$$MCR = f(P,\ V,\ SR),$$

where:

- P = volume of premiums;
- V = technical provisions;
- SR = sum at risk.

The function f is specified by regulatory coefficients calibrated to approximate a Value-at-Risk (VaR) at the 85% confidence level over a one-year horizon. This calibration implies that an insurer holding capital equal to the MCR should face no more than a 15% probability of default within twelve months.
To maintain proportionality between the two capital thresholds, the directive sets explicit bounds that tie the MCR to the SCR:

$$0.25 \cdot SCR \ \leq \ MCR \ \leq \ 0.45 \cdot SCR.$$

This corridor prevents the MCR from being disproportionately low or excessively high relative to the SCR. The supervisory ladder of intervention derives from this two-tiered structure:

- If the Available Solvency Margin (ASM) is greater than or equal to the SCR, the insurer is considered fully compliant;
- If the ASM falls below the SCR but remains above the MCR, the company must present a recovery plan and restore its solvency within a prescribed period;
- If the ASM drops below the MCR, the situation is deemed critical and immediate supervisory action follows, potentially leading to the withdrawal of authorisation.

Through this combination of linear calculation, probabilistic calibration, and regulatory boundaries, the MCR provides a simple but decisive safeguard against insolvency, complementing the broader solvency assessment offered by the SCR.

2.7 Valuation of Technical Provisions

A central innovation of Solvency II is the introduction of a market-consistent valuation of technical provisions, replacing the static and prudential methods of Solvency I. The objective is to align the balance sheet of insurers with principles consistent with financial markets, ensuring that liabilities are measured at a realistic transfer value. The value of technical provisions is defined as the sum of two components: the Best Estimate (BE) and the Risk Margin (RM). $TP = BE + RM$.

2.7.1 Best Estimate

From an actuarial perspective, the Best Estimate represents the expected present value of future losses arising from insurance obligations. Its assessment is based on stochastic models such as the Collective Risk Model (CRM), which describes the distribution of the aggregate cost of claims and allows for the estimation of key moments (mean, variance, and skewness). These parameters ensure that the reserve accurately reflects the true risk profile of the company, in line with the market-consistent valuation approach required by Solvency II.

In operational terms, the Best Estimate (BE) is calculated as the present value of all expected future cash flows arising from insurance liabilities, split between premium provisions (relating to unexpired risks) and claims provisions (relating to incurred but unpaid losses). For non-life business, the premium provision captures expected claims and expenses during the remaining coverage period, while the claims provision represents the discounted value of outstanding claims, including incurred but not reported (IBNR) losses. Actuaries often rely on the combined ratio (the sum of the loss ratio and the expense ratio) as an empirical indicator for assessing profitability and estimating expected future cash flows. By projecting future combined ratios under realistic assumptions of frequency, severity, and expenses, insurers can derive a robust estimation of the Best Estimate that aligns with the company's actual risk experience. The Best Estimate corresponds to the probability-weighted average of all future cash flows arising from insurance obligations, discounted at the risk-free interest rate term structure. Formally:

$$BE = \sum_{t=1}^{T} \frac{\mathbb{E}[CF_t]}{(1+r_t)^t},$$

where $\mathbb{E}[CF_t]$ denotes the expected cash flow at time t and r_t the relevant risk-free rate for maturity t. This removes the implicit prudence margins typical of traditional reserving and ensures that liabilities reflect realistic expectations.

2.7.2 Risk Margin

For the Risk Margin component, the actuarial approach adopts the Cost-of-Capital method, applied to the capital required to cover non-hedgeable risks over the run-off period of the liabilities. Within this framework, the CRM provides a useful structure for estimating tail risks, which play a critical role in determining the magnitude of the Risk Margin. Monte Carlo simulation techniques or analytical approximations (such as the Normal-Power or Wilson-Hilferty methods) are frequently used to estimate the extreme percentiles of the loss distribution, thereby enhancing the stability and robustness of actuarial valuations.

The Risk Margin (RM) is determined using the Cost-of-Capital (CoC) approach, which reflects the cost of maintaining sufficient capital to support non-hedgeable risks over the lifetime of the obligations. The regulatory CoC rate is currently set at 6% per annum in the Solvency II framework, applied to the projected Solvency Capital Requirements for non-hedgeable risks ($SCR_{NH,t}$) at each future time period t. Formally, the Risk Margin is given by:

$$RM = \sum_{t=1}^{T} \frac{CoC \cdot SCR_{NH,t}}{(1+r_t)^t}.$$

This ensures that, if the liabilities were transferred to another insurer, sufficient funds would be available to remunerate the capital required to bear these residual risks. In practice, insurers often approximate the projection of $SCR_{NH,t}$ using simplifications based on proportional decay or duration-adjusted factors, provided these remain consistent with the underlying risk profile.

2.7.3 Risk-free Interest Rate Term Structure

The risk-free interest rate term structure used for discounting technical provisions is published regularly by EIOPA and is based on euro swap rates adjusted for credit risk. For long maturities where observable market data are limited, the curve is extrapolated to an Ultimate Forward Rate (UFR), currently set at 3.25% per annum for the euro.
Two major adjustments can be applied to the risk-free curve:

- The Volatility Adjustment (VA), designed to mitigate artificial fluctuations in solvency ratios caused by temporary market volatility;
- The Matching Adjustment (MA), applicable to portfolios with predictable cash flows and eligible backing assets, allowing the discount rate to better reflect asset yields.

Both measures aim to ensure that the valuation of technical provisions reflects the long-term economic reality of insurance contracts, balancing prudence with stability.
The removal of implicit prudence margins and the consistent treatment of hedgeable and non-hedgeable risks represent a fundamental departure from previous frameworks. Assets and liabilities are now valued under the same principles, enhancing comparability, while the explicit split between Best Estimate and Risk Margin increases transparency in the solvency position.

2.8 The Solvency II Balance Sheet

The Solvency II balance sheet represents a fundamental shift from the accounting-based approach of Solvency I to an economic and market-consistent framework. Its purpose is to provide a realistic picture of the insurer's financial position by valuing both assets and liabilities on a basis consistent with observable market conditions.
On the liability side, technical provisions are calculated as the sum of Best Estimate and Risk Margin, ensuring that obligations reflect expected future cash flows and the cost of capital needed to cover non-hedgeable risks. On the asset side, valuations are made at market-consistent prices, removing historical cost accounting and embedding real-time information into solvency measurement. This consistency between assets and liabilities allows for a meaningful calculation of the insurer's available capital.
The measure of available capital under Solvency II is represented by Own Funds, defined as the excess of assets over liabilities according to the Solvency II valuation rules:

$$Own\ Funds = Assets - (BE + RM).$$

Own Funds are classified into three quality categories, or Tiers, based on their permanence, subordination, and loss-absorbing capacity:

- Tier 1: the highest-quality capital, including paid-up ordinary share capital, retained earnings, and other fully available reserves. These funds are permanent and fully loss-absorbing.
- Tier 2: subordinated liabilities and hybrid instruments with limited permanence and availability, which can absorb losses but to a lesser extent than Tier 1.
- Tier 3: the lowest-quality category, including items such as deferred tax assets, which have a limited ability to absorb losses and are often subject to stricter quantitative restrictions.

