TECHNICAL ASSISTANCE REPORT

LUXEMBOURG

Pension Projection Assessment

December 2025

Prepared By
Christoph Freudenberg, Timm Bönke and Céline Thévenot

Fiscal Affairs Department

International Monetary Fund, IMF Publications
P.O. Box 92780, Washington, DC 20090, U.S.A.
T. +(1) 202.623.7430 • F. +(1) 202.623.7201
publications@IMF.org
IMF.org/pubs

Contents

TABLES

ANNEXES

Abbreviations and Acronyms

AI	Artificial Intelligence
AWG	Ageing Working Group
CEFN	Conseil Économique et Financier National
CNFP	Conseil National des Finances Publiques
EU	European Union
FAD	Fiscal Affairs Department
IGSS	Inspection Générale de la Sécurité Sociale
IMF	International Monetary Fund
ILO	International Labor Organization
LIAM2	Dynamic Microsimulation for Labour, Income and Ageing Model
LPFP	Loi de Programmation des Finances Publiques
STATEC	Institut national de la statistique et des études économiques

Preface

At the request of the Minister of Finance of Luxembourg, Mr. Gilles Roth, a capacity development mission from the International Monetary Fund (IMF) was conducted in Luxembourg from July 2 to July 4, 2025, followed by online meetings in August 2025. The mission aimed to support the Government in its ongoing efforts to enhance the efficiency and sustainability of the pension system. The purpose of the mission was to evaluate short- and medium-term deviations between projected and actual pension balances, including an analysis of contributing factors, and to evaluate fluctuations in long-term pension projections.

The mission included Mr. Christoph Freudenberg (mission chief, FAD), Ms. Céline Thévenot (Senior Economist, FAD), and Dr. Timm Bönke (FAD expert).

The mission met with the Ministry of Finance, including Mr. Bob Kieffer, Mr. Nicolas Jost, Mr. Jérôme Merker, Mr. Yves Clarens; with the General Inspectorate of Social Security (IGSS), including Mr. Thomas Dominique, Mr. Thierry Mazoyer, Mr. Kevin Everard, the Statistical Institute STATEC team, comprising Mr. Bastien Larue, Mr. Gabriel Gomes, Mr. Michel Geller, Ms. Lena Rota.

The mission would like to extend its gratitude to Mr. Tom Englaro for his invaluable assistance in organizing this mission, as well as to Mr. Kevin Everard and Mr. Thierry Mazoyer for their excellent cooperation throughout the discussions.

Executive Summary

This report reviews Luxembourg's pension projections to help ensure their continued reliability. Short- and medium-term forecasts of fund balances affect fiscal planning, including projected Maastricht Deficit reported to the European Commission. The pension balance was underestimated only modestly over the past decade, averaging 0.04 percent of GDP for one-year horizon projections. A larger deviation was observed during the COVID years, with 0.17 percent of GDP in 2021. Long-term projections have been robust over past projection vintages. The review reflects the commitment of the authorities to maintaining the accuracy and transparency of pension projection balances.

The short-term projections perform well, reflecting regular updates and reviews, with deviations predominantly stemming from the revenue side. During periods of heightened uncertainty—such as the COVID-19 pandemic and the inflationary surge following Russia's war in Ukraine—forecast deviations were pronounced. The underestimation of average real contributions per employee has been the key driver of deviations. Similar deviations in forecasts were observed in peer countries, such as Germany, Belgium, and France. The specificities of the Luxembourg pension system, strongly anchored to inflation reinforces the vulnerability of projections to inflation shocks.

Continued refinements—particularly on the revenue side—could help maintain the high accuracy of short-term pension balances forecasts. Accuracy gains could be achieved by refining some of the foundational input variables, specifically employment and wage forecasts. Continuing to rely on a comprehensive multi-model approach could help to address the need for more flexible models. Further exploring input variables on labor markets in the greater Luxembourg region and gaining insights regarding the sensitivity of forecasts to economic and demographic shifts, could continue enhancing reliability and ensuring robustness.

The observed variability in projections reflects evolving assumptions, demographic shifts, continuous improvements to the pension model, and macroeconomic shocks—such as the COVID pandemic—which were difficult to anticipate. The volatility of long-term pension forecasts was mainly driven by changes in employment and demographic assumptions. The resulting change in projection results is common in EU countries and tends to be more pronounced in smaller states like Luxembourg.

While long-term projections have varied over time, the forecasted timing of key events for the pension fund—such as when reserves are fully depleted—has remained broadly stable. Between 2016 and 2025, estimates of when reserves would be exhausted (key Event 3) have shifted by only 2 years (from 2043 to 2045). Projections consistently also indicate that reserves will drop below the legal minimum of 1.5 times annual pension expenditure (key Event 2) in the late 2030s, triggering a statutory increase in contribution rates. The timing of this event has shifted by 4 years between 2016 and 2025 projections (from 2035 to 2039).

Luxembourg's long-term pension projection meets high international standards, though there remains scope for further improvement. It is recommended to continue reassessing the rate-of-return assumptions applied to the Compensation Fund in national projections and to present the impact of alternative rates: Even under more optimistic return assumptions key Events 2 and 3 would likely be postponed by no more than three years. Recent weak employment growth should be investigated to assess whether employment assumptions should be revised downward – considering also the potential labor market effects of rising AI adoption (discussed in the report). A lower employment growth path could shift critical years forward by around two years. Additionally, consideration could be given to emphasizing distributional aspects of pension reforms backed by micro-simulation models. To improve transparency and build trust in pension projections, communication efforts could be further strengthened. This includes a better communication why estimates have changed with model updates as well as a detailed model description.

Proposed refinements to the pension model are not expected to affect the overarching conclusion that reform is needed to ensure long-term sustainability. Because pension reforms are typically introduced gradually to allow individuals time to adjust, adopting reforms early is strongly advised.

Recommendations

Short-term Projections		
1.1	Publish the established systematic and regular reporting on projection deviations—highlighting the contribution of key macroeconomic variables.	For budget law preparation in 2026
1.2	Refine the input variables—specifically, employment and wage forecasts.	For budget law preparation
1.3	Further develop multi-model approaches to mitigate the risks of a single model forecast projections.	For budget law preparation
Long-term Projections		
2.1	Review rate of return assumptions of the Compensation Fund.	For the next long-term projection
2.2	Examine employment growth assumptions, amid low recent growth.	For the next long-term projection
2.3	Continue considering model improvements, including analyses backed by micro-simulation model.	For 2027+ Projections
2.4	Strengthening communication of model updates and calculations, through greater use of executive summaries.	For 2027+ Projections

I. Introduction

1. **This report reviews the reliability and performance of Luxembourg's pension projections, including aggregate pension expenditures, revenues and balances.** Over recent years, deviations between forecasted and actual pension balances have emerged, particularly during periods of economic volatility such as the COVID pandemic and the inflationary surge following the war in Ukraine. These shocks offer an opportunity to review the robustness of the projection methodologies and their suitability for informing fiscal planning and pension policy. Stakeholders involved in the current pension reform process are committed to regularly assessing the pension projection performance to underpin their decision making and make it evidence based.

2. **Building on existing efforts, this report aims to further strengthen the performance of pension projections by:**

- **Diagnosing the sources of recent projection errors** across short- and medium-term horizons, identifying patterns and structural weaknesses in current forecasting practices.
- **Evaluating the volatility of long-term pension projections** and the assumptions and methodology used to forecast long-term pension expenditure.
- **Benchmarking Luxembourg's experience against international peers**, offering comparative insights, including how pension projections in other countries have performed under recent macroeconomic shocks.
- **Reviewing options to improve accuracy and transparency** of pension forecasts, including enhancements to data integration, modeling techniques, and communication strategies.

3. **The report is structured as follows:** section 2 presents the institutional framework of pension projections, including the frequency of projections as well as the stakeholders involved. Section 3 evaluates past deviations of short- and medium-term projections from observed values, including recommendations on how to improve these forecasts. Finally, the volatility of long-term projections is assessed in section 4, with proposals on how to enhance the modeling framework going forward.

II. Institutional Framework

4. Luxembourg prepares both medium-term and long-term pension financial projections.[1] Every year, Luxembourg conducts two pension medium-term projection exercises (year y-y+4) - in February, as part of the intermediate update of the multiannual trajectory of the social security balance, and in August, in the context of the State budget and the multiannual financial programming act. In addition, long-term pension projections (over a 50-year horizon) are carried out every five years to ensure compliance with Article 238 of the Social Security Code[2]. In addition, projections are carried out every three years to contribute to the Ageing Report coordinated by the EU's Economic Policy Committee using a harmonized methodology and assumptions (AWG).

5. The General Inspectorate of Social Security (IGSS) plays a central role in pension forecasting. The pension projection process involves several institutions, each with clear responsibilities (Figure 1). IGSS oversees both the medium- and long-term forecast as well as the consistency of the overall framework.[3] The National Pension Insurance Office prepares annually the pension expenditure and revenue forecast for the following years based on a budgetary circular from IGSS. This budget is reviewed by IGSS and endorsed by the Minister of Health and Social Security. It is a key input for the medium-term pension projections performed by IGSS.

6. STATEC, the national statistical institute, provides macroeconomic assumptions for the medium-term projection (employment, wages and inflation). STATEC also supplies long-term demographic projections and alternate macroeconomic scenarios, which are critical for (national) long-term pension sustainability assessment.

7. The European Commission is part of the process by providing harmonized macro-economic assumptions for AWG projections as well as demographic assumptions based on Eurostat projections.

8. Last, the Ministry of Finance receives the results of the medium-term projections to build its pluriannual financial programming and the budget process.

9. The National Council of Public Finance (Conseil National des Finances Publiques, CNFP) and the National Economic and Financial Council (Comité Economique et Financier National, CEFN) serve as fora to discuss the projections. The CNFP is an independent body in charge of budgetary projections. The CEFN gathers IGSS, STATEC and Ministry of Finance to discuss the projection exercise. Meetings include an in-depth analysis of the factors that explain deviations from the previous projection, however, there is currently no formal communication on the sources of projection deviations—whether due to macroeconomic variables or to the projection methods themselves. This represents a gap that this report seeks to address, particularly for past estimates. The authorities,

---

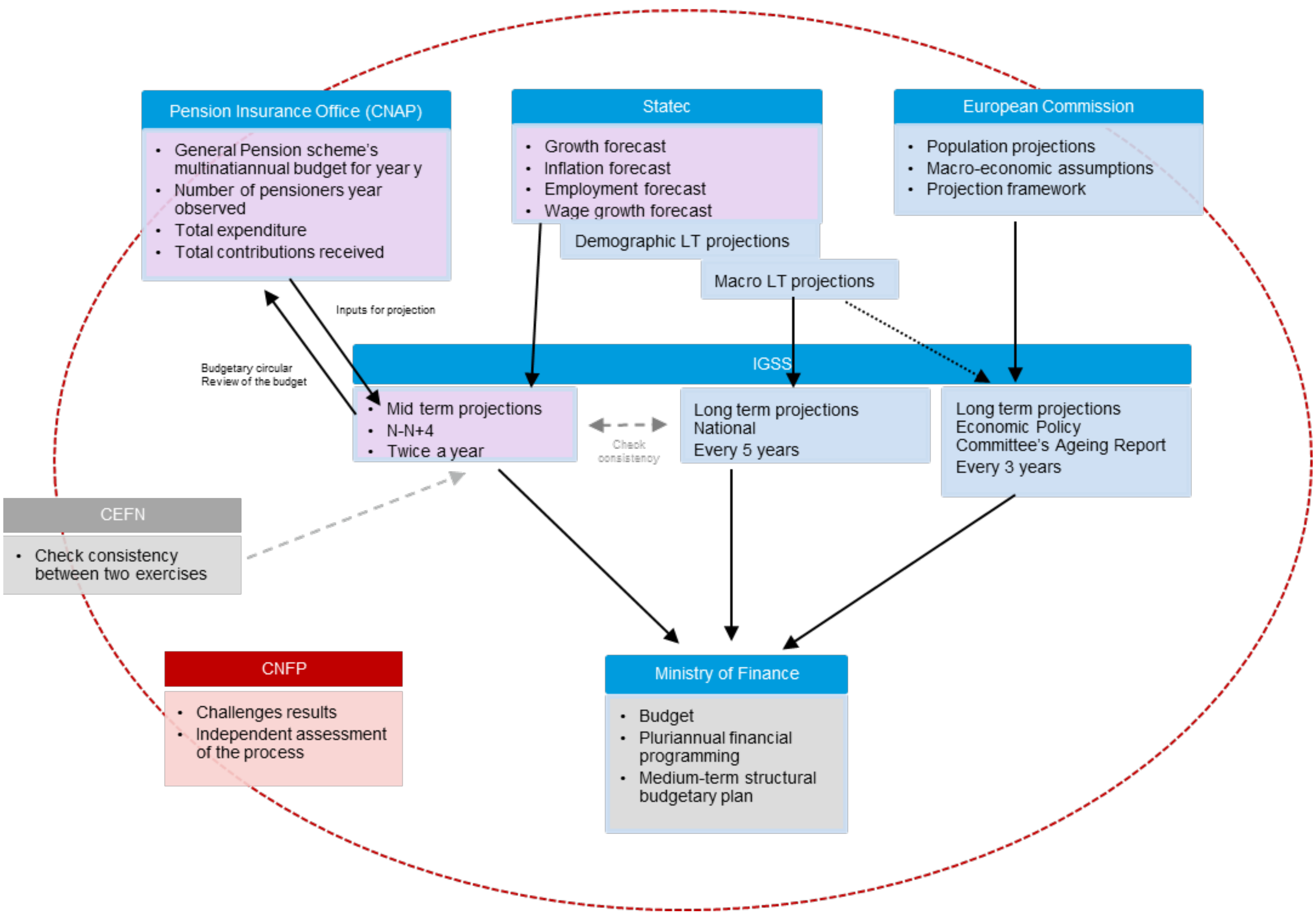
[1] In this report, we refer to short term and medium-term projections as "medium-term projections".

[2] Article 238 of the Social Security Code mandates that the contribution rate be set to ensure that pension reserves exceed 1.5 times the annual expenditure over a ten-year period. A medium-term update is required within each ten-year coverage period to verify compliance.

[3] IGSS also publishes regular technical reports analyzing the performance of the pension system, including fiscal impact assessments of reform options (see, e.g., IGSS, 2025b).

including IGSS, are nevertheless aware of these deviations and have already undertaken analysis to identify their possible drivers.

Figure 1. Institutional Roles in Pension Projections



Source: IMF staff calculations.

III. Short- and Medium-Term Projections

10. This section presents short-term projections (1 to 4 years). It compares the projected series published in Finance laws between 2016 and 2024 to actual outcomes. It identifies the factors driving discrepancies between projected and actual outcomes focusing on one-year projections – the most crucial for the budget. It then discusses options to enhance the accuracy and reliability of future projections.

A. Review of Recent Projections

11. Since 2016, projections have deviated from observed values by an average of 0.04 percent of GDP, with larger deviations during episodes of high uncertainty, such as COVID (2020-21) and the inflation peak following invasion of Ukraine (2022-23).[4] Medium-term projections include annual projections for the revenue, expenditure and the financial balance with a 4-year horizon. Revenues and expenditure were overall underestimated, indicating a negative bias of projections[5] (see negative Mean Error in Table 1), in a slightly more pronounced way for revenues.[6] The financial balance was generally underestimated except during COVID, on average by 0.04 percent of GDP for the 1 year horizon projection between 2016 and 2024.[7] The size of the deviation is higher for revenue projections (see higher Root Mean Square Error in Table 1 and Figure 2). Figure 3 illustrates the projections released in the budget since 2015 and compares them to the observed values. During COVID (2020 and 2021), as the shock was largely unexpected and difficult to estimate even for the current year, revenues were overestimated. The pattern reversed during the inflation shock following the war in Ukraine -another non anticipated shock- with underestimation of revenue and expenditure, in particular in 2022. The projections seem more accurate for 2023 and 2024, with the 2024 observed value being provisory at the time of writing.

