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Research Article

Radiological Equipment Quality in Albania: A National COCIR-Based Benchmarking Study

Dafina Xhako[1]*, Niko Hyka[2], Suela Hoxhaj[1], Albana Shahini[2], Joan Jani[1], Rudina Osmanaj[3], Elda Spahiu[4] Serxhi Qosja[5]

[1]Department of Physics Engineering, Polytechnic University of Tirana, Tirana, Albania
[2]Department of Diagnostic, University of Medicine, Tirana, Albania
[3]Department of Physics, University of Tirana, Tirana, Albania
[4]Institute of Applied Nuclear Physics, Tirana, Albania
[5]Department of Manufacturing and Civil Engineering, Norwegian University of Science and Technology, Gjovik, Norway
***d.xhako@fimif.edu.al**

Abstract

The radiological equipment quality and technological adequacy level plays a very important role in diagnostic accuracy, radiation protection and the future sustainability of diagnostic services. This study presents a national benchmarking analysis of radiological equipment quality in Albania based on the integration of data from the Klingo database, which is used by the official national biomedical authority for the registration and surveillance of devices in public healthcare institutions, together with acceptance, constancy, and quality control reports from ALBMEDTECH and other verified private-sector sources. A cross-sectional analytical method was adopted to compile a full national equipment inventory by modality, sector and installation date. Major technical performance parameters (kVp accuracy, expose time accuracy, total filtration, radiation output constant-cy/repeatability) were sampled from quality control records and compared against the relevant tolerance criteria. The age profile and availability of modalities in the national inventory as well as compliance findings were benchmarked with the COCIR Golden Rule structure whereas the OECD benchmarks were used for national density indicators and technology mix. The document signals on a heterogeneous situation across modalities and sectors, on the 6–10 years use range, an incidence of 45% on basic radiological devices, while the per-centage of lines very recent (less than five years use) is around 20%, and that of those more than 10 years old accounts for 35%. This percentage implies that 35% are used well beyond the technological window of their life cycle (10 years). As time passes by, technical deviations become more frequent and corrective maintenance is required more often; the OECD benchmarking also delineates a relatively lower density of imaging units in Albania (dental radiology is the highest, but advanced imaging techniques such as hybrid imaging or nuclear medicine are still deficient in Albania). The results offer substantiated input for possible future equipment renewal strategies, enhanced QA/QC system and policy alignment with other European standards on radiology.

Keywords: Klingo Registry; Medical Imaging Equipment; Radiology Infrastructure; COCIR Golden Rule; Equipment Age Profile; QA/QC.

INTRODUCTION

Medical imaging systems are an essential element in the delivery of today's healthcare, forming the basis of early diagnosis, disease staging, interventional procedures, therapeutic monitoring and evaluation in all branches of clinical practice [1-5]. X,ray radiography, computed tomography (CT), magnetic resonance imaging (MRI), mammography, fluoroscopy and interventional techniques not only influence available diagnoses and clinical options but when operational also determine time to deliver and image quality, workflow [1, 2, 6-8]. For X-ray systems the characteristics of technology also influence doses to patient and staff through management of the average incident fluence and implementation of dose reduction techniques [8-15]. Imaging system performance will influence the accuracy and reproducibility of diagnosis and the degree of variation in delivered exposure. Inadequate maintenance of aging imaging technology may be a cause of calibration drift, detector inefficiencies, repeat examinations and avoidable doses. Therefore, a strategic management framework for medical technology across the device lifecycle, incorporating dedicated quality assurance/quality control (QA/QC) protocols and evidence-based replacement strategies has been implemented in some European healthcare providers and internationally [8, 16-21].

In this policy and technology context, the European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry (COCIR) introduced the Golden Rule as a practical guide for sustainable renewal of imaging fleets and proposed an age profile in which at least 60% of the fleet is less than five years old, 30% predates six years and 10% predates ten years, see Figure 1 [6, 7, 21].