Eligibility limits are imposed on the use of Own Funds to cover capital requirements, in order to ensure that solvency is supported primarily by the most reliable resources. In particular, coverage of the Minimum Capital Requirement (MCR) must be met exclusively with Tier 1 and Tier 2 items, with strict caps on the latter, while the Solvency Capital Requirement (SCR) may be covered with a broader mix of Tiers but still subject to eligibility ratios.
This balance sheet design emphasises economic substance over accounting form, ensures comparability across jurisdictions, and provides supervisors and markets with a transparent view of the solvency position of each insurer. It is thus the backbone of the Solvency II regime, integrating valuation rules, technical provisions, and capital classification into a single coherent framework.

3. Solvency II: Framework Evolution

The evolution of the Solvency II framework shows that European insurance regulation is not meant to be a fixed or static regime but a prudential system that adapts to changing market conditions and emerging macroeconomic challenges. Solvency II has gradually incorporated new tools, recalibrated quantitative requirements and expanded qualitative expectations in response to shifts in the risk environment, from prolonged low interest rates to the shocks caused by the COVID-19 pandemic and the effects of geopolitical instability. Each revision, whether through delegated regulations or broader legislative amendments, aims to preserve the core objective of protecting policyholders while ensuring that insurers can continue to operate as long-term investors, contributors to financial stability and providers of private capital to the real economy. In particular, the updates introduced by Directives 2025/2 therefore demonstrate the built-in flexibility of the Solvency II framework, which evolves alongside market practice, supervisory experience and the Union's strategic priorities including sustainability, macroprudential resilience and support for long-term investment.

3.1 Directive (EU) 2025/2 - Solvency II Review

Directive (EU) 2025/2 [14] is adopted against the backdrop of a sequence of severe shocks to the Union's economy. The COVID-19 pandemic generated substantial social and economic damage, exposing structural vulnerabilities and calling for a recovery strategy that is not merely rapid but also sustainable, inclusive and fair. The economic and social consequences of Russia's war of aggression against Ukraine have added further pressure on the Union's policy priorities, for example through energy price volatility, heightened macroeconomic uncertainty and renewed concerns about financial stability. In this context, the insurance and reinsurance sector is identified as a key channel through which private capital can

be mobilised to support the real economy and to strengthen the resilience of European businesses.
The revision of the Solvency II framework through Directive (EU) 2025/2 pursues several interrelated objectives. A central aim is to encourage long-term investments by institutional investors, in particular insurance undertakings, so as to support the re-equity of the corporate sector and to facilitate the financing of the Union's economic recovery. To this end, the prudential framework is adjusted to better reflect the structurally long-term nature of insurance liabilities and investment horizons. Among other elements, the Directive facilitates the use of a more favourable standard parameter for equity investments held with a genuinely long-term perspective, on condition that the undertaking can demonstrate its capacity to avoid forced sales in stressed market conditions. The capital freed through the reduction of the Solvency Capital Requirement (SCR) is expected to be channelled primarily towards productive investments in the real economy rather than being used for shareholder distributions or variable remuneration.
At the same time, the Directive aligns Solvency II more closely with the objectives of the European Green Deal. It seeks to transform the Union into a climate-neutral and climate-resilient economy by 2050, in part by integrating climate and environmental risks more coherently into the prudential framework. Insurance undertakings are required to embed sustainability risks in their risk-management systems and to conduct climate-related scenario analyses over long-term horizons. The reform also reinforces the principle of proportionality so that small and less complex undertakings are not unduly burdened, and it strengthens supervisory tools and cooperation, especially with regard to cross-border activities and the monitoring of systemic risk in the insurance sector.

3.1.1 Proportionality and Scope of Application

A core dimension of Directive (EU) 2025/2 is the recalibration of proportionality and the refinement of the scope of application of the Solvency II regime. The legislator recognises that the framework should not apply inappropriately to very small undertakings and that the intensity of requirements must be aligned with the nature, scale and complexity of the risks inherent in each undertaking's business.
At the level of full exclusion from the regime, the quantitative thresholds determining when an undertaking falls outside Solvency II are increased. An undertaking may be excluded where its annual gross written premium income does not exceed EUR 15,000,000 and the total amount of its technical provisions, gross of recoverables, does not exceed EUR 50,000,000. For undertakings that belong to a group, the group's technical provisions must also remain below this threshold. Undertakings meeting these conditions may operate entirely outside Solvency II, while retaining the option to request authorisation in order to benefit from the single-licence framework. The conditions for excluding assistance activities are also revised, allowing occasional provision of roadside-assistance services in neighbouring Member States without altering the regulatory treatment of the undertaking.
Above the exclusion threshold, the Directive establishes a structured proportional regime for "small and non-complex undertakings" (SNCU) [9]. These are identified through a set of risk-based criteria that differ depending on whether the undertaking conducts life, non-life or mixed business, and the criteria must be satisfied for two consecutive years. For example, in the non-life sector, annual gross written premiums may not exceed EUR 100,000,000 and cross-border premium income may not exceed EUR 20,000,000 or 10% of total premiums. In the life sector, one criterion requires that the interest-rate risk exposure remain limited relative to the undertaking's technical provisions.

Classification as an SNCU grants automatic access to a broad set of proportionality measures relating to reporting, disclosure, governance, the own-risk and solvency assessment (ORSA) and liquidity-risk management. SNCU are exempted from the requirement to prepare a formal liquidity-risk management plan. The classification process is intentionally streamlined: the undertaking notifies its supervisory authority and, in the absence of objection within a defined period, acquires SNCU status.
The Directive also addresses the position of captive undertakings. Captives may be classified as SNCU even where they do not meet all general criteria, provided specific conditions are satisfied, such as limiting policyholders and beneficiaries to entities within the same group and avoiding coverage of mandatory third-party liability risks. Supervisory authorities maintain discretion to restrict an SNCU from using proportionality measures if serious concerns arise regarding its risk profile or governance. Conversely, undertakings that do not qualify as SNCU may still be permitted, following supervisory assessment, to rely on certain proportionality measures.
The resulting design distinguishes clearly between full exclusion from Solvency II for very small undertakings and SNCU status for undertakings that remain within the system but benefit from proportionate and simplified regulatory obligations.