Table 1. Mean Error and Root Mean Square Error by Projection Horizon for the Main Aggregates (2016-23)

	Mean Error (Bias)					Root Mean Square Error (Inaccuracy)				
	Same year	1 year	2 years	3 years	4 years	Same year	1 year	2 years	3 years	4 years
Financial Balance	-0.008	-0.030	-0.035	-0.034	-0.051	0.427	0.706	1.225	2.550	3.359
Revenues	-0.005	-0.013	-0.024	-0.038	-0.048	0.040	0.158	0.354	0.479	0.428
Expenditures	-0.005	-0.010	-0.022	-0.039	-0.048	0.045	0.110	0.305	0.419	0.409

Source: Authorities, IMF staff calculations.

[4] Similar deviations have also been observed for other branches of social insurance, see Chambre de Deputes (2024) https://www.chd.lu/fr/question/27638.

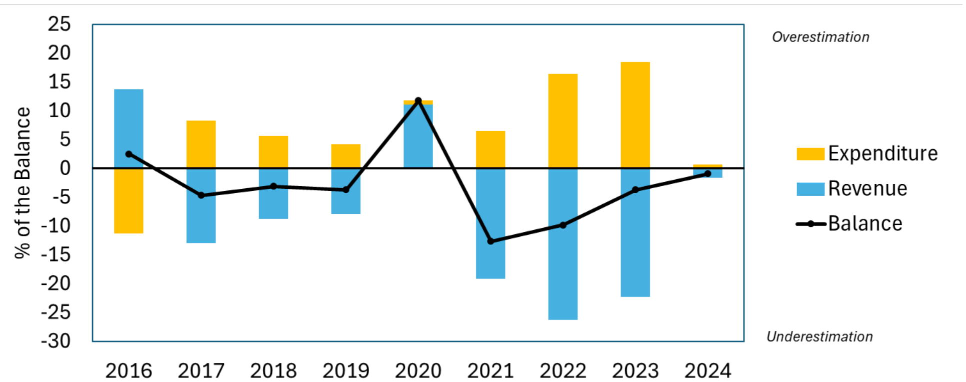
[5] Bias is defined as the difference between the projected value and the observed value. A positive bias means that the value was overestimated, and a negative bias means that it was underestimated.

[6] A former analysis from IGSS published in a parliamentary question looked at the average deviation for revenues and expenditure of the pension fund. It also concluded that revenues generated a larger deviation (but did not include any breakdown on the main drivers). See Question Parlementaire | Chambre des députés du grand-duché de Luxembourg.

[7] A larger deviation may be observed than assessing the deviation of the overall social insurance balance.

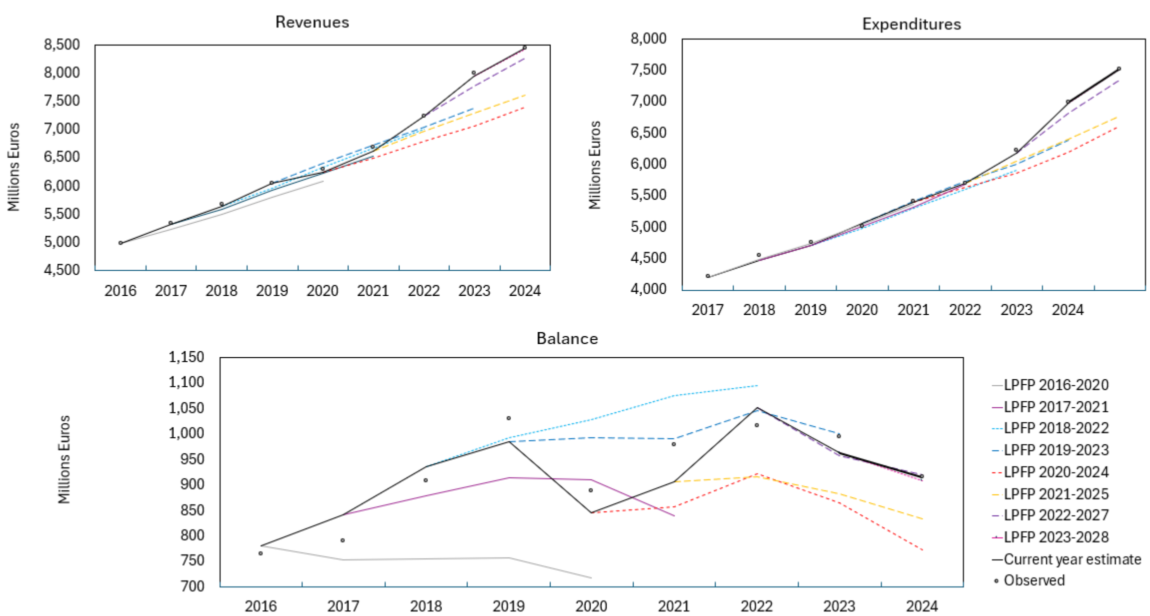
Note: The Mean Error indicates projection bias—whether projections systematically over- or underestimate actual values. For example, both revenues and expenditures show a growing negative bias over projection horizon, meaning both tend to be increasingly underestimated as the projection horizon lengthens. A negative mean error of -0.048 for total revenues after four years means revenues were generally underestimated by 4.8 percent. The Root Mean Square Error (RMSE) measures the average size of projection deviations regardless of direction; for example, after one year, revenue projection has a higher RMSE (0.016) compared to expenditures (0.007), indicating that revenue projections are less accurate than expenditure forecasts. 2024 is not included as the observed value is not final.

Figure 2. Decomposition of the Projection Deviation of the Balance at a 1-year Horizon between Revenue and Spending Side



Source: Authorities IMF Staff estimates.
Reading Note: The black line indicates the deviation between the balance projected one year ahead and the final value. Values above the black line indicate an overestimation, while values below the black line outline an underestimation. The bars show how much of this deviation was due to revenue and expenditure side. These contributions of subcomponents depend on the deviation of the component itself, but also on its weight within the aggregate.

Figure 3. Revenue, Expenditure and Balance Projections, 2016-2024



Source: Authorities, IMF Staff estimates.
Note: The black plain line represents the series of current year projections (quasi final estimates, from which the projection starts). Each colored line represents the projection of next 4 (resp 5) years as form the projection year. The isolated dots represent the final value of the observation (from which the deviation is calculated). The projection was underestimated if the colored line is below the black dot and overestimated if above.

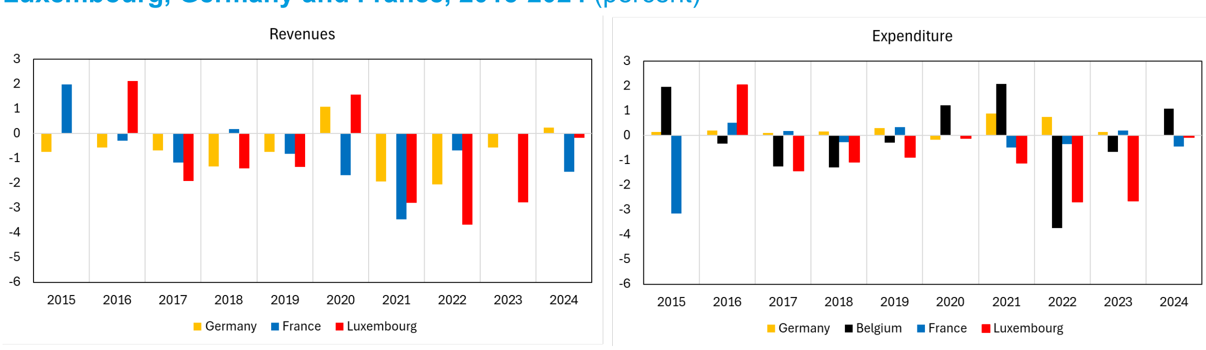
12. The relatively modest projection deviations in Luxembourg are similar to deviations observed in other countries. The mission compared deviation between past projections (1 year horizon) in Belgium, France, Germany and Luxembourg. Projections of the financial balance for Luxembourg are less biased than in France or Germany (Table 2). Revenues are underestimated in France and Germany as in Luxembourg. The bias for expenditures in Luxembourg is negative, compared to some positive bias in Germany and Belgium. The accuracy of the financial balance is of the same magnitude as in France, and much better than in Germany. The accuracy of revenue projection is slightly better than in France, and slightly worse than in Germany. The accuracy of expenditure forecast is similar to Belgium, and below the accuracy of forecasts in France and Germany. The projections in Luxembourg and Belgium (for expenditures) are slightly more sensitive to macroeconomic circumstances (Figure 4). The projections for France appeared closer to observed values than in Luxembourg, including during times of high uncertainty as COVID (2020-2021) and the inflation-peak (2022-2023). This is likely explained by the pension system and labor market designs, which are more strongly tied to inflation in Luxembourg.[8] For instance, minimum wage is not automatically indexed to inflation in Germany, and average wages are not adjusted to inflation neither in France nor Germany. Additionally, pensions are indexed to economic indicators (wages and prices) with a longer time lag of one and more years in France and Germany. As a result, the projections are less sensitive to projection errors on inflation.

Table 2. Mean Error and Root Mean Square Error in Peer Countries (1-year horizon, 2016-23)

	Mean Error (Bias)				Root Mean Square Error (Inaccuracy)			
	Germany	Belgium	France	Luxembourg	Germany	Belgium	France	Luxembourg
Financial Balance	-4.504	Na	1.350	-0.03	2.069	Na	0.659	0.706
Revenue	-0.009	Na	-0.010	-0.013	0.132	Na	0.189	0.158
Expenditure	0.003	0.151	0.000	-0.010	0.048	0.137	0.049	0.110

Source: Authorities and IMF Staff estimates (Luxembourg), Rentenversicherungsbericht der Bundesregierung (Germany), Conseil d'Orientation des Retraites (France), Comité d'études sur le vieillissement (Belgium).
Note: The Mean Error indicates projection bias—whether projections systematically over- or underestimate actual values. The Root Mean Square Error (RMSE) measures the average size of projection deviations regardless of direction.

Figure 4. Relative Deviations of Revenue and Expenditure Projections at a 1-year Horizon in Luxembourg, Germany and France, 2015-2024 (percent)



Source: Authorities and IMF Staff estimates (Luxembourg), Rentenversicherungsbericht der Bundesregierung (Germany), Conseil d'Orientation des Retraites (France), Comité d'études sur le vieillissement (Belgium).
Note: There is no data on revenue for Belgium as all social security contributions are collected.

[8] In Luxembourg, minimum wage is adjusted automatically to prices, as is the level of pensions. In France, and Germany, on the contrary, such price indexation of wages is not applied. See Annex I for an overview.

B. Drivers of Projection Deviations

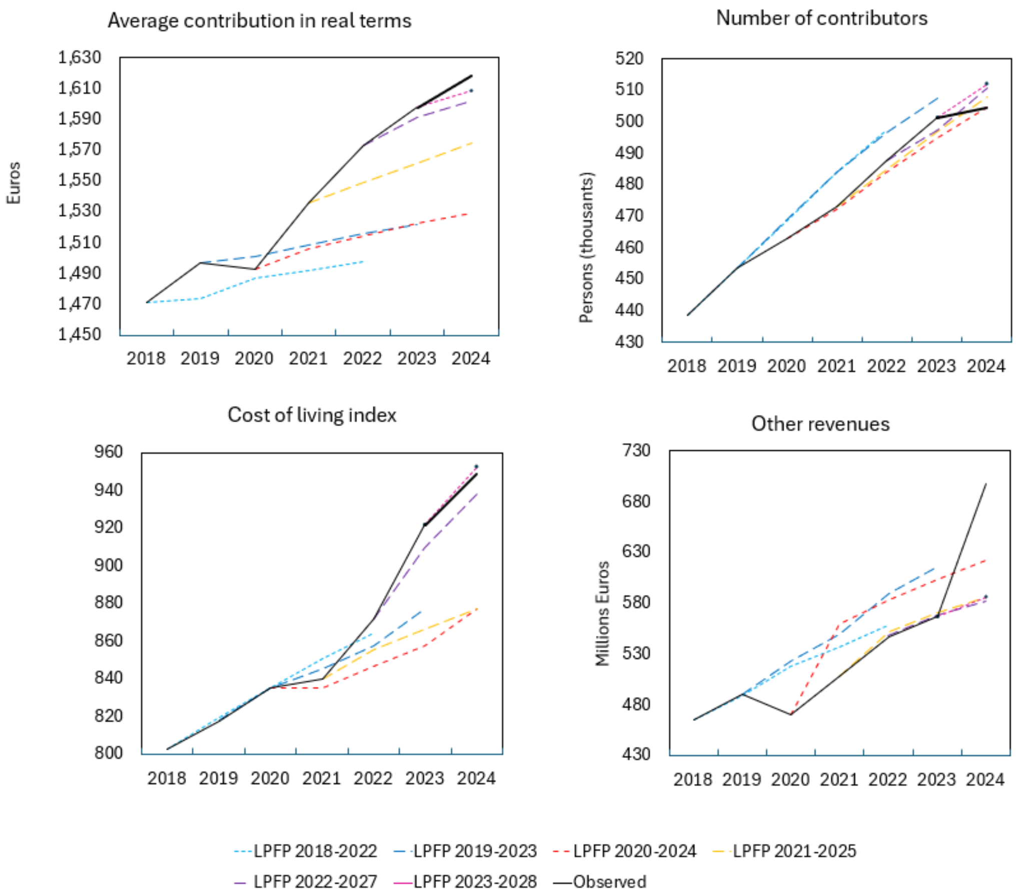
13. This section looks in more detail into each of the components of the revenue and expenditure projections to identify the major sources of deviation. A component's contribution to the overall deviation depends not only on the size of its own forecast error, but also on its weight within the aggregate. Annex 2 provides detailed calculations. Understanding the key drivers helps to focus efforts and prioritize improvements where they will have the greatest impact.

Revenue Projections

14. Pension fund revenue projection is built by aggregating four components. The main component is the revenue from contributions, calculated as the product of the number of contributors, the average real contribution per contributor, and a cost-of-living adjustment (COLA) factor (Figure 5). The fourth component (so called 'other revenues') includes mostly property income (returns on invested reserves), which account for almost 90 percent of 'other revenues'.

$$Revenue = Number\ of\ contributors * Average\ contribution * COLA/100 + Other\ revenues$$

Figure 5. Main Components of the Revenues and their Projections, 2018-24



Source: Authorities, IMF Staff estimates.