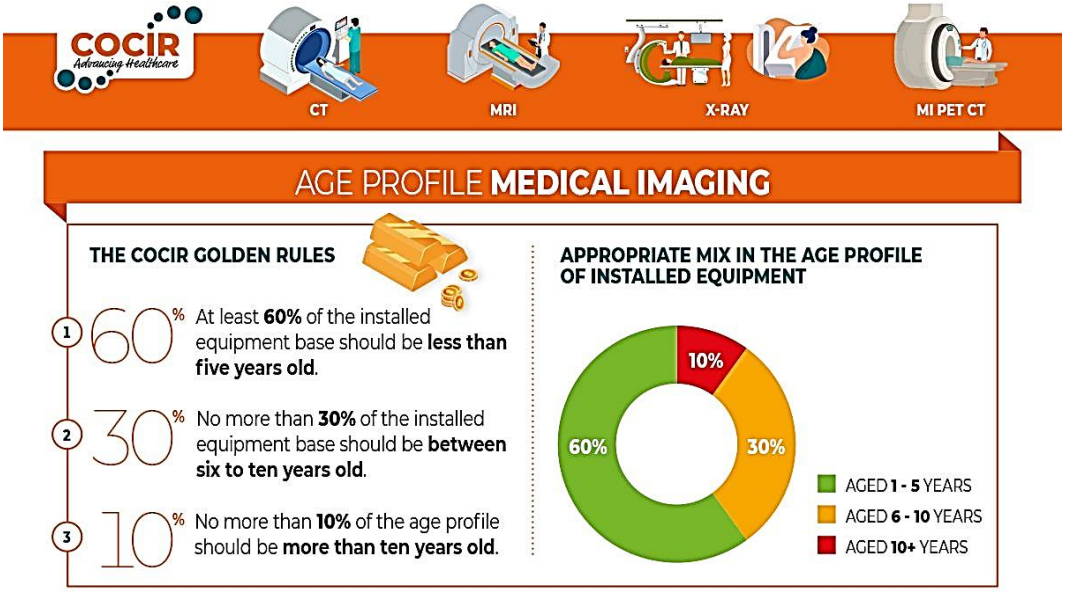

Figure 1. COCIR Golden Rule (COCIR)

This benchmark is currently used widely to indicate whether a national fleet will be likely to take advantage of state-of-the-art dose efficient features, ultra-modern detector technology, enhanced software capabilities, and improved operational reliability. In

Albania, modernization of radiological equipment has progressed unevenly and has often been shaped by institution specific procurement cycles, donor supported initiatives, and urgent service needs most visibly during the COVID-19 pandemic, when imaging (particularly CT) was used extensively to support clinical pathways [1, 2]. Although a national device registration and management platform Klingo, maintained by [5], provides an institutional basis for monitoring the installed base, a consolidated scientific benchmarking of the radiological fleet that integrates registry evidence with technical QA/QC findings and internationally comparable indicators has remained limited. This gap constrains transparent replacement planning, optimization of QA/QC programs, and systematic risk reduction [10, 21-25].

In the context above, our study offers integrated, country, specific evaluation of Albania 's imaging and radiology equipment based on Klinge registry data and accessible technical QC records, analyzed according to international standards (such as COCIR data to inform equipment renewal predictions, and OECD indicators to juxtapose utilization rate and installed base) [11]. We attempt to baseline a quantitative approach for characterizing the composition and distribution of the installed base, thus addressing modernization and risk based preventive maintenance planning, and providing the foundation for consolidating Albania's radiological practice both within and outside European borders. Existing research gaps due to fragmented registry data, a lack of centralized QA/QC benchmarking hamper risk, based radiological fleet management in LMICs, even though reliance on medical imaging for diagnosis accuracy, radiation safety, and healthcare system efficiency is constantly increasing. In the scientific literature, several urgent unresolved gaps are identified, which are increasingly relevant to LMIC settings, such as Albania: Gap 1: Incomplete registry data and fragmentation of information In LMIC countries, nomenclature and registry data incomplete, lifetime metadata, such as dates of installation/commissioning, prevent accurate age profiling and lifecycle, segmented policy development, leading to reliance on lesser predictive accuracy indirect back, casting or back, estimation methods. Gap 2: Absence of combined QA/QC integrated benchmarking frameworks While most studies identify and compare either inventory measures (e.g., COCIR age profiles) or technical QA/QC performance, few combine both elements into actionable risk, based benchmarking analyses, which limit systems, level contextual interpretations. Gap 3: Lack of quantitative modeling for renewal prioritization Most current publications (e.g., COCIR, OECD) present mainly descriptive statistics, estimation of proportions and ratios, and several static indicators.