3.1.2 Governance, Risk Management and Sustainability

Directive (EU) 2025/2 reinforces the qualitative dimension of the Solvency II regime (Pillar II) by strengthening governance requirements and broadening the scope of risk management to include macroprudential and sustainability-related considerations. Supervisory authorities are required to conduct periodic reviews of undertakings' governance systems as an integral part of the supervisory review process, assessing both the formal arrangements and their effective implementation in practice.
Persons who effectively run the undertaking or perform key functions must satisfy fit-and-proper requirements on a continuous basis in terms of competence, experience and integrity. Where these conditions are no longer met, the supervisory authority has the power to require the removal of the person concerned. Undertakings must adopt a policy promoting diversity at the level of the administrative, management or supervisory body, including the specification of quantitative objectives related to gender balance. The Directive also clarifies the expectations for key functions: risk management, actuarial, compliance and internal audit functions must be organised so as to ensure independence and effective challenge. For SNCU, certain combinations of key functions are allowed under defined conditions, with the important exception of the internal audit function, which must remain separate.
The integration of environmental, social and governance (ESG) risks is a prominent feature of the reform. Undertakings must establish strategies, policies, processes and systems for the identification, measurement, management and monitoring of sustainability risks over short, medium and long-term horizons. They are required to develop and monitor the implementation of specific plans that include quantifiable targets for addressing financial risks stemming from sustainability factors, in line with relevant Union climate and environmental objectives. These plans are expected to influence underwriting practices, investment strategies and product design, thereby embedding sustainability considerations in the core business model of insurance undertakings.
The own-risk and solvency assessment is significantly expanded. Undertakings with material exposure to climate-related risks must assess the impact of at least two long-term climate scenarios on their risk profile and solvency position. One scenario must be consistent with a global temperature increase below two degrees, while another must reflect

a significantly higher increase, capturing transition and physical risks under different policy and technological pathways. These scenario analyses must be carried out at regular intervals. SNCU are exempted from this specific requirement in recognition of their more limited resources and risk exposures. Beyond climate, the ORSA must systematically address macroprudential aspects: undertakings have to consider macroeconomic conditions, potential developments in financial markets and, where requested by the supervisory authority, structural macroprudential concerns such as credit cycles, herding behaviour in investment strategies or excessive concentrations at market level.
This macroprudential perspective must also be incorporated into underwriting and investment activities and into risk-management practices more broadly. Undertakings are expected to take into account the collective behaviour of market participants and the potential amplification of risks through common exposures or correlated strategies. Supervisory authorities, in turn, are required to share their assessments with relevant national bodies, thereby linking microprudential supervision with the broader framework of financial stability oversight. Cross-border activities considered significant receive particular attention, with formalised information flows between home and host authorities and the possibility for host supervisors to address requests directly to undertakings or to participate in joint on-site inspections where there are indications of non-compliance with capital requirements.

3.1.3 Quantitative Requirements, Macroprudential Tools, Supervision and Reporting

On the quantitative side (Pillar I), Directive (EU) 2025/2 introduces important changes to the valuation of technical provisions, to the calibration of the risk margin and to elements of the standard formula for the SCR. These changes are closely linked to the objective of supporting long-term business models while preserving a high level of policyholder protection.
The calculation of the risk margin is modified to take explicit account of the time dependency of risks. The new approach incorporates an exponential, time-dependent component that generally reduces the risk margin for long-term liabilities, thereby moderating the capital intensity of long-duration contracts and bringing the prudential valuation closer to underlying economic reality. The cost-of-capital rate used in the calculation is set at 4.75% from 2027 onwards, with periodic reviews to ensure that it remains within a corridor between 4% and 5%. With respect to the best estimate of technical provisions, SNCU and undertakings that obtain prior supervisory approval may use a prudent deterministic valuation for certain life obligations with options and guarantees that are not considered material, enabling targeted simplifications without undermining reliability.
Within the SCR standard formula, several sub-modules are recalibrated. In the interest-rate risk sub-module, methodologies and parameters must reflect the possibility of further declines in interest rates even when they are already low or negative, while excluding the risk of rates falling below a predetermined negative floor. The implementation of the revised interest-rate shock is phased in over a transitional period of up to five years to avoid abrupt changes in capital requirements. To incentivise genuinely long-term equity investments, the Directive facilitates the use of a more favourable standard parameter corresponding to an instantaneous loss of 22% for qualifying equity exposures held with an average holding period of more than five years, subject to stringent conditions demonstrating the undertaking's ability to avoid forced disposals in stressed market conditions. In addition, the symmetric adjustment to the equity capital charge is redesigned so that it cannot reduce or increase the equity requirement by more than 13 percentage points relative to its standard level, thereby dampening procyclicality. Undertakings may also rely

on simplified calculations for risk modules or sub-modules deemed non-material, provided that each such module represents less than 5% of the Basic SCR and that the aggregate effect of simplifications does not exceed 10% of the Basic SCR, with a maximum duration of three years.

New macroprudential and liquidity-related instruments complement these quantitative adjustments. Undertakings must establish and regularly update a liquidity risk management plan covering the analysis of short-term cash flows and, where required by the supervisory authority, medium- and long-term flows as well. SNCU are exempt from the requirement to prepare such a plan. Where an undertaking's solvency position deteriorates, supervisory authorities may take preventive measures, including the request to update preventive recovery plans or to implement the measures set out in those plans. They may also require the suspension or restriction of variable remuneration, bonuses or capital distributions when these would jeopardise the undertaking's financial position. In exceptional circumstances that give rise to material liquidity risk, and only as a measure of last resort, supervisory authorities may temporarily suspend policyholders' surrender rights in life insurance contracts for up to three months, provided that the suspension serves the collective interest of policyholders and beneficiaries. During periods of exceptional sector-wide shocks, authorities may also require particularly vulnerable undertakings to limit or suspend distributions such as dividends, bonuses and share buy-backs.

The Directive reshapes the reporting and disclosure framework (Pillar III). The Regular Supervisory Report is generally submitted every three years, with the possibility of longer intervals for SNCU, and may also be prepared on a consolidated basis for groups. Submission deadlines are extended to 18 weeks for solo undertakings and 24 weeks for groups to allow for improved reporting quality. The Solvency and Financial Condition Report is restructured into two parts with distinct audiences. One part is addressed to policyholders and beneficiaries and provides essential information on the nature of the business, the main risks, including sustainability-related risks, and the capital position. The other part targets professional users and contains detailed technical data, including the calculation of SCR and MCR, the effects of long-term guarantee and transitional measures and exposures to climate-related risks. The audit requirement applies to undertakings that are neither SNCU nor captives, and flexibility is introduced with regard to reporting deadlines and procedures in exceptional circumstances.