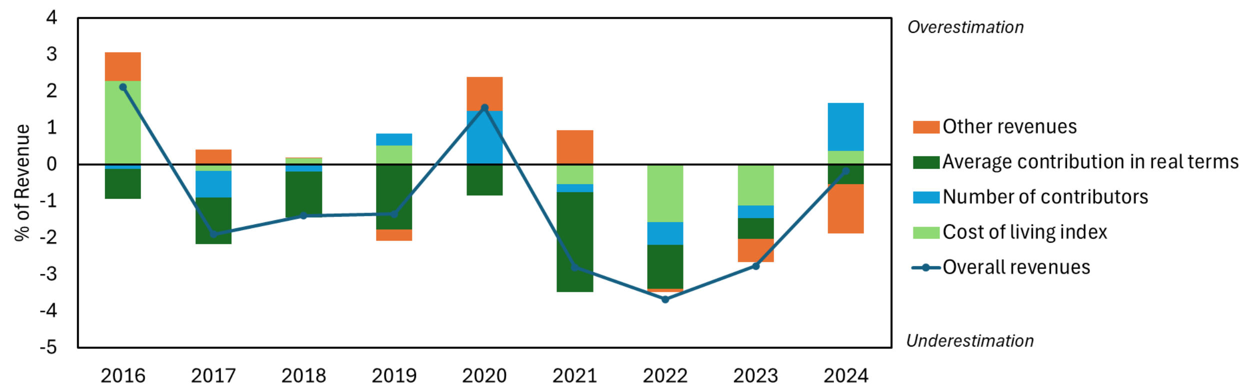
Table 3. Mean Error and Root Mean Square Error by Projection Horizon for the Revenue Components (2016-23)

	Mean Error					Root Mean Square Error				
	Same year	1 year	2 years	3 years	4 years	Same year	1 year	2 years	3 years	4 years
Revenues	-0.005	-0.013	-0.024	-0.038	-0.048	0.040	0.158	0.354	0.479	0.428
Contributions and other current transfers	-0.005	-0.014	-0.024	-0.038	-0.048	0.046	0.165	0.369	0.516	0.481
Number of contributors	0.002	0.001	0.003	0.006	0.006	0.043	0.106	0.220	0.375	0.601
Average contribution in real terms	-0.008	-0.014	-0.021	-0.028	-0.035	0.271	0.502	0.804	1.248	1.625
Cost of living index	0.001	-0.001	-0.007	-0.017	-0.020	0.025	0.216	0.528	0.638	0.556
Other revenues	-0.009	-0.001	-0.019	-0.036	-0.056	0.329	0.596	0.655	0.536	0.547

Source: Authorities, IMF Staff estimates.
Note: The Mean Error shows whether projections are biased and tend to over- or underestimate actual values; for example, a negative mean error of -0.048 for total revenues after four years means revenues were generally underestimated by 4.8 percent. The Root Mean Square Error (RMSE) measures the average size of projections deviation regardless of direction; for example, an RMSE of 1.629 for the average contribution (real terms) after four years is substantially larger than for other revenue components, indicating much greater uncertainty and lower accuracy in forecasting this item.

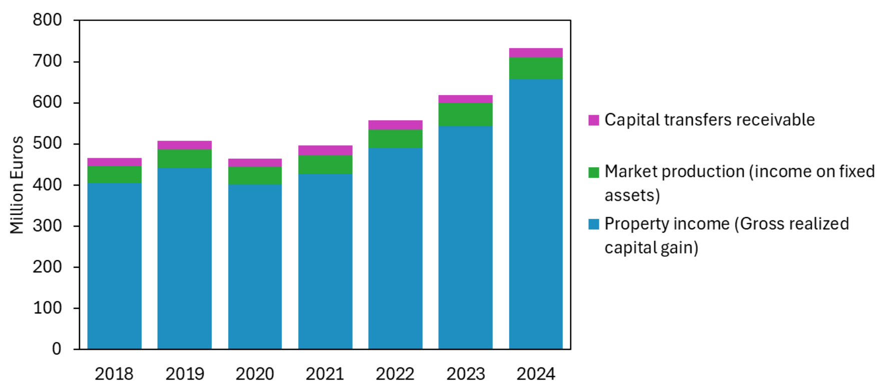
15. The main driver of revenues projection deviation is a systematic underestimation of average real contribution per employee. The largest deviations of the revenue projection with a 1-year horizon come from (1) the average contribution, especially in 2022-2023, (2) the number of contributors, especially during COVID years, and (3) inflation (cost of living adjustment factor), especially in 2022 and 2023 (Figure 6 and Table 3). [9] The inflation surprise in 2022-23 was challenging to anticipate.[10] Other revenues, mostly property incomes (see Figure 7), including for instance the interests received on the reserve fund, were overestimated before COVID and underestimated during the inflation peak. This likely reflects challenges in anticipating changes in the interest rates, or conservative assumptions, on the downside during COVID, and upside in the aftermath of the policy responses to inflation surge in 2023.

Figure 6. Deviation between 1-year Projection and Observation of Revenue, 2016-2024



Source: IMF Staff estimates.

Figure 7. Composition of Other Revenues, 2018-24



Source: IMF Staff estimates.

[9] The decomposition method of the overall deviation among several components is detailed in Annex 2.

[10] Backward looking exercise from STATEC explored alternative methodology for inflation projections improving the granularity of the projection, but without improving the overall performance of the projection.See Note de Conjoncture 1-25 « De nouvelles équations de prévision de l'inflation trimestrielle au Luxembourg » (pages 89 and 93).

Expenditure Projections

16. Pension expenditure corresponds to cash benefits paid to pensioners and other expenditure components. The cash benefits expenditure is the product of number of pensioners; average real pension, cost-of-living adjustment coefficient, and real wage adjustment factor. The two latter indexes are specific to Luxembourg pension system design, where pensions are indexed with wage growth and cost of living adjustment. Other expenditure components include operational and capital expenditures, including intermediate consumption, gross capital formation, and employee compensation.

$$Expenditure = Number\ of\ pensioners * Average\ pension *COLA/100 * Readjustment + Other\ Expenditure$$

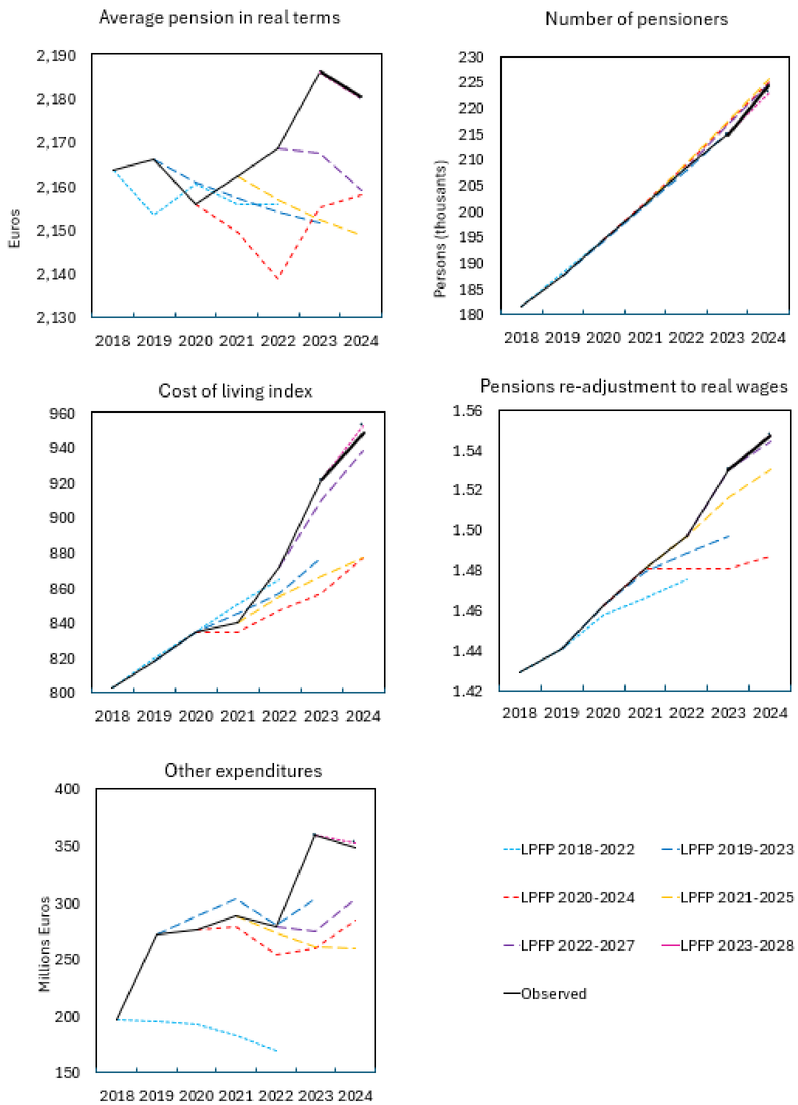
Table 4. Mean Error and Root Mean Square Error by Projection Horizon for the Expenditure Components (2016-23)

	Mean Error					Root Mean Square Error				
	Same year	1 year	2 years	3 years	4 years	Same year	1 year	2 years	3 years	4 years
Expenditures	-0.005	-0.010	-0.022	-0.039	-0.048	0.045	0.110	0.305	0.419	0.409
Cash benefits	0.000	-0.002	-0.012	-0.028	-0.038	0.012	0.084	0.273	0.393	0.391
Average pension in real terms	-0.009	-0.012	-0.013	-0.013	-0.014	3.393	4.649	5.707	5.748	5.771
Number of pensioners	0.009	0.012	0.013	0.012	0.011	0.128	0.198	0.273	0.365	0.483
Cost of living index	0.00	0.00	-0.01	-0.02	-0.02	0.03	0.22	0.53	0.64	0.56
Pensions in paiment re-adjustment to real wages	-0.005	-0.013	-0.022	-0.039	-0.048	0.005	0.006	0.202	0.544	0.484
Other expenditures	-0.096	-0.170	-0.224	-0.256	-0.248	0.641	1.008	1.892	2.432	2.945

Source: Authorities, IMF Staff estimates.

Note: Mean error is the average of projection deviation divided by the average observed value over the period; Root mean square error is the square root of the average square error divided by the variance of the observed values over the period.

Figure 8. Main Components of the Expenditure and their Projections, 2018-24



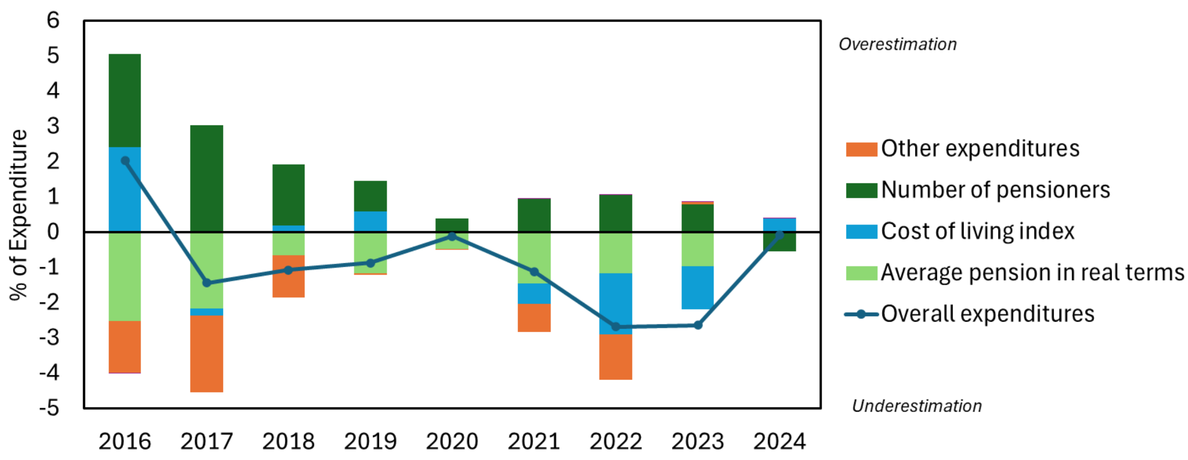
Source: Authorities, IMF Staff estimates.

17. Since 2017, the overall expenditures were underestimated due to a combination of underestimation in the average pension in real terms, the cost-of-living adjustment, and other expenditures. By contrast, the number of pensioners was slightly overestimated, which contributed to mitigating the overall deviation (Figure 9 and Table 4).[11] This is explained by the fact that both estimates are linked. The average real pension is calculated as the total cash benefit spending divided by the number of pensioners and inflation adjustments. A deviation in the overall number of pensioners for instance might result in an opposite deviation for the average pension. Other expenditures, including

[11] The decomposition method of the overall deviation among several components is detailed in Annex 2.

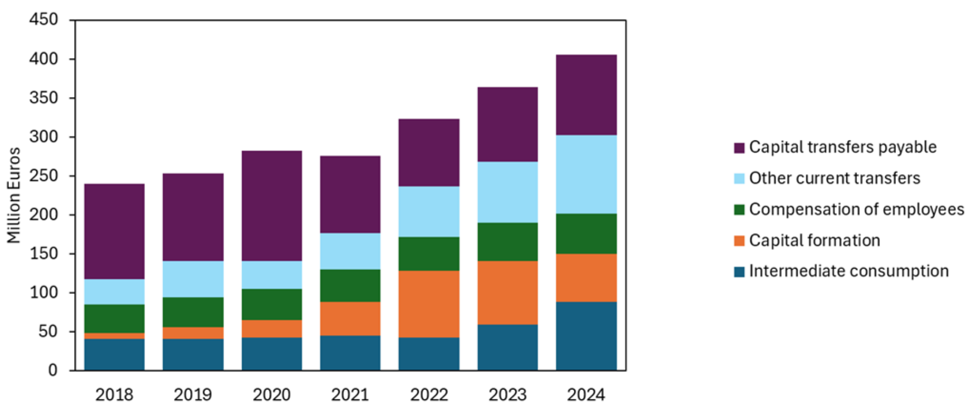
capital transfers, capital formation and intermediate consumption, were underestimated, possibly through an indirect effect of inflation on nominal values (Figure 10).

Figure 9. Deviation between 1-year Projection and Observation of Expenditure, 2018-2024



Source: authorities, IMF Staff estimates.

Figure 10. Illustration of other Expenditure Components, 2018-24



Source: authorities, IMF Staff estimates.

Financial Balance Projections

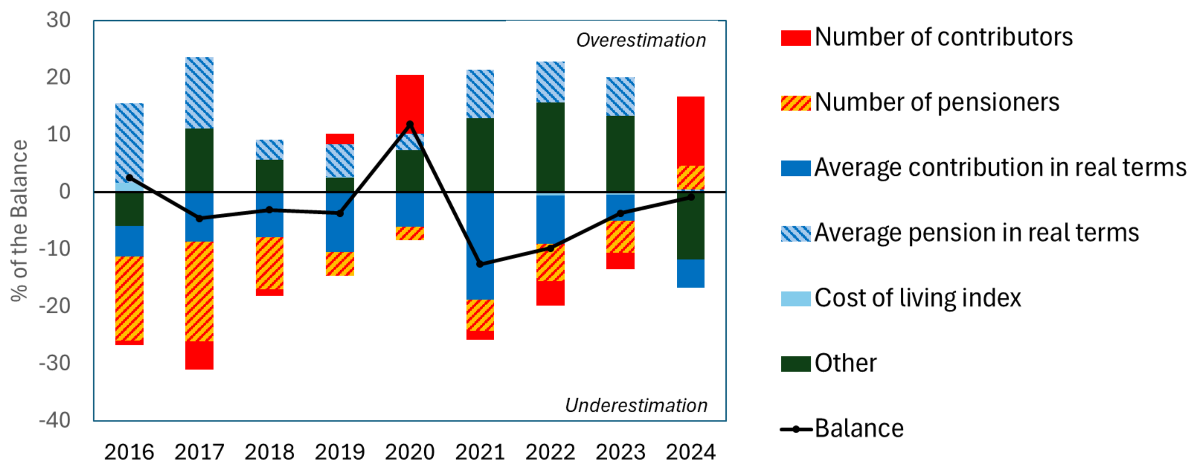
18. The average contribution in real terms is an important driver of financial balance projection deviations. Some projection deviations drivers tend to net out between the revenue and expenditure sides (see Figure 11). [12] This is the case for instance for inflation, as the cost-of-living adjustment appears both on the revenue and expenditure side through indexation of pensions but also of wages. This is a very specific feature to Luxembourg, as in most other countries, there is no indexation of wages to inflation. This might change in future, as pension law article 225 requests a lower index once expenditures exceed contributions, which is expected by 2026. Thereafter, real wage growth will only

[12] The decomposition method of the overall deviation among several components is detailed in Annex 2.

partially be reflected in the pension indexation. The number of pensioners- and average pension in real terms projections also tend to balance each other, and do not appear as major drivers of the projection deviation. By contrast, the average contribution and number of contributors drive more significantly the bias. The 'other' category is another significant driver, where projection deviations sometimes add up.