However, there is a deficiency of inferential approaches such as multiple regression modeling, inequality indicators, or correlational analyses to support decision making. Gap 4: unsatisfactory intersection of equipment quality benchmarks and sustainability criteria. While the influence of average fleet age on equipment energy use, circularity and Lifecyle efficiency are highlighted by [6, 7] and European sustainability mechanisms, such as minimum energy purchase obligation (MEPA), the connections between QA/QC and sustainability indicators need amplification.

Research Hypotheses

To fill the above, mentioned gaps, this study proposes four hypotheses that form a testable analytical framework:

- H1 (COCIR deviation hypothesis): The age distribution of the Albanian radiological equipment fleet differs drastically from the COCIR Golden Rule fleet. Statistical test applied: Chi, square goodness of fit () <44>
- H2 (Age–performance degradation hypothesis): The chance of noncompliance in terms of QA/QC values (kVp accuracy, exposure time, output variation) is a function of the age group. Logistic regression was used as the statistical test.
- H3 (Infrastructure inequality hypothesis): The distribution of radiology within institutions reveals marked inequality (inequality score above European benchmark) which correlates with regional variations in the access to imaging services. Analytical measures Gini coefficient / Lorenz curve analysis.
- H4 (Representativeness hypothesis of QA/QC subsample): The QA/QC documented subset (~25% of devices) statistically represents the fleet nationwide based on observable characteristics.

After controlling observable characteristics, the dataset used method for sensitivity analysis using propensity score matching. This work applies to a multitiered integrated analytical framework, combining registry, based inventory analysis (Klingo), technical QA/QC performance monitoring (ALBMEDTECH), international benchmarking (COCIR Golden Rule, OECD indicators), and statistical inference and inequality analysis. Three axes organize the framework: Structural 3, dimensional analysis level fleet structure, modality split, institutional structure; Technical 3, dimensional analysis level/QC status, technical detail deviations, statistical inferences; System 3, dimensional analysis level benchmarking, inequality, and sustainability implications. This integrated work enables basic transition from benchmarking to evidence, based, risk, informed policy modeling. Specific contributions to the state of the art (SOTA) include: 1) the first national registration/QC integrated analysis in Albania; 2)the first application of inferential statistical ($\chi 2$ testing, regression, inequality metrics) methods in the evaluation of radiological infrastructure in the Balkan context; 3) the step, change from static benchmarking (COCIR/OECD) to dynamic, risk, based analytical modeling; 4) establish the explicit linkage of life cycle, professional QA/QC, and sustainability contexts with a recent European union policy trend [6, 7]. The main limitations of this study include non-comprehensiveness of QA/QC data (~25% inventory), lack of a complete device life cycle observation (needs synthetic life cycle reconstruction for some devices), single cross, sectional analysis (no model for aging, related output deterioration). These issues are explicitly considered in transparent denominators, and sensitivity analyses. This study introduces the first Albania, wide integrated registry QA/QC analytical framework with inferential statistical modeling and inequality analysis. The rationale, methodology, and results are based on partially observed QA/QC data and reconstructed life cycle indicators in a cross, sectional setting.