At group level, supervision and consolidated solvency assessment are modernised and harmonised. The definition of a group is expanded to capture de facto groups and certain types of third-country holding structures, addressing configurations that may pose systemic or contagion risks but would otherwise escape comprehensive oversight. Group supervisors are granted powers to request structural modifications where the organisation of the group impairs effective supervision. The notion of a small and non-complex group is introduced, enabling proportionality measures similar to those available to SNCU at solo level. The calculation of group solvency is clarified for participations in other financial sectors, which must be assessed in line with the requirements applicable to those sectors, and for immaterial participations and the application of the consolidated minimum capital requirement, including transitional arrangements. Macroprudential tools are extended to the group level, with requirements for group-wide liquidity management plans, the possibility to restrict intragroup transactions in exceptional situations and enhanced reporting obligations through consolidated supervisory and public reports, subject to audit. For groups whose ultimate parent is located in a non-equivalent third country, the group supervisor may require the establishment of an intermediate EU holding company or impose limits on transactions that could threaten the financial position of EU-authorised undertakings.

The updates introduced by Directive (EU) 2025/2 regarding the Internal Model, whether full or partial, are aimed at increasing harmonisation across undertakings' modelling approaches, enhancing the comparability of outcomes, and supporting a more effective integration of macro-prudential considerations into the broader risk-assessment framework. A key change compared with the regime established under Directive 2009 is the introduction of a mandatory requirement for undertakings using an Internal Model to periodically provide an estimate of the Solvency Capital Requirement calculated using the Standard Formula. Under the previous framework, such estimates could be requested at the discretion of the supervisory authority and subject to appropriate justification. The 2025 update makes this a systematic exercise for all Internal Model users, requiring them to submit, every two years, an SCR calculated in accordance with the Standard Formula. The objective is to generate comparable indicators across undertakings using different modelling approaches and to facilitate longitudinal assessments of their evolving risk profiles, ensuring consistency with the methods and assumptions underlying the Standard Formula.
Directive (EU) 2025/2 also introduces stricter rules for the treatment within Internal Models of the impact of credit-spread movements on the Volatility Adjustment. When a supervisory authority authorises an undertaking to reflect such effects in its model, the resulting SCR may not fall below a predefined notional minimum. This floor must be calculated either using EIOPA's methodology or on the basis of the undertaking's asset portfolio. The intention is to prevent the VA from producing disproportionately large reductions in capital requirements and to preserve its role as a stabilising mechanism intended to mitigate excessive bond-spread volatility.
Furthermore, undertakings using an Internal Model must fully exclude the macro-component of the Volatility Adjustment. Including such a component within the Internal Model would materially weaken incentives to maintain resilience during systemic stress and would undermine the prudential purpose of the macro-component within the macro-prudential framework.
The changes introduced by Directive (EU) 2025/2 to the Standard Formula affect several core dimensions: the adjustments to the risk-free curve and to technical provisions, the calibration of SCR risk modules, and the reinforcement of the proportionality principle through explicit quantitative criteria.

- **Adjustments and technical provisions.**
  - Risk Margin: the Risk Margin is subject to significant methodological and parametric revisions. From 30 January 2027, the cost-of-capital rate is set at 4.75% (currently 6%), with the possibility of revision only from 31 January 2032 and within a 4 to 5% corridor. The calculation method is refined through the introduction of a time-dependent exponential factor, built on a time-adjusted SCR profile. This update provides a more realistic representation of the temporal decline of non-hedgeable risks and results in a lower Risk Margin, particularly for long-duration liabilities.
  - Volatility Adjustment: the Volatility Adjustment framework is strengthened from both an authorisation and methodological perspective. Its application is now subject to prior supervisory approval. The calculation must include an undertaking-specific adjustment that incorporates the credit-spread sensitivity ratio of the asset portfolio and the interest-rate sensitivity of the best estimate of technical provisions. The proportion of the risk-corrected spread that can be added to the risk-free curve is increased to 85%. The previous country component is replaced with a macro-component defined by the difference between the euro-

area risk-corrected spread and the country-specific risk-corrected spread, with the aim of reducing discontinuities and mitigating cliff-edge effects.

  – Risk-free interest-rate term structure: the revised extrapolation methodology for the risk-free curve includes a phased-in transition mechanism to ensure a gradual implementation. This feature is particularly relevant for life insurers with long-term liabilities that are sensitive to changes in the extrapolated section of the curve.

- **SCR risk modules.**
  – Equity risk: the symmetric adjustment for equity risk is revised to allow a broader variation range, enabling adjustments of up to 13 percentage points relative to the standard charge, compared with the previous 10-point limit. The Directive also introduces a dedicated prudential treatment for long-term equity investments, allowing for a more favourable calibration under specific conditions. As a result, the duration-based equity sub-module under Article 304 of Directive 2009, already subject to restrictive criteria, is discontinued for new applications from 30 January 2027, with grandfathering for undertakings that were already applying it.
  – Interest-rate risk: the interest-rate risk sub-module is recalibrated to reflect environments characterised by very low or negative interest rates. The revised calibration includes an explicit negative floor designed to avoid excessively large downward shocks to the curve and preserve realistic rate dynamics.

- **Proportionality and simplified calculation.**
  – Simplifications for immaterial risks: Directive (EU) 2025/2 introduces explicit quantitative criteria defining when a risk module or sub-module may be considered immaterial. Undertakings may use simplified calculations if the module contributes no more than 5% to the basic SCR, subject to a cumulative ceiling of 10% and a maximum duration of three years. This approach allows undertakings to focus analytical efforts on material areas while maintaining robust capital assessment standards.
  – Small and Non-Complex Undertakings (SNCU): the Directive formally introduces the category of small and non-complex undertakings, which automatically benefit from proportionality measures. These undertakings may use simplified calculations when a module or sub-module contributes less than 2% to the basic SCR, subject to the cumulative limit of 10%. This clarification supports a more consistent and coherent application of the proportionality principle across Member States.

4. Deep Dive Into Standard Approach and Internal Models in Insurance

With the entry into force of Solvency II, European insurance undertakings must hold enough capital to ensure that, with a probability of 99.5% over a one-year horizon, losses do not wipe out their own funds. The regulation provides two methodologies for calculating the capital requirement (SCR):

1. **Standard approach (Standard Formula)**: a predefined method applicable to all firms using uniform regulatory parameters. It is based on risk modules (market, counterparty, life, non-life, health, operational, intangible) and uses fixed correlation coefficients. This is the default option for companies that do not have an approved internal model.