19. The mission reviewed the accuracy of current-year pension projections and the potential for improvement using more timely data, concluding that only modest gains are likely. It assessed whether real-time information could enhance estimates, given that projections start mid-year with only partial data available. Analysis showed that mid-year estimates for cash benefits are generally accurate (Box 1), while "other expenditure" and revenue estimates—especially during the COVID years—are less precise. Overall, improving estimates for subcomponents would likely have only a modest effect on total revenue and expenditure forecasts for the current year.

Figure 11. Relative Deviation between 1-year Projection and Observation of the Financial Balance, 2018-2024



Source: authorities, IMF Staff estimates.

Box 1. Accuracy of Current Year's Estimates

Given the partial nature of available data in the current year, the mission explored whether greater use of real-time information could enhance current-year estimates. Projections begin in the current year, but since the exercise is conducted in August, [13] only data from the first few months are available, and these are subject to revision. Consequently, the current-year figures must themselves be partially projected. The mission therefore examined the accuracy of these estimates and the potential to improve them with more timely data inputs.

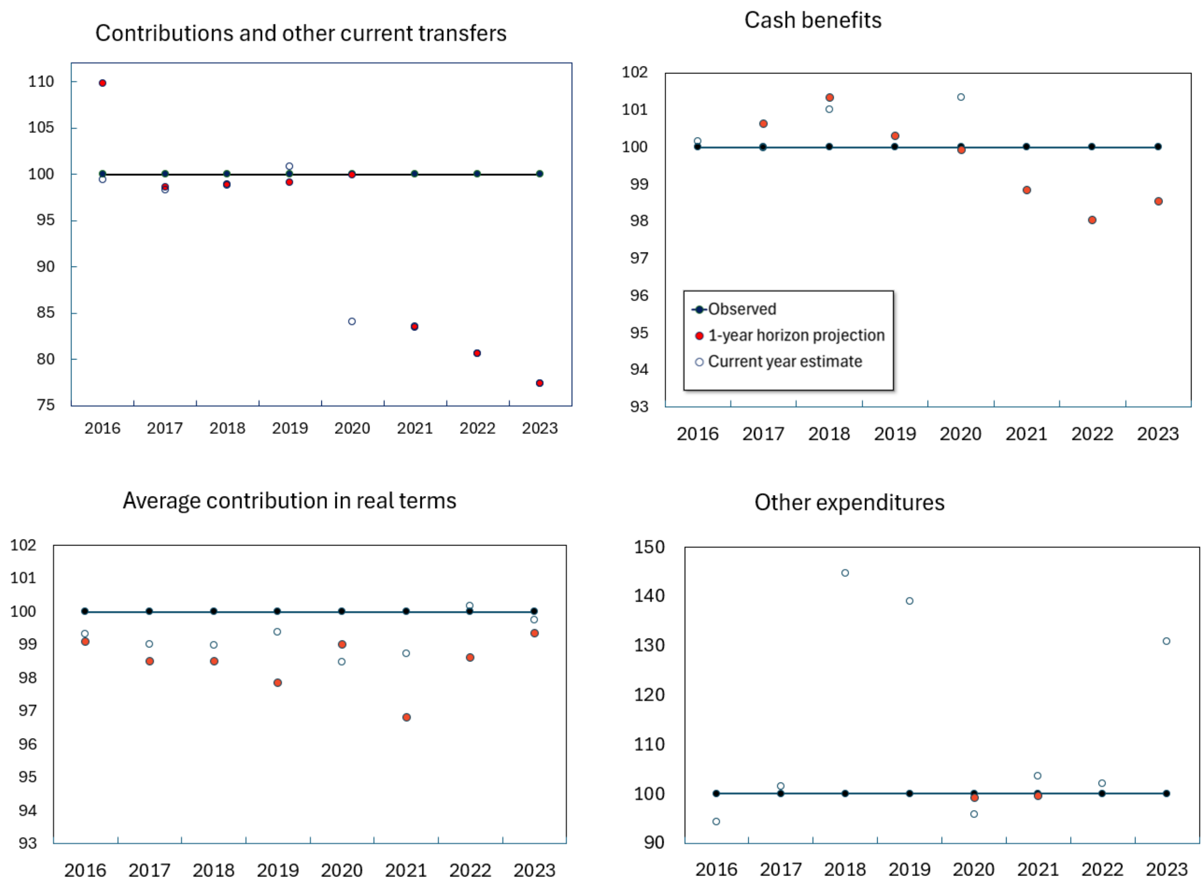
The mission analyzed the accuracy of current-year estimates—the difference between projected and actual values for the same year and found limited scope for improvements. As shown in Figure 12, mid-year estimates of cash benefits closely align with actual outcomes (ex-post).[14] The 'other expenditure' component is estimated with less precision. On the revenue side, deviations are somewhat larger, particularly during the highly uncertain COVID

[13] The section on 1-year horizon projections focuses mostly on PLFP data, i.e. projections done in August.

[14] For some components, such as the number of pensioners and the average pension, the magnitude of the deviation is significant. However, the overall aggregate (see 'cash benefits') does not deviate significantly for the current year (i.e. the deviation of the components cancels out).

years of 2020 and 2021. Overall, the findings suggest that improving current-year estimates for subcomponents would have only a modest impact for total revenue and expenditure estimates of the current year—the most relevant fiscal aggregates.

Figure 12. Accuracy of Current Year t Aggregates, Estimated in Mid-year t and in t-1



Source: authorities, IMF Staff estimates.

C. Recommendations

20. The current short-term pension projection is of high quality, reflecting the authorities' strong commitment to continuous improvement. The following options to improve forecasting focus on the 1) the improvement of the forecasting methodology, 2) the refinement of input sources and 3) the communication of model results.

21. A multi-model approach that leverages advanced methodologies and modern technological tools is critical to maintaining high projection accuracy and robustness. IGSS has already taken important steps by adopting such approach to examine the underestimation of average contributions. Options to continue improving on these approaches include:

- **Further adopt Multivariate and Ensemble Models:** To improve the reliability of contribution forecasts, combining multiple models is particularly valuable. Rather than relying on a single approach, integrating both traditional and more advanced models can help reduce individual model biases and better reflect the complexity of current economic conditions. Combining outputs from diverse models—both univariate and multivariate—by assigning appropriate weights (discussed in the Annex 3) allows the forecast to draw on a broader set of information. This multi-model strategy has already proven effective at IGSS for estimating average real contributions.

- **Continue using flexible models:** Expanding the model set beyond the currently used models (Table 5) could further enhance forecast accuracy. Various models, such as GRU (Gated Recurrent Unit) neural networks and SCAR VAR models offer greater flexibility than traditional approaches by capturing non-linear, time-varying relationships. This is particularly useful during atypical periods, such as the high inflation years of 2022 and 2023 in which the elasticity of contributions to wages were distorted.[15] Traditional models, such as ARMA or error correction frameworks currently used by IGSS, assume generally stable and linear relationships, making them less capable of adapting to these shifts. Annex 3 presents various more flexible models which may be considered for future short-term forecasts.
- **Leverage AI-Powered Frameworks:** For small teams with limited resources, a highly automated (AI-powered) framework or low-code infrastructure can be helpful. These tools can automate model selection, testing, and even recommend alternative models, freeing up valuable time for analysis and interpretation.
- **Apply for other revenue streams:** The same principles of multi-model forecasting and AI-driven automation can be applied to other revenue streams as well. This would create a more consistent and robust forecasting system across all components of the pension report.

22. To improve the overall quality of the projection, it is crucial to enhance the forecasting of key macroeconomic inputs:

- **Strengthen macro-economic inputs:** The analysis of forecast errors shows that employment and wage predictions are a key source of uncertainty in short-term projections. To strengthen pension finance forecasts, it is advisable to develop complementary projections for important macroeconomic inputs and use them to test the sensitivity of existing forecasts. The aim of this exercise is not to substitute current STATEC inputs, but rather to offer options for further enhancing them. It is recommended to explore multivariate models, with examples presented in the Annex 3, and to draw on a broader set of variables for wage and employment forecasts. For instance, incorporating labor-market data from the wider Luxembourg region could make the models more responsive to economic and demographic changes. Table 5 summarizes the main conclusions of the improvements that could be considered.

[15] Contributions are influenced not only by wages but also by a ceiling linked to the minimum wage (see pension system description in Annex 4). As a result, wage increases impact contributions through both the direct wage effect and the minimum wage ceiling effect. This dual mechanism contributes to the difference between short-term and long-term elasticities of contributions with respect to wages.

Table 5. Summary of the Projection Methodology and Suggestions for Improvement

	Projection gap	Current method	Suggestions
Demographic variables			
Number of contributors	Small	Based on STATEC employment forecast	Refine employment projection (input from STATEC) and consider an alternative model on employed workers' compensation (instead of total)
Number of pensioners	Small but persistent	Linear regression	None, continue past forecast improvements to further sink the projection gap.
Income variables			
Average real contribution	Most significant and persistent	Error Correction Model Transfer Function Model ARMA	Refine wage projection (input form STATEC), extend use of flexible, multi-models.
Indexation			
Cost of living adjustment	Negligible	Inflation forecast (input from STATEC)	None
Other revenue and expenditure			
Other revenues	Heterogenous	Linear based on past observations	Fine tune projection with additional co-variates
Other expenditure	Heterogenous	Linear based on past observations	Fine tune projection with additional co-variates

Source: IMF Staff analysis.

23. To further strengthen the transparency of pension projections, communication could be improved to clarify the sources of forecast revisions and to better convey the inherent uncertainties surrounding the projections:

- **Outline drivers of projection changes in the executive summary**: The executive summary should clearly quantify how much of any change in projections stems from data revisions, methodological adjustments, or updated assumptions.[16] Such transparency will improve understanding among stakeholders and strengthen confidence in the forecasts.
- **Present sensitivity analysis:** Including a sensitivity analysis would help illustrate the degree of uncertainty surrounding the projections. This could be outlined by building a margin of error around the central projection, using confidence intervals.

[16] For this purpose, the authorities can benefit from the systematic analysis of deviations between subsequent projections twice a year within the framework of the CEFN.

- **More frequent reporting to line Ministries:** In particular, in years of large economic shocks and high uncertainty, a more frequent reporting cycle to Ministries could be considered to enable the early detection of deviations from the previously projected path. This would ensure the government is informed in a timely manner for budget planning purposes. While the frequency of STATEC data inputs is limited, it is advisable to aim for shorter intervals of data collection and provision in times of crisis, as demonstrated by good practice in Belgium during the COVID pandemic.[17]

[17] Under the framework of the Economic Risk Management Group real time data was compiled to evaluate the state of the Belgian Economy in short intervals using different datasets and special ad-hoc surveys distributed to businesses by various employer associations. See OECD (2023a)

IV. Long-term Projections

A. Overview of Projection Methodology

24. The model used for the long-term projection of future pension finances is based on the deterministic cohort model from the ILO, customized to the pension system of Luxembourg. The model includes two components: A demographic component projects the number of contributors and pensioners, and a financial component estimates income and expenditure of the public pension scheme. Each status of a scheme member (active, inactive, pensioner) is modeled, with associated financial variables (salaries/revenues, pensions, etc.) projected on an annual basis until 2070. Age- and career-length-specific earning profiles are used to determine total economic wage levels, which remain fixed over the projection period, apart from adjustments due to general real wage growth and inflation. Labor productivity assumptions are utilized to simulate real wage growth. The model relies on actuarially determined transition probabilities (including mortality rates, disability rates and retirement rates). These probabilities are used to consider transitions of scheme members (active, inactive, pensioner) from one year to the next. To reflect the high share of non-resident pension scheme members, benefits and contributions are not only calculated by one year age groups and gender but also by residency, in contrast to the standard ILO model. The macrosimulation model is written in the in the LIAM2 microsimulation-developing environment, provided by the Belgian Federal Planning Bureau LIAM2. Macro-economic and demographic assumptions are provided by the AWG, Eurostat and STATEC, see Figure 1.

B. Volatility of Past Projections

25. Projection results have varied across forecast vintages, potentially undermining trust in the reliability of long-term forecasts—an issue particularly sensitive in the context of ongoing pension reform discussions. The debate has focused on three key milestones of the pension fund:

- **Event 1**: The year when pension expenditures exceed contribution revenues (i.e., the pay-as-you-go rate surpasses the statutory contribution rate of 24 percent of wages); Under current law Event 1 requires adopting a lower pension indexation, limited to inflation and not more than 50 percent of real wage growth.
- **Event 2**: The year when the pension reserve falls below the statutory threshold of 1.5 times the annual expenditure; If Event 2 is projected for the current or forthcoming 10-year coverage period—in line with Art. 238 of the Social Security Code— a higher contribution rate needs to be legislated.
- **Event 3**: The year when the pension reserve is fully depleted.

26. The projected timing of key milestones has shifted across projection vintages (Table 6), though changes between the 2016 and 2025 projections were limited overall. For example, Event 3 was projected to occur in 2043 in the 2016 national projections and was delayed by only two years to 2045 in the latest 2025 projection. Similarly, Event 2 has consistently been projected to occur around 2040, with slightly earlier dates in the 2016 and 2018 vintages due to lower assumed rates of return on the reserve fund (affecting likewise Event 3).[18] Notably, in the latest 2025 projections, all three critical events occur two years earlier—a development further discussed below. While projection results have shown overall only modest variation over the past decade, this evolution has nonetheless contributed to some public uncertainty and skepticism regarding pension forecasts, including concerns that projections may systematically underestimate the financial performance of the system (Forbes, 2025).

Table 6. Timing of Critical Events – Comparison of Past Projections

	National 2016	National 2018	AWG 2018	AWG 2021	National 2022	AWG 2024	National 2025
Event 1: Pay-as-you-go premium exceeds contribution rate (24 %)	2023	2024	2024	2026	2027	2028	2026
Event 2: Reserve falls below statutory threshold *	2035	2035	2041	2041	2041	2041	2039
Event 3: Reserves depleted	2043	2041	2047	2047	2047	2047	2045

* 1.5 times annual expenditures

Source: Ageing Reports and IGSS.
Notes: 2025 Projections refer to the projections provided in March 2025 for the consultation process on the long-term sustainability of the pension system. See IGSS (2025a). The timing of the critical events is equal to the estimates of the 2024 Multiannual Financial Programming Law projections of September 2024.

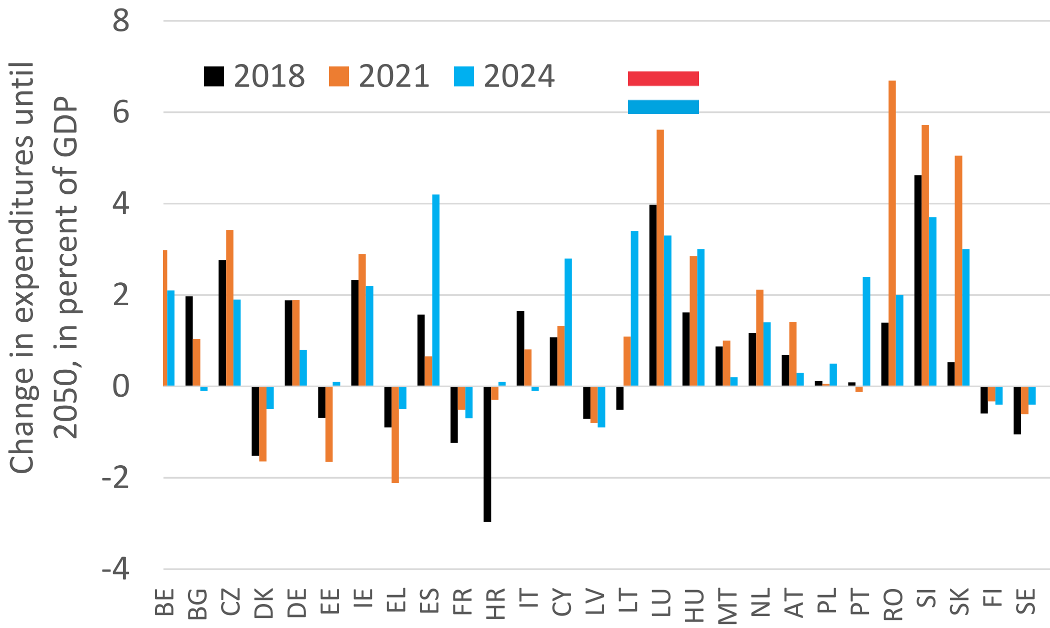
27. **International comparison confirms that deviations in pension expenditure projections across vintages are common, reflecting regular updates in macroeconomic assumptions, demographic trends, pension legislation, methodological refinements, and input data, with larger deviations in smaller countries like Luxembourg.** This is illustrated in Figure 13, which compares the change in projected pension expenditures (as a percentage of GDP) between 2018, 2021, and 2024 AWG projection vintages across EU countries. Notably, between the 2021 and 2024 AWG projections, 16 out of 27 EU Member States revised their pension expenditure projections for 2050 downwards, by an average of 1.3 percentage points of GDP. The revision for Luxembourg was larger than the EU average, with a reduction of 2.3 percentage points of GDP. It is important to note that Luxembourg's economy and pension system is smaller, with a very high degree of trade openness and more dependent on migration flows than those of most other EU countries (Eurostat, 2025). This structural feature may contribute to the greater variability in Luxembourg's projection results across different vintages. Overall, deviations across EU countries are somewhat larger for smaller countries (with less than 3 million inhabitants), like Luxembourg, with a standard deviation of 1.0 percent of GDP, compared to larger EU-countries (standard deviation 0.85 percent of GDP).

28. **These deviations highlight the sensitivity of long-term projections to even minor changes in underlying parameters.** Generally, the longer the projection horizon, the more pronounced the impact of changes in assumptions—hence, larger discrepancies tend to emerge further into the future. Estimates

[18] The 2018 national projections were based on a 3% nominal rate of return assumption, while the 2018 AWG projections were based on a 5% nominal rate of return.

in the further future also feature more uncertainty.[19] By contrast, projections for shorter horizons, for instance over the next 15 years, tend to be more stable across vintages. As a result, some countries focus on projections of the next two decades, like Germany with its annual "Rentenversicherungsbericht" with a 15-year horizon.

Figure 13. Projection Deviations by Country and Time: Expenditure Rise by 2050, Percent of GDP



Source: AWG Projections and IMF Staff estimates.
Note: The Figure illustrates the change in pension expenditures projected by 2050 for three projection vintages (2018, 2021, 2024). With the 2018 projection, for instance, an increase of pension expenditures of 4.0 percent of GDP was projected by 2050, while the 2021 projection estimated an increase of 5.6 percent of GDP.

C. Main Drivers of Past Volatility

Drivers of Volatility for Event 1

29. Crucial for the current pension policy debate is the anticipated advancement of the critical Event 1 to 2026. With the latest IGSS projections of 2024[20] and IGSS (2025a) it is estimated that total expenditures will surpass pension contributions by 2026, rather than 2028 (projected with the 2024 AWG estimates). This will necessitate adopting earlier a lower pension indexation, limited to inflation and not more than 50 percent of real wage growth, with implementation expected from 2029 onwards.

30. The earlier occurrence of Event 1, now projected for 2026, is primarily driven by revised assumptions of lower employment growth. The change in employment assumptions alone accounts for approximately 81 percent of the increase in the projected PAYG rate by 2026 from 23.4 percent (projection

[19] This is also shown by the so called STATEC scenario, applied in the latest AWG 2024 country fiche. This alternative scenario considers a substantially higher net-migration to Luxembourg, leading to large deviations in pension expenditures, mainly after 2040.

[20] The 2024 Multiannual Financial Programming Law projections of September 2024.

2023) to 24.3 percent (projection 2024). Other factors, such as a slight increase in the number of pensioners and real pension indexation, play a smaller role in this change (Figure 14).[21]

31. Employment assumptions provided by STATEC in 2024[22] suggest that employee growth—and consequently, growth in pension contributors—will be significantly lower than previously assumed in 2023[23], with a downward adjustment of about one percentage point for the period between 2024-2026. This marks a notable decline compared to realized values between 2017-2022 (Figure 15)–reflecting also a turning point in contributors growth observed in 2024 (Section 3, Figure 5). It remains uncertain whether this low growth will become the new norm.

Figure 14. Drivers of Shift to 2026

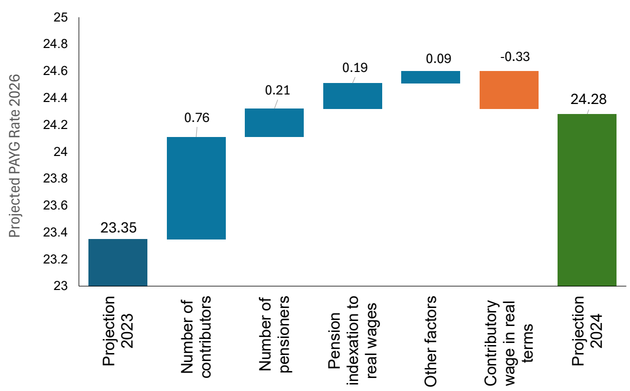
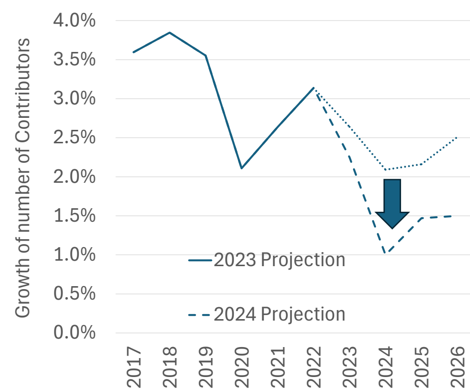


Figure 15. Drop in Contributors' Growth Assumption



Source: Estimates of Authorities and IMF Staff estimates.

Drivers of Volatility of Long-term Pension Expenditures and Events 2 and 3

32. Changes in assumptions and updated data have contributed to the volatility of long-term pension expenditures between projection vintages. This can be shown by comparing the drivers leading to changes in 2021 and 2024 AWG pension expenditure projections. Actual pension spending in 2022, expressed as a percentage of GDP, were situated below the levels anticipated in the 2021 Ageing Working Group (AWG) projections by 0.8 percentage points. This discrepancy is largely due to conservative assumptions embedded in the 2021 projections, particularly concerning the pace of economic recovery following the COVID pandemic—an event whose trajectory was inherently uncertain. Updated 2022 data alone account for approximately one-third of the deviation observed between the 2021 and 2024 projections for pension expenditures in 2050. Beyond these data revisions, further assumption changes contributed to a downward adjustment in the projected expenditure path.

[21] This breakdown validates internal analyses conducted by IGSS. Quantitative results are slightly different, due to some differences in methodology, coming still to the same conclusion.

[22] STATEC inputs for the 2024 Multiannual Financial Programming Law projections of September 2024.

[23] STATEC inputs for the 2023 Multiannual Financial Programming Law projections of September 2023.

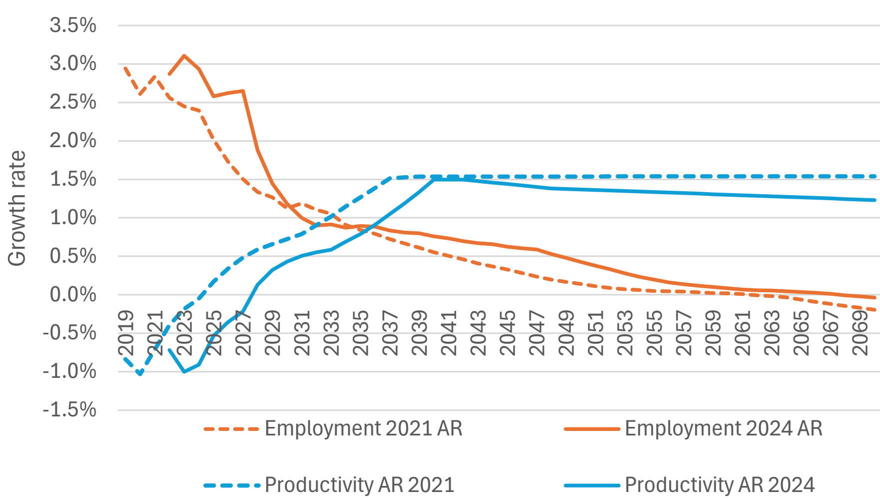
33. Changes in employment growth assumptions were a determining factor for adjustments of long-term pension expenditures. This becomes apparent when comparing 2021 and 2024 AWG pension expenditure projections. Upward employment growth expectations of 2024 AWG projections (as shown in Figure 16) increased projected GDP, thereby raising the denominator in the expenditure-to-GDP ratio. This alone had a substantial reducing effect on the expenditure to GDP ratio. Conversely, lower productivity growth assumptions had a more limited effect, as they influenced both the numerator (due to a (partial) consideration in the pension indexation) and the denominator (GDP). In addition, revisions to Eurostat's demographic projections—particularly assumptions on net migration, which have shown significant volatility across past vintages—were a key driver behind the changes in Luxembourg's pension outlook, affecting directly employment growth (CNFP, 2021; IGSS, 2024). Overall, the downward revision of pension expenditure between 2021 and 2024 AWG projections is primarily explained by revisions to economic and demographic assumptions, as detailed in Table 7.

Table 7. Drivers of Changes in Long-term Expenditures between 2021 and 2024 AWG Projections, in Terms of GDP

	2022	2030	2040	2050	2060	2070
2021 Aeging Report	**10**	**11.4**	**13**	**14.8**	**16.7**	**18**
Change in assumptions (pp of GDP)	-0.8	-1.3	-1.4	-2	-2.2	-2.2
Improvement in modelling (pp of GDP)	0	-0.3	-0.4	-0.3	0.5	1.7
2024 Aeging Report	**9.2**	**9.7**	**11.2**	**12.5**	**15**	**17.5**

Source: Estimates of Authorities and IMF Staff estimates.
Notes: Changes in assumptions include the lower 2022 starting pension expenditure to GDP ratio, observed with 2024 projections.

Figure 16. Employment and Productivity Growth Assumptions



Source: Authorities and IMF Staff estimates.

34. The downward revision of employment growth considered in the latest IGSS (2025a) projections explains the earlier occurrence of critical Events 2 and 3. The only changes introduced in the 2025 projection compared to the AWG 2024 projections were the update of input data to reflect the year 2024 and the use of a lower employment growth assumption, which fully explains the earlier projected timing of critical Events 1 to 3.

35. Major revisions to the pension model have improved accuracy of projection results, leading to changes between projections. Main model updates have been implemented with the 2024 AWG projection: The inclusion of non-active insured individuals—those with past contributions but inactive in the base year—enhanced estimates of new retirees' pension expenditures. Foreign insurance periods are now modeled endogenously by replicating base-year retirement records, leading to more retirees with incomplete Luxembourg careers, most retiring at 65, and increasing the share of non-resident new retirees. Non-contributory insurance periods are newly estimated using current retiree data. The model also incorporates a three-year delay for the automatic adjustment mechanism under the constant policy assumption, rather than assuming immediate implementation. Assumptions for disability and survivor pensions were revised to better reflect observed trends, reducing overestimation and lowering expenditures until the 2050s. In contrast, the number of old-age pensioners has been revised upward, driving higher expenditures in later decades. Entry ages into the labor market have also been adjusted upward, shortening insurance careers in Luxembourg and contributing to the rise in old-age pensioners. The accrual rate calculation has been updated to include the full pension, not just the earnings-related part, relative to total contributory income. Overall, these methodological changes improved accuracy of projections and resulted in lower projected pension expenditures compared to previous estimates by 2050, but higher expenditure estimates by 2070 (Table 7).

D. Recommendations

36. The choice of the rate-of-return assumption may follow different established practices, and for national estimates, alternative but prudent rates could be considered—though their impact on projection outcomes would likely be limited. International practice varies: The EU Ageing Working Group (AWG) sets interest rate assumptions in line with financial markets' country-specific expectations for the medium term, applying common convergence values for the long term to ensure comparability. Others, like the ILO as well as countries with large reserve funds, apply prudence-adjusted expected portfolio returns (mainly) based on historical performance. Luxembourg's current assumption—2.2 percent nominal at the start (based on historic cash income only),[24] rising to 4 percent by 2050—translates to just 0.2–2 percent in real terms (assuming 2 percent inflation). This is lower than the 2.5–3.7 percent real rates observed in countries with large reserve funds (like Canada, Norway or Sweden see Table 9), though not directly comparable due to differing portfolio structures. The assumed rate of return path for Luxembourg is notably below the Fund's historical average nominal return of 5.0 percent since the launch of the SICAV (Société d'Investissement à Capital Variable) in 2007 (Figure 17). Recent diversification toward higher-risk assets may allow for somewhat higher returns over time. Sensitivity analysis shows, however, that alternative assumptions would have only a modest impact on the timing of key funding events. If, for example, a 4 percent rate of return is assumed over the entire projection period 2024-2070 the critical event years would shift as follows: the projected year of Event 2 (Reserves fall

[24] The starting value of a 2.2 percent rate of return reflects historic rates in the period 2012-2021. For its calculation capital gain on investment (unrealized capital gains + net profit) is excluded. As a result, this past rate of return reflects only cash income, mainly interest income and dividends.

below 1.5 times annual expenditure) would be delayed from 2039 to 2041, and the expected year of Event 3 (reserve depletion) would move from 2045 to 2046. Using a more optimistic rate of return of 5 percent, event 2 would shift to 2042 and event 3 to 2048. Overall, this indicates that even under higher rates of return assumptions the projection outcomes would not differ significantly.

Table 8. Options for Model Improvements

Model Improvement	Priority	Fiscal Impact	Distributional Impact	Resource Intensity
Reassess rate of return assumption	High	Medium	Low	Low
Reassess employment growth assumptions	High	Medium	Medium	Low
Implement dynamic micro-simulation	Medium	Medium/Low	High	High
Improve survivor pension projections	Medium	Low (mainly after 2040)	Medium	Medium
Model documentation	Medium	None	None	Medium
Further improve revenue and expenditure projection	Medium	Medium/Low	Medium	Medium

Source: IMF Staff analysis.