2. **Internal model (IM)**: a quantitative model developed by the company to reflect its own risk profile. It requires approval by the supervisory authority and must meet criteria for effective use, statistical quality, calibration, validation and documentation. The company is free to define risks, risk measures and aggregation methods [8].

The choice between the standard approach and an internal model influences the level of capital required, risk sensitivity and management strategies. The following sections present technical details of the two methods, with formulas, analogies and practical implications for a technically advanced audience.

4.1 The Standard Approach

The standard approach provides a module-based approximation of the Solvency Capital Requirement. It translates complex risk profiles into a modular structure supported by prescribed shocks and linear correlations.
At its core, the method offers a transparent and harmonised framework for capital calculation, enabling comparability across undertakings while relying on strong simplifying assumptions.

4.1.1 Modular Architecture and Variance-Covariance Method

The standard formula is built hierarchically. Each risk (e.g., market, counterparty, non-life) is decomposed into sub-modules (interest rate, equity, spread, catastrophe, etc.). For each sub-module an undiversified capital requirement SCR_i is calculated via volatility factors or shock scenarios. Aggregation is performed using the square-root formula:

$$SCR_{module} = \sqrt{\sum_{i,j} \rho_{ij}\ SCR_i\ SCR_j},$$

where ρ_{ij} is the correlation coefficient prescribed by the regulation between sub-modules i and j . For example, QIS5 for life risk proposes correlations such as -0.25 between longevity and mortality risk or 0.5 between expenses and revision risk [2]. The same scheme applies at the higher level to aggregate modules into the Basic SCR and then add operational risk and the loss-absorbing capacity adjustment.
The key assumption of the previous formula is that losses are elliptically distributed (normal or lognormal) and dependence is linear. The square-root formula derives from an approximation of the total variance: if $L = \sum_i L_i$ with $\mathbb{E}\left[L_i\right] = 0$, then $Var\left(L\right) = \sum_i \rho_{i,j}\sigma_i\sigma_j$. Implicitly, the risk measure is assumed to be proportional to the standard deviation. Correlations include a prudence margin and are typically 1, 0.5 or 0.25 [3].

4.1.2 Non-life Risk Calculation: Combining Premium and Reserve

In the non-life module the standard formula estimates three components: premium risk, reserve risk and catastrophe risk. For each of the 12 lines of business (LOB) the standard deviations σ_{prem} and σ_{res} are determined from regulatory tables [3]. The two risks for each LOB are combined with a fixed correlation of 50%:

$$\sigma_{LOB} = \sqrt{\frac{Prem^2\sigma_{prem}^2 + Res^2\sigma_{res}^2 + Prem \cdot Res \cdot \sigma_{prem} \cdot \sigma_{res}}{(Prem + Res)^2}}.$$

A geographic diversification factor is then applied to reduce the volume if the portfolio is spread across multiple countries [3]. Aggregation across LOBs uses a 12x12 correlation matrix with entries 1, 0.5 or 0.25 [3]; the total standard deviation is:

$$\sigma_{\text{tot}} = \sqrt{\frac{1}{V_{\text{tot}}^2} \sum_{j,k} \rho_{jk}\, \sigma_j\, \sigma_k\, V_j\, V_k},$$

where V_j are the volumes (premiums + reserves) after diversification. Finally, the underwriting capital requirement is approximated as three times σ_{tot}, consistent with the 99.5% VaR of a lognormal distribution [3]. Analogous formulas exist for life, health and market modules, with predefined shock scenarios (e.g., $\pm$15% on mortality rates, $\pm$100 bps interest-rate shock, 39% equity drop) [2]. Risk factors are calibrated at European level and represent a compromise between simplicity and prudence.

4.1.3 Conceptual Limitations and Issues

Although the standard formula offers a coherent and easily implementable framework, its underlying assumptions and structural design inevitably introduce some conceptual limitations. In practice, several recurring issues are well-known to practitioners:

- **Simplicity vs. realism**: the standard approach operates like a "pre-printed correlation matrix". All insurers use the same parameters regardless of portfolio composition. This ensures comparability, but penalises companies with highly diversified portfolios or strongly skewed distributions.
- **Normality and linearity**: the square-root formula and constant correlations assume losses follow an elliptical distribution and dependence is linear. In the presence of heavy tails or conditional correlations (tail dependency), aggregation may under- or over-estimate diversification [8].
- **Fixed modularity**: the structure of modules and sub-modules is predefined; risks cannot be refined further. The standard approach does not include expected profits or stochastic expenses and can be conservative for complex assets (e.g. equity-release mortgages, infrastructure).
- **Risk proxies**: the formula does not account for the full spectrum of emerging risks (cyber, climate change, ESG risks) and does not allow multi-year measurements. It is therefore suitable as a rule of thumb but not as a trategic planning tool.

4.2 Internal Models

An internal model allows the SCR to be calculated using the company's own definitions of risks, measures and aggregation methods. According to EIOPA, a firm can:

- Define risk factors and build the full loss distribution instead of focusing solely on volatility [8];
- Choose risk measures other than VaR, such as Tail Value-at-Risk (TVaR) or Expected Shortfall, which are more sensitive to tails;

- Use longer time horizons to capture economic cycles;
- Model dependence via copulas (Gaussian, t-Student, vine copula) and introduce tail dependency, going beyond linearity [8];
- Adopt alternative aggregation schemes: bottom-up integration (joint simulation of all risks), modular approach (aggregating profits and losses at module level with calculated correlations) or sideways integration (aggregating cross-cutting risks) [8].

The flexibility of an internal model is comparable to designing a high-resolution navigation system: instead of following a pre-printed map, the firm builds a dynamic map based on its own data and chooses the desired level of detail. This freedom enables recognition of diversification between segments ignored by the standard formula and inclusion of mitigation strategies (reinsurance, derivatives, matching adjustment).
Unlike the standard formula, internal models compute the risk measure directly from the simulated distribution. The 99.5% VaR is defined as $\inf\{x : F_L(x) \geq 0.995\}$, while Expected Shortfall (TVaR) is the conditional expectation of loss beyond the VaR: $TVaR_{99.5\%} = \mathbb{E}\left[L \mid L > VaR_{99.5\%}\right]$. Many firms use TVaR because it penalises tails more and provides a more stable estimate. Risk aggregation can be performed via copulas; for example, a t-Student copula with 10 degrees of freedom captures greater tail dependency than the Gaussian. The internal model can also calibrate stochastic correlations that vary with market conditions.
Sensitivity and capital contributions. The EIOPA study introduces risk multiplier and correlation multiplier indicators to assess sensitivity of diversified capital to individual risks and correlations:

- **Risk multiplier**: measures how much the diversified capital requirement changes in response to a small increase in an undiversified SCR. Formally, if SCR^{VC} is the diversified SCR and $undivSCR_i$ the undiversified requirement of risk i, the risk multiplier is approximately:

$$riskMultiplier_i = \sum_j \rho_{ij} \frac{undivSCR_i}{SCR^{VC}} \frac{undivSCR_j}{SCR^{VC}},$$

  where $SCR^{VC} = \sqrt{\sum_i \sum_j \rho_{ij} undivSCR_i undivSCR_j}$ is the variance covariance diversified capital requirement. A risk multiplier of 50% for market risk implies that increasing its undiversified SCR by 2 units raises the diversified SCR by 1 unit [8].