Table 9. Choice of Rate of Return Assumption – International Comparison

Institution / Country	Basis for Assumption	Latest Published Rate	Source
Luxembourg AWG	Linked to market expectations of bond interest rates in mid-term, prudent choice for long-term	real: 0.2% in 2024 → 2% by 2050 (assuming 2% inflation)	European Commission, *2024 Ageing Report – Luxembourg fiche* & Underlying Assumptions Report, p. 73
Norway	past rates of return and capital market expectations	3% real	Norwegian Ministry of Finance, *White Paper on the Government Pension Fund 2025*
Sweden	Historical buffer fund returns; prudence-adjusted scenarios	Base: 3.25% real; Optimistic: 5.5% real	Pensionsmyndigheten, *Orange Report 2020*
Finland	Asset-class–weighted expected returns from surveys, adjusted to portfolio	2.5% real (to 2031) → 3.5% real (from 2032)	Finnish Centre for Pensions, *Long-term Projections 2022*
Canada (CPP)	Based on asset mix + long-term capital market assumptions	3.69% real	Office of the Chief Actuary, *31st CPP Actuarial Report 2022*
ILO	Expected return based on asset allocation, past performance, investment policy	Country-specific	ILO Country reports
OECD	n/a	2.5% real (net of fees)	OECD, *Pensions at a Glance 2023*

Source: IMF Staff analysis.

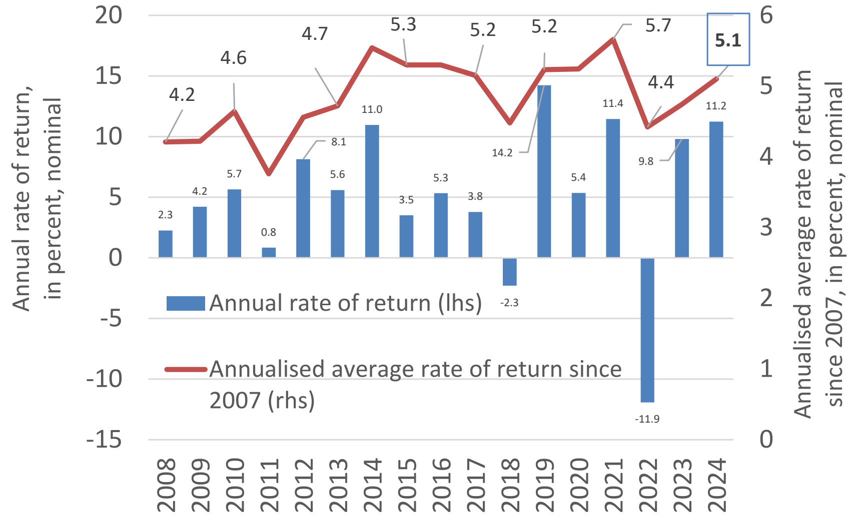
37. **Sensitivity analysis should be systematically included in projections to show the limited impact of alternative return assumptions,[25] and this point should also be highlighted in executive summaries.[26]** For EU reporting, retaining the AWG-aligned assumption ensures comparability and fiscal prudence, while for national analyses, complementary scenarios could be considered. Maintaining a prudent central scenario will help avoid overestimating fund growth, while presenting alternative scenarios can provide valuable context, support informed policymaking, and help stakeholders understand the robustness of possible outcomes.[27] This reflects the heightened uncertainty in Luxembourg, where the small size and high degree of openness of the economy make key macroeconomic variables—such as employment growth—particularly volatile.

[25] Major IGSS pension projection publications, such as the 5-year actuarial reports and the last Cahier 18 already present sensitivity analysis. The authorities are encouraged to adding executive summaries to these reports outlining also the issue of sensitivity and robustness of results.

[26] For a good practice of reporting see Actuarial Report of the Canada Pension Plan: [Actuarial Report (31st) on the Canada Pension Plan - Office of the Superintendent of Financial Institutions].

[27] The authorities have proactively outlined the fiscal impact of alternative policy scenarios, including increases in retirement ages, in selected publications such as IGSS (2025b).

Figure 17. Average Rates of Return of the Pension Reserve Fund



Source: Fonds de Compensation (2025) and IMF Staff estimates.

38. **The drivers behind recent weak employment growth should be thoroughly examined, with a view to potentially revising downward the medium- and possibly also long-term employment growth assumptions.** Over the period 2023–2024, employment growth was significantly overestimated (Figure 15). STATEC is currently analyzing these trends and considering whether to revise medium- and long-term employment growth further downward as a result. In the most recent projections, employment growth of over 2 percent per year is assumed for the period 2026–2030. If this assumption were revised to 1 percent, the timing of key fiscal events would be affected. Specifically, the projected year of Event 2 (when reserves fall below 1.5 times annual expenditure) would shift from 2039 to 2037, and the expected year of Event 3 (reserve depletion) would move from 2045 to 2043. This assessment should also account for the potential impact of artificial intelligence on both employment and productivity growth, given Luxembourg's high exposure to AI adoption and the associated risks of sector-specific job displacement alongside possible productivity gains, see Box 2.

39. **The pension model has seen notable improvements in recent years; however, further refinements should be considered, particularly after the finalization of the next AWG 2027 long-term projections.** Key areas for improvement include introducing greater distributional granularity based on micro-simulation, and enhancing survivor pension projections, further discussed below. These updates differ significantly in terms of fiscal and distributional relevance as well as resource needs, see Table 8. Given limited administrative capacity, the cost-benefit of each refinement should guide prioritization. Low-resource, high-impact measures—such as updating the assumed rate of return or revisiting mid- and long-term employment growth assumptions—could be addressed as a priority. In contrast, more resource-intensive improvements—like a dynamic and granular micro-simulation—could be deferred after completing the next AWG projections in 2026. Enhancing model documentation could support transparency and continuity with relatively modest effort.

40. The model lacks distributional micro-simulation, limiting its ability to accurately reflect the distributional effects and non-linearities of the pension system. No micro-simulation is used to project future contribution careers. As a result, the projection remains relatively static, incorporating only limited heterogeneity in earnings and contribution density (i.e. the number of contribution months accrued per year). Individuals are assumed to follow the average contribution density of their respective age, gender, and insurance year group (i.e., based on the year of entry into the insurance system). As a result, episodes of high or low contribution density are generally not captured, potentially leading to an underestimation of the tails of the distribution of accrued insurance years. This, in turn, may impair the accurate modeling of non-linear features of the benefit formula, such as the minimum and maximum pension (see system description in Annex 4). To address this, it is recommended to introduce greater distributional granularity based on micro-simulation—e.g., by projecting contribution careers and resulting pensions not only by age and gender but also across percentiles of lifetime earnings and/or contribution density. As an intermediate step, individuals could be assumed to remain in their observed contribution density and earnings percentile position (by age and gender) based on recent historical data. In the longer term, a more dynamic micro-simulation could be considered, where individuals transition between earnings and contribution density states over time, based on socio-economic characteristics and lagged labor market performance. For good practice of pension micro-simulation across EU-countries, case studies of e.g. Belgium and Norway may be considered, see for instance Dekkers et al. (2024). Consideration could be given to applying the updated ILO Pension Model, which now incorporates micro-simulation of contribution careers. In addition, collaboration with the Luxembourg Institute of Socio-Economic Research (LISER)—an internationally renowned institute with strong expertise in microsimulation—could be considered.

41. Despite improvements in survivor pension projections, further refinements are recommended to account for evolving marriage patterns and the impact of income testing on benefit levels. The 2024 AWG projections have enhanced the modeling of survivor pensions by linking inflows to current eligibility probabilities. As a result, projected expenditures in 2070 are 0.7 percentage points of GDP lower than in the 2021 projections However, inflows into survivor pensions may decline further due to falling marriage and cohabitation rates among younger cohorts. Since 2011, both the likelihood of having a partner and being married have decreased substantially for individuals under age 50 (STATEC, 2024). In addition, projected survivor benefits may be overstated, as an increasing share of women build substantial own pension entitlements, placing them above the income threshold for benefit reductions. Survivor pensions are reduced when the total income (survivor pension plus personal income) exceeds 1.5 times the reference amount—€3,918 per month per month. The pension is then reduced by 30 percent of the amount exceeding this threshold. IGSS is encouraged to reflect both the trends in marriage and cohabitation as well as the likely increasing share of survivors affected by income testing in upcoming model updates.

42. Minor changes may be considered to improve revenue and the expenditure side projections. On the revenue side, projections already account for differences in labor force participation and employment rates by gender, sector, and residence status. However, employment rates are not sufficiently modeled by age, with a constant rate applied for most ages. Introducing age-specific employment rates more precisely could improve accuracy further. On the expenditure side, changes in labor market participation are considered through the simulation of contribution careers, which determine future pension entitlements. In this context, some elements could be improved. For example, the estimation of non-contributory periods currently relies on stock measures from the base year, without projecting how these periods may evolve across cohorts—despite changes in parental leave, unemployment, education and other non-contributory periods. While such refinements are unlikely to change the baseline projection results significantly, they would strengthen the model's accuracy also for reform evaluation.

43. To improve transparency and build trust in pension projections, communication efforts could be further strengthened. Additional resources could be allocated to produce concise executive summaries that clearly present the main drivers of long-term pension finances and explain deviations between projection vintages. In this context, changes between projection rounds should be systematically categorized into: (1) updates to assumptions, (2) data revisions, and (3) methodological adjustments.[28] To further improve transparency and ensure reproducibility, a detailed model description—documenting the main calculation steps, assumptions, and data sources—could be developed and made available. This would not only enhance the credibility of the projections but also facilitate internal knowledge transfer and continuity, especially given that the current pension modelling in Luxembourg relies on only two individuals.

44. It is recommended to monitor closely the impact of Artificial Intelligence (AI) on Luxembourg's labor market and to conduct a stress test of the pension system under "Future of Work" scenarios. Evidence from the OECD (2023b), IMF (2024), and other studies suggest that AI could extend working lives and raise productivity, but its adoption is expected to reshape employment patterns unevenly across sectors, with routine-intensive and middle-skill jobs most vulnerable to automation (see Box 2). While around one-third of jobs in Luxembourg are in high-exposure sectors such as IT, finance, and specialized scientific services, most roles are more likely to be augmented than displaced; however, workers with non-physical routine tasks (e.g. in administrative support) may face greater displacement risks. These shifts could trigger more frequent job transitions, career interruptions, and growth in non-standard work, leading to more fragmented careers, weaker contribution histories, and greater reliance on minimum or partial pensions. Continuous monitoring of sectoral and demographic labor market trends will be essential to detect emerging risks early and adjust policy responses accordingly. To prepare, forward-looking labor market scenarios—including AI adoption pathways—should be integrated into pension modelling, as in Finland (2017), enabling policymakers to identify vulnerabilities early, adjust assumptions, and design reforms that enhance resilience and equity.

Box 2. The Potential Impact of Artificial Intelligence on the Labor Market and Pension Finances

The structure of Luxembourg's economy makes it one of the European countries most likely to see sizable benefits from AI adoption in terms of productivity gains. AI offers a potential boost to pension system revenues mainly by lifting productivity. IMF (2025) simulations for Europe project that medium-term productivity gains (over a five-year horizon) could reach around 0.8 percent cumulatively, compared with approximately 0.7 percent for the U.S. as estimated by Acemoglu (2024). Luxembourg stands out within that aggregate: the paper estimates cumulative productivity gains near 1 percent under the baseline scenario, and as much as 3 percent under more optimistic assumptions about AI exposure and adoption. Elevated wage levels and a strong orientation toward white-collar, services-based sectors—especially finance, administrative, and scientific services (see below) create stronger incentives for AI adoption in Luxembourg, amplifying its productivity potential. An OECD (2023b) survey finds that

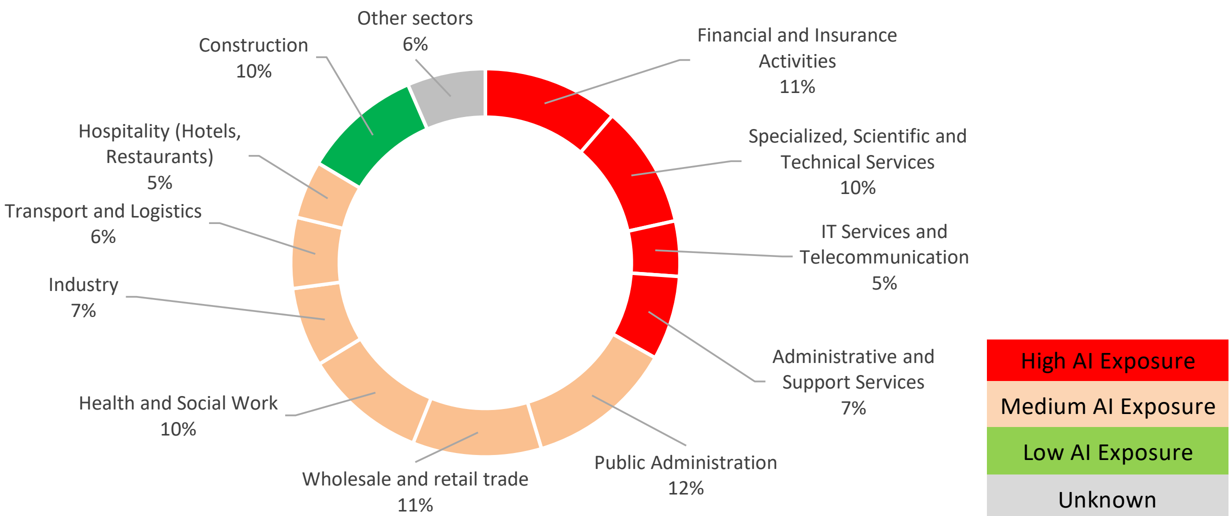
[28] Past AWG country fiche for Luxembourg already highlights the drivers leading to changes in results between projection vintages. Similar information could be communicated more prominently in Executive Summaries.

many workers report improved job performance, satisfaction, and physical and mental well-being following AI adoption—indicating that AI can make work less demanding and more adaptable. In aging economies such as Luxembourg (OECD Economic Surveys, 2025), this could also support longer working lives, particularly for older workers. Higher productivity can also cushion pension expenditure growth in pension systems where benefits are inflation indexed and not (fully) linked to productivity-driven wage growth —likely applicable for Luxembourg from 2029, when indexation changes take effect after Event 1.

AI adoption is expected to reshape employment patterns in Luxembourg, with impacts likely varying sharply across sectors and worker groups. Structural shifts in Luxembourg's labor market from AI adoption are likely to be uneven, potentially mirroring patterns observed in other advanced economies. Empirical evidence from the U.S. shows that during 2010–2021, commuting zones with higher AI adoption experienced significant declines in employment-to-population ratios, especially in manufacturing and low-skill service sectors, among middle-skill, non-STEM (non-science, technology, engineering, or mathematics), young and older workers, with disproportionate effects on men (Bonfiglioli et al., 2025). Although Luxembourg's economy is dominated by high-wage service sectors—possibly shielding some jobs—routine-intensive roles in logistics, hospitality, and administrative support could be vulnerable to similar displacement pressures. These job losses may not only lower the tax and social security contribution base but also increase reliance on minimum pension schemes. Given the still-limited evidence base and the rapid evolution of AI technologies, the scale of these effects remains uncertain and warrants close monitoring of sectoral and demographic labor market outcomes.

Luxembourg's sectoral employment structure suggests a substantial share of jobs are exposed to AI, though most are more likely to be augmented than displaced. The analysis of Luxembourg's employment distribution reveals that approximately 33 percent of jobs fall into sectors with high exposure to AI-driven automation and transformation (Figure 18), such as IT Services, Financial Activities, Specialized Scientific Services, where the impact of AI can vary, often enhancing and augmenting work but in some cases leading to job displacement. This is consistent with the OECD Employment Outlook 2023 as well we the ILO global exposure index (2025), which identifies these sectors and job categories as having significant automation potential due to AI advances. A larger share, about 50 percent, lies in sectors with medium risk of AI impact, including Public Administration, Health, and Hospitality, where AI adoption is typically more regulated, gradual and augmentative (OECD, 2023). The remaining 16 percent are in sectors with lower or variable AI risk, such as Construction and miscellaneous sectors. Similarly, a study by the Implement Consulting Group (2024), estimates that for 72 percent of jobs in Luxembourg are likely to be augmented due to generative AI, 6 percent of jobs may be partially or fully displaced and 22 percent of jobs may experience no automation at all due to AI.

Figure 181. AI Exposure by Employment Distribution and Sector



Source: STATEC and IMF Staff estimates.

Luxembourg's economic profile as a small, high-income (per capita), and highly specialized European country makes it instructive to compare its AI journey with that of its peers. Both Ireland and Switzerland share a similar economic structure, with thriving financial sectors and significant investments in technology and innovation. This comparison highlights shared challenges and opportunities, however, also underscores Luxembourg's unique strategic advantages.

In Ireland, a significant portion of jobs—approximately 63 percent—are exposed to AI-driven disruption, with the financial services sector being one of the most affected (Irish Finance Department, 2024).[29] Similar to Luxembourg, Irish experts emphasize that the future is about "partnering with AI," not competing against it, and they foresee a strong expansion in AI-related roles, particularly within the multinational sector. However, this potential is tempered by a widely acknowledged and "urgent" IT skills gap that needs to be addressed through a strategic and inclusive approach involving government, organizations, and educational institutions.

Switzerland, another European financial and innovation hub, ranks third globally in the potential for automation and augmentation, with 45 percent of work time impacted by generative AI (Accenture, 2024). Despite this high ranking and a robust AI ecosystem, a report reveals a significant deficit in the practical adoption of AI, particularly among SMEs. A primary obstacle is the lack of a consistent data foundation, with only 8 percent of Swiss companies having a fully consistent data structure. This demonstrates that having a strong innovative ecosystem is not sufficient; the ability to implement AI effectively hinges on foundational data readiness.

Luxembourg's position is distinguished by its proactive and coordinated approach. Its "Accelerating Digital Sovereignty 2030" strategy integrates AI with national strategies on data and quantum technologies. This whole-of-government approach, supported by new dedicated budgetary resources for the 2025–2030 period, is a rare international model and is designed to chart a clear course for long-term growth. This integrated framework, which links technological ambition with policy and workforce development, could provide Luxembourg with a decisive edge in converting its high AI exposure into a sustained leadership position.

Overall, Luxembourg is well positioned to benefit from AI adoption but should make deliberate policy choices to ensure that these gains are inclusive and broadly shared. Experience from other advanced

[29] Due to methodological issues the share of jobs exposed to AI in Ireland cannot be compared to estimates for Luxembourg.

economies shows that, without proactive measures, AI can amplify skill mismatches, widen labor market disparities, and accelerate job polarization (IMF, 2023). To mitigate displacement risks and maximize the benefits of AI technologies, Luxembourg should implement comprehensive workforce development and social protection strategies. This includes policies that strengthen upskilling and reskilling, facilitate smooth job transitions across sectors, and reduce rigidities in hiring and termination practices (Chen, 2024). As AI becomes integral to a growing number of economic sectors, basic AI literacy should be promoted across the workforce—not only among specialists—to avoid creating a two-tiered labor market. Well-targeted policy instruments, such as tax incentives for training and public-private partnerships, can help existing workers adapt to evolving hybrid roles, preserve career viability, and support job stability (Yejati, 2025). It is also recommended to carry out stress test simulations to assess how AI adoption could affect public finances in general and pension finances and the distribution of pension benefits in particular (via micro-simulation), helping policymakers anticipate fiscal impacts and design mitigating measures in advance.

Bibliography

Accenture. 2024. *Can Switzerland Lead the Way in Gen AI?* Report. Available at: Can Switzerland lead the way in gen AI? | Report | Accenture

Bonfiglioli, A., R. Crinò, G. Gancia, and K. Papadakis. 2025. "Robots, AI, and the Labor Market: Evidence from US Commuting Zones." *Economic Policy* 40 (121): 145–194.

Chambre des Députés. 2024. *Question Parlementaire.* Grand-Duché de Luxembourg. Available at: Question Parlementaire | Chambre des députés du grand-duché de Luxembourg

CNFP. 2021 Evaluation de la soutenabilité à long terme des finances publiques, Report available at: Evaluation de la soutenabilité à long terme des finances publiques - Octobre 2021

Dekkers, G., et al. 2024. *Long-Term Projections of Pension Adequacy in a Selection of Countries.* Luxembourg: Publications Office of the European Union.

Eurostat. 2025. "EU Received 4.3 Million Immigrants in 2023." News Article available at: EU received 4.3 million immigrants in 2023 - News articles - Eurostat

Finnish Centre for Pensions. 2017. *Scenario Calculations of the Impact of the Change in Work on the Pension System and Public Finances.* Reports of the Finnish Centre for Pensions No. 03/2017. Tikanmäki, H., I. Ahola, J. Koponen, K. Reipas, and H. Suikkanen. Available at: Skenaariolaskelmia_tyon_muutoksen_vaikutuksesta.pdf

Forbes. 2025. "Intense Debates Over Pension System Reform." Forbes Luxembourg. Available at: Intense Debates Over Pension System Reform | Forbes Luxembourg

IGSS, 2024, 2024 Aging Report – Pension Projections, Country Fiche for Luxembourg, Available at: fb78e27d-6c9d-45ff-9bea-9832b9bf5c49_en

IGSS. 2025a. *Contribution de l'IGSS dans la Consultation sur la Viabilité du Système des Retraites. Available at:* Contribution de l'IGSS dans la consultation sur la viabilité du système des retraites

IGSS, 2025b. Prolongation de la carrière professionnelle dans le contexte du régime général d'assurance pension. Available at: Overview No 29 - Extension of professional careers in the context of the general pension insurance scheme - General Inspectorate of Social Security - The Luxembourg Government

Implement Consulting Group. 2024. *The Economic Opportunity of AI in Luxembourg. Available at: The economic opportunity of AI in Luxembourg*

Irish Department of Finance. 2024. *Artificial Intelligence: Friend or Foe. Available at: Artificial Intelligence: Friend or Foe*

OECD. 2023a. Evaluation of Belgium’s COVID-19 Responses: Fostering Trust for a More Resilient Society, Paris: Organisation for Economic Co-operation and Development., *Available at:* https://doi.org/10.1787/990b14aa-en

OECD. 2023b. *The Impact of AI on the Workplace: Main Findings from the OECD AI Surveys of Employers and Workers.* Paris: Organisation for Economic Co-operation and Development.

Question Parlementaire n°1327. *Chambre des Députés du Grand-Duché de Luxembourg.*

Yejati, A. 2025. “Hybrid Jobs: How AI Is Rewriting Work in Finance.” Brookings Institution. Available at: https://www.brookings.edu/articles/hybrid-jobs-how-ai-is-rewriting-work-in-finance/

Annex 1. Comparison of Aggregates Sensitivity to Inflation in Peer Countries

Table A1.1. Indexation of Minimum Wage, Average Wage and Pensions to Inflation in France, Germany and Luxembourg

Country	Income Type	Indexed to Inflation	Automatic Indexation	Details
Germany	Minimum Wage (Mindestlohn)	Yes	No	Adjusted every two years by an independent commission. No automatic link to inflation.
	Average Wages	No	No	Depends on collective agreements. Adjustments often delayed.
	Pensions	Yes	Partially	Adjusted using a formula based on wages and inflation, with a lag.
Belgium	Minimum Wage (Mindestlohn)	Yes	Yes	The minimum wage is indexed to the so-called “health index”, i.e. past CPI excluding alcohol and tobacco and petrol but including heating fuel, gas, and electricity (every time the index increases by 2% or more since last increase)
	Average Wages	Yes	Yes	Wages in most sectors are automatically indexed to inflation based on the health index. The frequency and method of adjustment vary by sector, but indexation remains a core feature of wage-setting mechanisms.
	Pensions	Yes	Yes	Social benefits, including pensions, are automatically increased by 2% each time the index exceeds a certain level (the “threshold index”).
France	Minimum Wage (SMIC)	Yes	Yes	If the consumer price index increases by at least 2% Minimum wage increases automatically in the same proportions; the minimum wage is increased every year to measured inflation for 20% households with the lowest incomes and half of the gain in purchasing power of the average hourly wage of workers and employees.
	Average Wages	No	No	Depends on collective bargaining. No automatic indexation.
	Pensions	Yes	Partially	Adjusted annually based on forecast inflation, with correction the following year.
Luxembourg	Minimum Wage	Yes	Yes	Automatically adjusted via wage indexation system when CPI increases by 2.5%.
	Average Wages	Yes	Yes	All wages are subject to automatic indexation via the wage scale.
	Pensions	Yes	Yes	Automatically adjusted with the wage indexation system, like wages.

Source: OECD Employment Outlook 2023, Missoc (European Commission) and European Central Bank (2008), Wage indexation mechanisms in euro area countries, ECB Monthly Bulletin, May 2008, Box 5.

Annex 2. Decomposition of Projection Deviations

Starting from the following equations, one can decompose the relative deviation of revenue, spending and balance among the deviation of their main components, weighted by the share of the component.

“Δx” is equal to the difference between forecast and observed value of x. :

Decomposition of the Revenue Projection Gap

*Revenue = Number of contributors * Average contribution *COLA/100 +Other revenue*

$$\frac{\Delta Revenue}{Revenue} = \frac{Contributions}{Revenue} * \left(\frac{\Delta NbContrib}{NbContrib} + \frac{\Delta AverageContrib}{AverageContrib} + \frac{\Delta Cola}{Cola}\right) + \frac{Other}{Revenue} * \frac{\Delta Other}{Other}$$

Decomposition of the Expenditure Projection Gap

*Expenditure = Number of pensioners * Average pension *COLA/100 * Readjustment + Other Expenditure*

$$\frac{\Delta Spending}{Spending} = \frac{Cash\ Benefits}{Spending}\left(\frac{\Delta NbPensioners}{NbPensioners} + \frac{\Delta AveragePension}{AveragePension} + \frac{\Delta Cola}{Cola} + \frac{\Delta readjust}{Readjust}\right) + \frac{Other}{Spending} * \frac{\Delta Other}{Other}$$

Decomposition of the Financial Balance Projection Gap

Balance = Revenue - Expenditure

$$\frac{\Delta Balance}{Balance} = \frac{Revenue}{Balance} * \frac{\Delta\ Revenue}{Revenue} - \frac{Spending}{Balance} * \frac{\Delta Spending}{Spending}$$

It can also be expressed in a more detailed form:

*Balance = Number of contributors * Average contribution *COLA/100 +Other revenue -*

*Number of pensioners * Average pension *COLA/100 * Readjustment - Other Expenditure*

$$\frac{\Delta Balance}{Balance} = \frac{OtherR}{Balance} + \frac{Contributions}{Balance}\left(\frac{\Delta NbContrib}{NbContrib} + \frac{\Delta AverageContrib}{AverageContrib} + \frac{\Delta Cola}{Cola}\right) - \frac{\Delta OtherS}{OtherS}\frac{OtherS}{Balance} + \frac{Cash\ Benefits}{Balance}\left(\frac{\Delta NbPensioners}{NbPensioners} + \frac{\Delta AveragePension}{AveragePension} + \frac{\Delta Cola}{Cola} + \frac{\Delta Readjust}{Readjust}\right)$$

And the terms can be rearranged for a more concise form

$$\frac{\Delta Balance}{Balance} = \frac{Contributions}{Balance} * \frac{\Delta NbContrib}{NbContrib} + \frac{Contributions}{Balance}\frac{\Delta AverageContrib}{AverageContrib} + \frac{Contributions}{Balance}\ \frac{\Delta Cola}{Cola} - - - \frac{Cash\ Benefits}{Balance} * \frac{\Delta NbPensioners}{NbPensioners} - \frac{Cash\ Benefits}{Balance} * \frac{\Delta AveragePension}{AveragePension} - \frac{Cash\ Benefits}{Balance}\frac{\Delta Cola}{Cola} - \frac{Cash\ Benefits}{Balance}\frac{\Delta Readjust}{Readjust} + \frac{\Delta Other\ R}{OtherR}\ \frac{OtherR}{Balance} - - \frac{\Delta OtherS}{OtherS}\ \frac{OtherS}{Balance}$$

Annex 3. Options for Short-term Forecast Refinements

This methodological annex describes the proposed ensemble approach considering additional and more flexible models for short-term projections. Examples of such models are outlined for the projection of total contributions and the alternative employment projection.

Weighted Average Forecast

A wide range of model specifications is tested, including classical models, penalized models, machine learning (ML) models and mixed frequency (MF) models (see Glossary of all models below). Results are calculated as a weighted average of the forecasts (see below). Each model is tested for different specifications of the main variable (diff and log specification).[30] If a model passes and yields a result, it is included in the set of models δ_m from which the weighted average forecast is calculated. The weight of a model in the total average is calculated based on its accuracy compared to the accuracy of other selected models. If the accuracy for the model m is δ_m and its inverse $\varphi_m = \frac{1}{\delta_m}$model, the weight ξ_m of model m in the set of models M are then calculated as $\xi m = \frac{\varphi m}{[\sum_{m \in M} \quad \varphi m]}$.

To bias the weights towards the better models, an exponent p is added, which gives the general weight formula: $\xi_m^p = \frac{\varphi_m^p}{[\sum_{m \in M} \varphi_m^p]}$. p is determined based on lasso method.

Contribution Forecast Models

For the total contribution forecast, 48 models were estimated (Table A3.1). The final estimate is their weighted average. To integrate both quarterly and monthly data effectively, we use mixed-frequency models.[31] Two models perform best in terms of in-sample and out-of-sample error indicators: the Gated Recurrent Unit and the VARX Own/Other Sparse Group Penalty. They show the lowest error rates. Table A3.2 provides more details on their specifications.

Table A3.1: Multivariate models tested for the contributions (Monthly)

	In Sample		Out Sample	
Model	**MAPE**	**RMSE**	**MAPE**	**RMSE**
VAR Smoothly Clipped Absolute Deviation org	0.92%	4,950,000	2.59%	11,600,000
VAR Smoothly Clipped Absolute Deviation log	1.10%	5,770,000	0.98%	5,260,000
VAR Smoothly Clipped Absolute Deviation diff	0.78%	4,670,000	0.98%	5,520,000
VAR Elastic Net org	1.18%	6,130,000	1.56%	8,130,000
VAR Elastic Net log	1.22%	6,240,000	1.50%	6,980,000

[30] For the model application, all input variables are tested and treated for outliers, seasonally adjusted, nowcasted and decomposed if frequencies differ. After ensuring consistency of main variable and explanatory variables, an analysis (VARX Lasso) is performed to test for the influence of the variable.

[31] Mixed-frequency models allow to combine data collected at different frequencies (e.g., quarterly and monthly) into a single, cohesive forecasting framework. This approach captures the rich detail of monthly data while leveraging the long-term trends available in the quarterly series, leading to more robust and accurate projections.