- **Correlation multiplier**: evaluates how a small variation in the correlation ρ_{ij} between two risks affects the diversified capital. It is defined as the derivative of $\mathrm{SCR}_{\mathrm{div}}$ with respect to ρ_{ij}, normalised by the diversified SCR [8]. High values indicate that dependence between those risks is a major driver; validating this requires sensitivity tests on alternative copula structures [17].

4.2.1 Advanced Modelling Techniques

For non-life risk, internal models use frequency-severity or collective risk models. Frequencies are modelled with Poisson, negative binomial or more complex count models; severities with lognormal, Pareto or Burr distributions. Monte Carlo simulation aggregates the number of claims and loss amounts to generate the loss distribution. For instance, an internal model may combine collective risk theory with log-normal bootstrap techniques

for reserve risk, potentially achieving a more risk-sensitive capital assessment than the standard volatility-factor approach.
Beyond simulation-based approaches, there is also an extensive actuarial and operational-risk literature on analytical and semi-analytical approximations for frequency-severity models. In the classical collective risk framework, the aggregate annual loss can be represented as a compound process:

$$S_T = \sum_{k=1}^{N_T} X_k,$$

where N_T denotes the number of loss events over the time horizon T, typically modelled as a Poisson or mixed Poisson process, and X_k are independent severity amounts. When $N_T \sim Poisson(\lambda T)$, the aggregate loss S_T follows a compound Poisson process. This representation is common in insurance risk modelling and has also been extensively developed in the banking literature on Operational Risk under the Basel framework, particularly through the Loss Distribution Approach, where frequency and severity distributions are estimated separately and then compounded to obtain the annual loss distribution.
The Operational Risk literature has provided important contributions to analytical approximations for high quantiles of aggregate loss distributions, especially in heavy-tailed settings where direct convolution is difficult and Monte Carlo simulation may require a very large number of scenarios to estimate extreme percentiles accurately. Among these methods, the Single Loss Approximation provides closed-form asymptotic approximations of risk measures such as Value-at-Risk and Expected Shortfall by exploiting the fact that, for sub-exponential or heavy-tailed severity distributions, the tail of the aggregate loss is often dominated by the largest individual loss [18]. A first-order intuition is that, at high confidence levels, the aggregate loss quantile can be approximated through a transformed severity quantile:

$$VaR_\alpha(S_T) \approx F_X^{-1}\left(1 - \frac{1-\alpha}{\lambda T}\right),$$

with refined versions adding correction terms depending on the expected number of losses and the severity moments. These results are particularly relevant when comparing numerical methods, such as Monte Carlo, Panjer recursion or Fourier-transform techniques, with analytical approximations for capital estimation.
For market and balance sheet risk, internal models employ nested simulations: each real-world scenario (outer simulation) is linked to multiple risk-neutral scenarios to value assets and liabilities. This technique, known as Nested Monte Carlo, is computationally intensive. To reduce the burden, replicating portfolios and Least Squares Monte Carlo (LSMC) are used. LSMC approximates the value of assets and liabilities with regressions on a few inner simulations, producing accurate estimates in shorter times [16]. LSMC and replicating portfolios are now standard in life internal models to value products with options and guarantees.

4.2.2 Approval, Governance and Validation

To obtain approval of an internal model, a company must pass the Use Test (showing use in day-to-day management), meet statistical quality and calibration standards and document the model. The process includes:

- **Calibration**: deriving parameters from internal data (claims, exposures) or external sources; for market risk, forward curves, implied volatilities and updated mortality tables are used. Supervisors require external benchmarks to avoid excessively optimistic calibrations [1].

- **Validation**: testing model adequacy bottom-up and top-down. Lloyd's 2025 guidelines emphasise that validating dependencies is complex and requires sensitivity tests on copula parameters and comparisons with historical data or stress tests [17]. It is necessary to justify the choice of dependency structures and show the presence (or absence) of tail dependency.

- **Profit & Loss attribution and model drift**: comparing simulated performances with actual results, analysing deviations and updating parameters. Documentation must be complete and available to the supervisor [17].

4.2.3 Practical Advantages and Disadvantages

Internal models offer clear advantages over the standard formula but introduce their own set of challenges. Their use therefore reflects a balance between greater accuracy and increased complexity. The main benefits and drawbacks typically recognised in practice are the following:

Advantages

- Customisation and precision: internal models capture portfolio-specific volatility, fully recognise diversification and include expected profits and stochastic expenses. Tail and copula modelling provides a more robust estimate of capital than the standard approach.

- Capital optimisation: numerous studies show that internal models reduce the SCR relative to the standard formula, with average reductions of 8.7% for life companies. This benefits investments and asset-liability management strategies.

- Support for risk management: building the model enhances risk awareness, provides indicators for capital allocation and allows designing more efficient products and reinsurance [1]. The longer time horizon (>1 year) enables inclusion of climate and sustainability risks.

Disadvantages

- Costs and complexity: developing an internal model requires significant investment in systems, data and expertise. Even with proxy modelling techniques like LSMC, data management and maintenance remain onerous [1].

- Regulatory oversight and conservatism: supervisors may impose prudential margins or limit diversification benefits [1]. Approval is a formal process and the company is obliged to use the model until new approval is granted.

- Modelling risk: errors, wrong assumptions or unstable parameters can lead to misestimation of capital. Validation must address tail dependency and consistency with reality.

- Comparability and transparency: modelling freedom makes it difficult to compare results across firms. EIOPA has highlighted wide variation in diversification levels; metrics such as the risk multiplier are needed to understand which risks drive capital [8].