	In Sample		Out Sample	
Model	**MAPE**	**RMSE**	**MAPE**	**RMSE**
VAR Elastic Net diff	0.79%	4,440,000	1.05%	5,440,000
VARX Lasso org	1.31%	6,600,000	1.50%	7,840,000
VARX Lasso log	1.29%	6,470,000	1.50%	6,980,000
VARX Lasso diff	0.81%	4,470,000	1.06%	5,460,000
VECM org	0.60%	3,210,000	1.35%	8,100,000
VECM log	0.68%	3,530,000	1.41%	8,630,000
HVAR Elementwise Lasso org	0.80%	4,550,000	2.06%	9,260,000
HVAR Elementwise Lasso log	0.88%	4,790,000	1.86%	8,440,000
HVAR Elementwise Lasso diff	0.73%	3,950,000	0.93%	5,030,000
HVAR Componentwise Lasso org	0.84%	4,780,000	1.65%	7,750,000
HVAR Componentwise Lasso log	1.10%	5,600,000	1.14%	5,870,000
HVAR Componentwise Lasso diff	0.64%	3,400,000	0.98%	5,110,000
VAR org	0.61%	3,220,000	1.16%	6,630,000
HVAR Own/Other Lasso org	0.83%	4,560,000	1.86%	8,420,000
HVAR Own/Other Lasso log	0.83%	4,520,000	1.24%	6,110,000
HVAR Own/Other Lasso diff	0.65%	3,460,000	0.95%	5,040,000
VAR Minimax Concave Penalty org	0.93%	5,130,000	4.11%	18,100,000
VAR Minimax Concave Penalty log	1.43%	7,070,000	3.87%	17,000,000
VAR Minimax Concave Penalty diff	0.82%	4,700,000	0.92%	5,170,000
VARMA org	0.63%	3,600,000	1.31%	6,850,000
VARMA log	0.57%	3,390,000	1.09%	5,650,000
VARMA diff	0.68%	3,770,000	1.44%	6,690,000
ARDL org	0.71%	3,900,000	1.10%	5,470,000
ARDL log	0.63%	3,680,000	0.83%	4,350,000
VARX Lag Group Lasso org	0.72%	4,140,000	2.02%	9,030,000
VARX Lag Group Lasso log	0.68%	3,980,000	1.38%	6,490,000
VARX Lag Group Lasso diff	0.65%	3,570,000	1.07%	5,540,000
VARX Own/Other Group Penalty org	0.82%	4,560,000	0.99%	5,170,000
VARX Own/Other Group Penalty log	0.82%	4,610,000	0.93%	5,010,000
VARX Own/Other Group Penalty diff	0.75%	4,200,000	1.06%	5,470,000
ANN diff	0.84%	4,690,000	0.85%	4,730,000
VAR Weighted Lag Lasso org	0.89%	4,830,000	3.37%	15,000,000
LSTM diff	0.82%	4,610,000	0.82%	4,490,000
GRU diff	0.77%	4,630,000	0.79%	4,680,000
VARX Own/Other Sparse Group Penalty org	1.48%	7,740,000	2.20%	10,700,000
VARX Own/Other Sparse Group Penalty log	1.75%	9,140,000	1.77%	9,200,000
VARX Own/Other Sparse Group Penalty diff	0.77%	4,660,000	0.80%	4,520,000
Minnesota BVAR org	0.59%	3,170,000	0.97%	5,010,000
Minnesota BVAR log	0.59%	3,150,000	0.74%	3,920,000
Minnesota BVAR diff	0.66%	3,620,000	0.89%	4,870,000
TVP BVAR with SV org	0.55%	2,890,000	1.40%	6,560,000
TVP BVAR with SV log	0.57%	2,870,000	1.15%	5,500,000
TVP BVAR with SV diff	0.68%	3,510,000	1.13%	5,760,000
Naive org	6.25%	47,300,000	6.25%	47,300,000

Source: Authorities, mission calculations

Note: The performance of the models is based on the in-sample and out-of-sample performance metrics. The best models are those with the lowest Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) values.
Naïve estimates correspond to simple ARMA model with no explanatory variable.

Table A3.2. Comparison of the Two Best Performing Models for Contributions

	Model 1	Model 2
Main Variable	Pensions contributions (differenced)	Pensions contributions (differenced)
Unit	Euros	Euros
Explanatory Variables	Y2: Contribution ceiling (differenced) Y3: Compensation of Employees, Current Prices (differenced) Y4: Number of contributors (differenced)	Y2: Contribution ceiling EUR Y3: Compensation of Employees, Current Prices Y4: Number of contributors
Model Type	GRU model with 4 endogenous variables	VARX Own/Other Sparse Group Penalty model with 4 endogenous variables
Technical details	1 layer with a hidden state size of 80 8 epochs Training stopped after 5 consecutive increases in validation loss	Maximum of 12 modelled lag(s). Penalty parameter: 0.0031 selected using time series cross-validation

Source. Mission's findings.

Employment Forecast Models

The model approach for the estimation of employment is like the total contribution estimation. 27 models are used for the employment forecast (Table A3.3). A broad set of labor market input variables are used, including total employment, employed, migrants, low-skilled, and labor market variables from the greater Luxembourg area. Three models perform better in terms of in-sample and out-of-sample error indicators. Table A3.4 provides more details on their specification and the penalty parameter for these models using time series cross-validations.

Table A3.3 Comparison of the Two Selected Models for Employment

Model	In-sample MAPE	In-sample RMSE	Out-of-sample MAPE	Out-of-sample RMSE
ARDL org	0.06%	329	0.34%	1,753
ARDL log	0.06%	376	0.32%	1,744
VARX Lasso org	0.98%	5,244	0.74%	3,796
VARX Lasso log	1.50%	7,937	0.76%	3,890
VARX Lasso diff	0.09%	495	0.09%	533
VAR Elastic Net org	0.95%	4,704	0.76%	3,907
VAR Elastic Net log	0.92%	4,501	0.83%	4,213
VAR Elastic Net diff	0.09%	512	0.10%	556
HVAR Componentwise Lasso org	0.36%	2,013	0.57%	2,936
HVAR Componentwise Lasso log	0.31%	1,957	0.84%	4,168
HVAR Componentwise Lasso diff	0.07%	429	0.08%	469
HVAR Elementwise Lasso org	0.92%	4,736	1.41%	6,862
HVAR Elementwise Lasso log	1.54%	7,869	1.42%	6,903
HVAR Elementwise Lasso diff	0.08%	494	0.09%	533
HVAR Own/Other Lasso org	0.62%	3,061	1.04%	5,061
HVAR Own/Other Lasso log	0.91%	4,459	1.30%	6,313
HVAR Own/Other Lasso diff	0.07%	416	0.08%	460
VARX Lag Group Lasso org	0.16%	956	0.50%	2,471
VARX Lag Group Lasso log	0.48%	2,376	0.76%	3,683

Model	In-sample MAPE	In-sample RMSE	Out-of-sample MAPE	Out-of-sample RMSE
VARX Lag Group Lasso diff	0.06%	368	0.07%	425
VAR Weighted Lag Lasso org	0.22%	1,140	2.92%	14,156
VAR Weighted Lag Lasso diff	0.05%	305	0.07%	433
VAR Minimax Concave Penalty org	1.84%	8,936	0.60%	2,928
VAR Minimax Concave Penalty log	1.43%	6,959	1.80%	8,726
VAR Smoothly Clipped Absolute Deviation org	0.79%	3,853	0.97%	4,732
VAR Smoothly Clipped Absolute Deviation log	1.43%	6,959	1.16%	5,646
Naive org	0.57%	3,502	0.57%	3,502

Source: Authorities, mission's calculations.

Note: The selection of the best models is based on the in-sample and out-of-sample performance metrics. The best models are those with the lowest Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) values.
Naïve estimates correspond to simple ARMA model with no explanatory variable.

Table A3.4 Comparison of the Two Selected Models for Wages

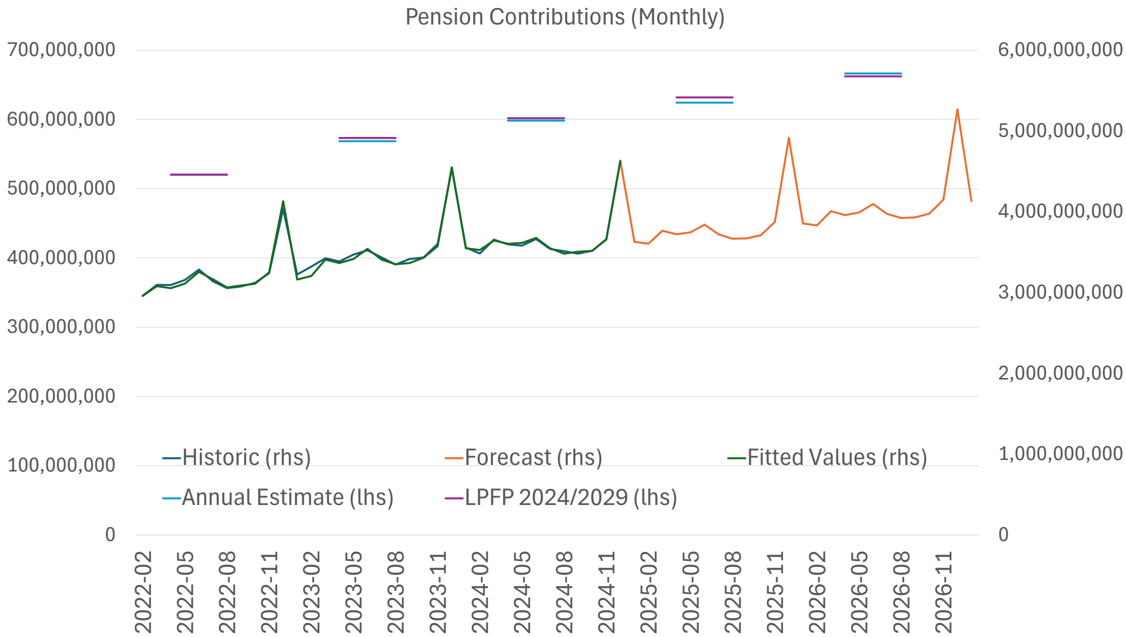
Feature	VARX Lag Group Lasso	HVAR Own/Other Lasso	VAR Weighted Lag Lasso
Number of Endogenous Variables	15	15	15
Maximum Modelled Lags	12	12	12
Penalty Parameter	7.9718	2.7827	0.0004

Source: Authorities, mission's calculations

Comparison of Results with LPFP Projections

The projection for contribution discussed above uses our own forecasts of macro-economic inputs (employment and wages). Differences between the weighted average forecast of contributions presented above and the LFPF 2024/2029 projections are small but still noteworthy. Compared to the LFPF 2024/2029, this method suggests a lower level of total contributions for 2025 by 1.2 percent, with slightly higher contributions by 0.6 percent projected for 2026 (see Figure below). This alternative contribution projection indicates that the forecasts of IGSS are relatively robust. Similar robust checks may be carried out by the authorities for other model components and for longer time series.

Figure A3.1 Total Contributions in Euro: Model Fit and Forecast



Source: IMF Staff estimates, LPFP 2024-2029 Projection.
Note: Pension Contributions only (D61).

Glossary of the Projection Models

Table A3.5 Glossary of Projection Models

Model	Description
Classical Models	
VAR (Vector Auto Regression)	Captures linear relationships between multiple time series using past values and error terms.
VECM (Vector Error Correction Model)	Estimates both short-term and long-term effects for datasets with long-run relationships (cointegration).
VARMA (Vector Auto-Regressive–Moving-Average)	Combines autoregression (AR) and moving average (MA) components for multivariate time series.
ARDL (Auto-Regressive Distributed Lag)	A simpler model where the main variable depends on indicators, but the indicators do not depend on each other or the main variable.
Bayesian VAR (BVAR) with Steady State Prior	Uses informative priors to reduce parameter uncertainty, incorporating economic theory.
Minnesota BVAR	A type of Bayesian VAR that shrinks parameters towards a random walk, assuming shorter lags have a larger impact.
Time-varying Bayesian VAR	Addresses the limitation of constant parameters and equal-sized shocks over time, useful for longer periods or policy changes.
Penalized Models (Regularization Methods)	
Ridge Regression	Shrinks large regression coefficients to reduce overfitting, improving prediction accuracy.
Lasso (Least Absolute Shrinkage and Selection Operator)	Adds a penalty to the absolute value of coefficients, performing variable selection and simplifying the model.
Elastic Net	Combines Ridge and Lasso penalties, addressing limitations of Lasso with highly correlated variables.
VECM Lasso	Combines VECM with Lasso penalty, simplifying the model and selecting important variables.
Group Lasso	Selects predefined groups of variables into or out of a model together.
Lag Group Lasso	Groups variables based on their lags, penalizing and excluding non-contributing groups.

Model	Description
Lagweighted Lasso	Applies a Lasso penalty that increases with lag length, prioritizing shorter lags.
Endogenous-First VARX	Prioritizes endogenous series by penalizing them differently.
VARX Own/Other Group Penalty	Distinguishes between a variable's own lags and the lags of other variables, prioritizing the former.
VARX Own/Other Sparse Group Penalty	A less restrictive variation of the Own/Other Group Penalty.
HVAR Models	More flexible VAR models allowing different lags for each variable.
Componentwise Lasso	All variables have the same maximum lag.
Own/Other Lasso	Prioritizes a variable's own lags over others.
Elementwise Lasso	Each variable can have its own maximum lag.
Machine Learning Models	
Artificial Neural Network (ANN)	Inspired by the human brain, with fewer connections and parameters, reducing overfitting.
Long Short-Term Memory (LSTM)	A type of recurrent neural network (RNN) good at processing sequences of data, identifying complex patterns.
Gated Recurrent Unit (GRU)	Similar to LSTM but with fewer parameters, less prone to overfitting on smaller datasets.
Mixed Frequency Models	
MIDAS (Mixed Data Sampling)	Uses high-frequency indicators to predict a low-frequency variable, fitting a lag distribution function to prevent overfitting.
Unrestricted MIDAS	Uses high-frequency data without a lag distribution function.
MIDAS with Penalties	Incorporates penalty functions to shrink parameters, reducing overfitting.
MIDAS Sparse Group Penalty	Uses a sparse group penalty function for variable selection.
MIDAS Lasso	Applies a Lasso penalty function, performing variable selection.

Annex 4. Overview of Pension System Rules

Table A4.1 Pension System Parameters

Parameter	Description
Contribution rates	24% total: 8% employer, 8% employee, 8% government; up to 5× minimum wage ceiling.
Contribution ceilings	Pensionable earnings capped at 5× social minimum wage.
Normal retirement age	65 years with at least 10 years of insurance.
Early retirement	57 years with 40 years of contributions; or 60 years with 40 years of insurance (including credited).
Insurance years needed (old age)	40 years for maximum accrual; minimum 10 years for lifelong payment.
Old age benefit formula	Mixed: flat-rate benefit + earnings-related benefit with accrual rate of 1.782% of adjusted lifetime total earnings (gradually decreasing until reaching 1.6% by 2052) plus 0.015% (gradually rising to 0.025% by 2052) of adjusted lifetime total earnings for each year the insured's age and years of coverage exceeds 94 years (gradually rising until reaching 100 by 2052).
Minimum Pension	€2,293.55 a month is paid in 2025 with at least 40 years of coverage. If the insured contributed for at least 20 years but less than 40 years, the guaranteed minimum pension is reduced by 1/40 for each year of coverage less than 40 years.
Pension indexation	Fully indexed to prices and, under a semi-automatic readjustment mechanism, also to real wage growth, with the latter applied in full when contributions exceed expenditures but reduced (via a moderator coefficient between 0 and 0.5) if the system's balance deteriorates.
Credited periods	Periods during which the insured was covered by sickness, maternity, or work injury benefits (since 2011), unemployment support, or the minimum income allowance are treated as credited contribution periods. The same applies to years spent in study or apprenticeship between ages 18 and 27, to time spent caring for a child under age 6 (or under age 18 if the child is disabled), and to periods of receiving long-term care or invalidity benefits.
Pension penalty/bonus for early/late retirement	not applied

Source: IMF Staff based on ISSA Country Profile.