Aspect	Standard Formula	Internal Model
Metaphor	A "cut-and-paste" method: the firm applies predefined parameters and correlations, akin to using a recipe book.	A custom lab: the firm builds its own model like an engineer designing an aircraft, choosing materials and testing interactions.
Definition of risks	Fixed modules and sub-modules with predefined volatility factors.	Risks defined by the firm; can include emerging risks, climate risks, options and guarantees [10].
Dependence	Constant linear correlations (0, 0.25, 0.5, 1). Do not capture tail dependency [5].	Flexible dependence structures: Gaussian or t-Student copulas, stochastic correlations, dynamic market factors. Can model tail dependence [10].
Risk measure	Based on standard deviation and lognormal approximation. Implicitly uses VaR at 99.5% via constant 3 [5].	Can adopt VaR, TVaR or other coherent measures. Uses the simulated distribution of results.
Diversification	Predefined by the correlation matrix; does not recognise complex diversification across new risks.	Calculated based on portfolio profile. Can fully recognise reinsurance and hedging strategies.
Expected profits and expenses	Not considered, leading to higher capital.	Included in the economic valuation.
Regulation and costs	No approval required; quick and low-cost implementation.	Requires approval and high costs; mandatory use once approved.
Governance	No need for complex internal structures; compliance is limited.	Requires use tests, validation, documentation, robust governance and ongoing review [18].

TABLE 1: Comparison of Standard Formula and Internal Model.

4.3 Analogies and Comparisons between the Two Approaches and Strategic Implications

Some practical and strategic implications emerge when comparing the two approaches, as the choice between standard formula and internal model affects not only the level of capital but also pricing, risk management, investment decisions and the way results are communicated across the organisation:

- **Capital and pricing**: the standard approach tends to generate higher capital when loss distributions are asymmetric or when real correlations are lower than the prescribed ones. For companies with simple or monoline portfolios, this excess capital represents a safety margin and can reduce modelling burdens. However, for diversified firms or those with complex mitigation structures, extra capital may hurt competitiveness. Internal models allow pricing optimisation by accounting for capital costs per line of business and enabling targeted reinsurance strategies.

- **Risk management and asset allocation**: an internal model provides granular analysis for each risk driver, allowing identification of the most capital-consuming lines of business. Sensitivity metrics (risk multiplier) help understand which risks have the greatest impact on capital and evaluate the effectiveness of hedges [8]. In financial terms, replicating portfolios and LSMC techniques improve asset-liability matching, enabling optimisation of the investment portfolio composition and dynamic evaluation of the matching adjustment.

- **Reporting and communication**: the standard formula produces a result that is easily communicated to supervisors and shareholders. Internal models, while more accurate, generate complex outputs that require technical expertise to interpret. It is vital to create clear reports for management and ensure that governance understands key assumptions and sources of uncertainty.

- **Key elements to be taken into account when choosing the approach**:
  1. Size and complexity of the firm: large companies with multi-line portfolios and sophisticated strategies benefit more from internal models; smaller companies may prefer the standard approach to minimise costs;
  2. Data availability and resources: an internal model requires long, granular time series, IT infrastructure and quantitative teams; without these resources, the standard formula remains the only option;
  3. Capital benefit vs. costs: the company must assess whether the reduction in SCR justifies development costs and approval risk. The presence of expected profits not recognised by the standard formula can be a decisive driver;
  4. Mitigation strategies: heavy use of reinsurance, derivatives or asset-liability management techniques can only be fully valued through an internal model;
  5. Regulatory outlook: more flexible regulations (like Solvency UK) simplify internal model approval [5]; firms should anticipate such developments.

4.4 Solvency II Review and Implications

At the end of 2023 European institutions reached a compromise on the review of Solvency II; the amended directive entered into force in January 2025 (see Section *"Solvency II: Framework Evolution"*) and member states have two years to transpose it, with full effect expected by 2027 [20]. This review aims to free up capital and encourage long-term investment while maintaining policyholder protection. The main changes affect long-term measures and the interest-rate framework and include:

1. **Risk Margin reduction and introduction of λ**: the review lowers the Cost of Capital (CoC) from 6% to 4.75% and introduces a tapering factor (lambda) to reduce the weight of long-term exposures. In the new scheme the Risk Margin is calculated by projecting the SCR for each year t, multiplying each projection by λ_t (with $0 \leq \lambda_t \leq 1$) and discounting at the risk-free rate [19]. EIOPA proposed an exponential curve with $\lambda_t = 0.975^t$ and a floor at 50%; the final compromise removed the floor but keeps the flexibility to define λ in Level 2 texts [15]. In a case study, applying a CoC of 4.75% and λ=0.975 reduces the Risk Margin by about 34%, freeing capital and boosting the solvency ratio by more than 20 percentage points [19]. Aegon notes that the exponential taper reduces interest-rate sensitivity of the Risk Margin by 40% for maturities of 20 years and brings the European CoC close to the UK regime, though still higher than in other jurisdictions [20].

2. **Volatility Adjustment (VA) revision**: the VA, added to the discount rate to dampen the impact of spread movements, is recalibrated. The general application ratio for the risk-corrected spread increases from 65% to 85%, and a Credit Spread Sensitivity Ratio (CSSR) is introduced to measure the alignment of the company's portfolio with the representative portfolio [19]. The new currency component formula becomes $VA_{\text{currency}} = 85\% \times CSSR_{\text{currency}} \times RCS_{\text{currency}}$ [20]. The volatility adjustment for the euro can be increased by a macro volatility adjustment, that depends on the country. A firm-specific adjustment is also allowed, subject to supervisory approval, to use the

firm's own portfolio spreads for two consecutive quarters, capped at 105% [15]. The case study company's simulations show that increasing the VA by 10 bps raises the solvency ratio by about 4 points by reducing the best estimate of reserves [19].

3. **Relaxing Long-Term Equity (LTE) constraints**: the LTE module provides a reduced capital charge (22%) for equities intended to be held long term. The review removes the ring-fencing requirement of assets and liabilities and reduces the minimum holding period from 12 to 5 years; it also extends eligibility to all OECD countries (not just EU/EEA) and requires adequate portfolio diversification [19]. Aegon reports that the new directive eliminates the need to couple the equity portfolio to a specific liability portfolio and limits the no forced-selling condition to five years [20]. In the case study mentioned above, reallocating 30% of equities into LTE reduces the market capital charge by about CHF 101 k and raises the solvency ratio by 5 points [19].

4. **Revising interest-rate risk and discount-curve extrapolation**: a new extrapolation method will replace the Smith-Wilson model: starting at the First Smoothing Point (FSP, 20 years for the euro), forward rates will converge gradually to the Ultimate Forward Rate (UFR) with a minimum weight of 77.5% after 40 years [15]. The proposed curve is slightly lower at long maturities and alters rate sensitivity; the transition will be gradual until 2032 [15]. In parallel, interest-rate shock parameters in the standard module have been revised: in addition to multiplicative factors, additive shocks are introduced and the 1% floor for up-rate scenarios is removed [15]. A five-year transition period is envisaged for these new shocks.

5. **Width of the Symmetric Adjustment and other novelties**: the band for the symmetric adjustment on equity risk widens from ±10% to ±13%, allowing a stronger counter-cyclical margin during extreme markets [20]; parameters for infrastructure assets and matching adjustment are revised to recognise diversification; criteria are introduced to classify small and non-complex undertakings (SNCU) with proportional reporting measures and reduced requirements [15]. In Pillar 2, the review introduces requirements on liquidity planning, diversity objectives and sustainability risks, while Pillar 3 provides more flexible reporting deadlines and certification by registered actuaries [15].

4.4.1 Implications for Internal Models and Standard Approach

The changes will have different impacts on the two approaches:

- **Standard formula**: the reduction of the Risk Margin and the higher VA will result in a lower solvency capital requirement, partly narrowing the gap with internal models. The expanded LTE eligibility and the new symmetric adjustment provide more flexibility in investment strategies. However, the complexity of the new VA (CSSR, macro-VA and firm-specific factor) may require more elaborate calculations and portfolio data collection, bringing the standard approach closer to a quasi-model approach.

- **Internal models**: the new framework allows firms with internal models to use dynamic VAs based on their own spreads and to model the curve extrapolation and Risk Margin with the new λ. Copula and simulation techniques can incorporate the CSSR and the new interest-rate shocks to reflect the risk profile faithfully. However, the overall reduction of capital under the standard formula could reduce the competitive advantage of internal models; to justify their costs, firms will need to exploit the flexibility to include emerging risks, ESG planning and advanced reinsurance structures. The introduction of sustainability and liquidity measures in Pillar 2 aligns well with internal models, which can model multi-period scenarios and measure capital resilience.

In summary, the review of Solvency II is a step towards a more calibrated and sustainable regulatory framework, but its effectiveness will depend on the final calibration of parameters and the adoption of proportionate operational tools. Companies must carefully evaluate how to integrate the new rules into their capital management strategy and whether to retain or develop an internal model to maintain a competitive edge.

4.4.2 Industry Criticism and Comments

Despite the expected benefits, several associations believe the Level 2 proposals are not ambitious enough. Insurance Europe warned in 2025 that mis-calibration of the VA (especially the risk-correction component) and the new long-term interest-rate model could leave insurers exposed to artificial volatility, and that the review still limits the use of the LTE module. It emphasised that, while welcoming the reduction of the Risk Margin, Europe remains less competitive than other jurisdictions and the new rules introduce additional operational complexity and administrative burdens. The association therefore calls for further refinement of calibrations to generate growth and free up capital.

4.4.3 Further Developments

- **Regulatory reforms and proportionality**: the review of Solvency II and the adoption of Solvency UK will introduce greater proportionality and simplification. The shift from an "approval" regime to a "permission" regime reduces documentation burdens and accelerates authorisation, encouraging internal model adoption [5]. In parallel, EIOPA is studying metrics to compare diversification levels among models and may issue guidelines for comparability [8].

- **Integration of emerging risks**: Supervisors will require integration of climate, ESG and cyber risks in both the standard formula and internal models. The standard approach may be updated with new factors or scenario shocks; internal models, thanks to their flexibility, can already incorporate climate transition scenarios or sustainability-related shocks. Convergence between Solvency II and IFRS 17 means valuation models must align with accounting; internal models facilitate this integration.

- **Technological innovation**: the use of machine learning and artificial intelligence (e.g., neural networks for LSMC, deep learning models for replicating portfolios) is improving the ability to model losses and reduce computation times. Research is underway on transformer-based and explainable models for risk quantification. Authorities are exploring digital tools to monitor model adequacy in real time and facilitate continuous validation.

References

[1] **Chaplin, R. A.** *The Standard Formula: A Guide to Solvency II - Chapter 9: Internal Models*. Skadden Publication, July 2024.

[2] **Christiansen, M.C.** *A sensitivity analysis concept for life insurance with respect to a valuation basis of infinite dimension*. Insurance: Mathematics and Economics, April 2008.

[3] **Cofield, J., Kaufman, A. and Zhou, C.** *Solvency II Standard Formula and NAIC Risk-Based Capital (RBC)*. Casualty Actuarial Society, Fall 2012.

[4] **Consiglio dei Ministri.** *Decreto Legislativo 3 novembre 2003, n. 307*. Gazzetta Ufficiale della Repubblica Italiana, November 2003.

[5] **Dooley, A.** *Internal Models Under Solvency UK: Challenges and Opportunities*. Insurance Insights, July 2024.

[6] **EIOPA.** *Insurance Risk Dashboard*. EIOPA-BoS-25-174, April 2025.

[7] **EIOPA.** *Peer Review Work Plan 2023-2024*. EIOPA-BoS-22/345, June 2022.

[8] **EIOPA.** *Study on Diversification in Internal Models*. January 2024.

[9] **EIOPA.** *Technical advice on the implementation of the new proportionality framework under Solvency II*. EIOPA-BoS-24-590, January 2025.

[10] **European Parliament and the Council.** *Directive 2002/12/EC*. Official Journal of the European Communities, March 2002.

[11] **European Parliament and the Council.** *Directive 2009/138/EC*. Official Journal of the European Union, November 2009.

[12] **European Parliament and the Council.** *Directive 2014/51/EU*. Official Journal of the European Union, April 2014.

[13] **European Parliament and the Council.** *Commission Delegated Regulation (EU) 2015/35*. Official Journal of the European Union, October 2014.

[14] **European Parliament and the Council.** *Directive (EU) 2025/2*. Official Journal of the European Union, November 2024.

[15] **Garg, D. and Burke, S.** *Solvency II Amendments*. Finalyse, June 2024.

[16] **Leitschkis, M.** *Solvency II proxy modelling via Least Squares Monte Carlo*. Milliman, January 2012.

[17] **Lloyd.** *Internal Model Validation Guidance*. Lloyd's Guidance on Solvency UK Internal Model Validation, April 2025.

[18] **Peters, G. W. and Shevchenko, P. V.** *Single Loss Closed-Form Approximations of Risk Measures*. In *Advances in Heavy Tailed Risk Modeling: A Handbook of Operational Risk*, Chapter 8, pp. 433–516. John Wiley & Sons, 2015.

[19] **PwC.** *Unlocking opportunities under Solvency II Revisions effective 2027*. 2025.

[20] **Van Bragt, D.** *The Solvency II review has finished - What will change?* AEGON Insights, September 2024.

Iason is an international firm that consults Financial Institutions on Risk Management. Iason is a leader in quantitative analysis and advanced risk methodology, offering a unique mix of know-how and expertise on the pricing of complex financial products and the management of financial, credit and liquidity risks. In addition Iason provides a suite of essential solutions to meet the fundamental needs of Financial Institutions.