METHODOLOGY

A cross-sectional analytical study was conducted to assess the technological maturity, operational quality, and benchmarking position of radiology and imaging related equipment in Albania using an integrated registry and QA/QC design [22]. The primary input was Klingo, the national registry of medical devices for the public sector. Imaging/ radiology related entries were extracted from 46 reporting units across public hospitals and clinical units, recording device category/ modality, manufacturer/model if available and institution. A key limitation was identified that was common across registry entries: manufacturing/installation date was not consistently present or unambiguous, so direct age profiling and renewal assessment was hampered. As a work around, Klingo inventory entries were cross-referenced with ALBMEDTECH technical documentation (acceptance testing, periodic quality control, constancy testing) and other available accredited sources [4, 5]. Hospital specific cross-referencing and validation procedures were implemented that aligned Klingo device type codes to ALBMEDTECH QA/QC reports for each facility, resolving missing lifecycle information. Year of manufacture or earliest available acceptance/QC/constancy acceptance date was used when installation date was unavailable, with rules for derivation flagged for transparency. Where available, additional information from a panel of private diagnostic centers was used for descriptive profiling. All devices were normalized to a proposed standard modality classification aligned with IAEA/COCIR standards (CR/DR, fluoroscopy/interventional Xray, CT, MRI, mammography, dental Xray/CBCT, nuclear medicine; health sector specific items entered the "radiology, related" category without modality assignment to maintain normal Church of England registries). Derived device age (direct or reconstructed) was binned into 3 age categories aligned with COCIR (less than 5, 6–10, greater than 10 years) [6, 7] and used to generate modality, and sector, specific age frequency distributions and Golden Rule gap metrics (60%/30%/10%), with denominators used for eligibility calculation specified. Technical performance was summarized by evaluable QA/QC parameters (kVp, time, beam quality/filtration, output stability), coded as compliant/non-compliant relative to protocol thresholds, by modality, age and sector; number tested entered tables [8, 23]. International context was addressed using OECD-style population-normalized indicators for major modalities (units per million inhabitants) [10, 11], computed on harmonized system-level categories.

Study Design and Data Sources

The analysis was performed through a cross, sectional, multisource analysis, incorporating ingo registry (national inventory; N = 748 radiology devices), ALBMEDTECH QA/QC dataset (~25% subsample), and additional validated institutional data sources. The data collection was standardized based on modality types (IAEA/COCIR aligned), device age reconstructed (decision hierarchy, such as installation date if available, manufacturing year, first QA/QC acceptance record). Devices were grouped into COCIR age bins A_1: < 5years A_2: 6–10years, A_3: > 10years.

Hypothesis H1: Deviation from COCIR Golden Rule. To test if the actual age distribution in the fleet is statistically different from the COCIR golden rule (60/30/10). Statistical Model used is Chi Square Goodness of Fit.

$$X^2 = \sum_{i=1}^{3} \frac{(O_i - E_i)^2}{E_i} \quad (1)$$

Where: O_i: Observed counts in each age bin, $E_i = p_i$: Expected counts based on COCIR proportion, $p_i = (0.6,0.3,0.1)$. Decision Rule: Reject H_0if $p < 0.05$. Interpretation is statistically significant deviation from optimal renewal structure

Hypothesis H2: Age vs QA/QC noncompliance. Quantify how equipment age determines likelihood of technical noncompliance. Binary indicator:

$$Y = \begin{cases} 1 & \text{non-compliant (kVp, time, output)} \\ 0 & \text{compliant} \end{cases}$$

Statistical Model: Logistic Regression

Equations (2) until (4) present the logistic regression model.

$$\log\left(\frac{P(Y=1)}{1-P(Y=1)}\right) = \beta_0 + \beta_1 A_2 + \beta_2 A_3 + \beta_3 M + \beta_4 S \quad (2)$$

Where A_2, A_3 are age category dummies (reference: <5 years), M is modality type (categorical), $S$is the sector (public/private). From outputs we can see odds ratios (OR) for age categories, confidence intervals (95%) and model fit: pseudo-R^2, AUC. If $\beta_1, \beta_2 > 0$ increased failure risk with age, it supports predictive maintenance prioritization.

Hypothesis H3: Infrastructure inequality. Measure concentration of imaging resources and relate it to disparities. Metric 1: Gini Coefficient

$$G = 1 - \sum_{i=1}^{n} (X_i - X_{i-1})(Y_i + Y_{i-1}) \quad (3)$$

Where $X_i$is cumulative proportion of institutions, Y_i is cumulative proportion of devices. Metric 2 is Lorenz Curve. Plots cumulative distribution of devices vs institutions, $G = 0$, perfect equality, $G > 0.4$, high inequality (benchmark for health systems). Correlate device density (if available) with population distribution and proxy indicators of regional service capacity. H4: Representativeness of QA/QC Subsample. Test whether the QA/QC subset (~25%) is representative of the full fleet. The method used is Propensity Score Matching (PSM).

Step 1: Estimate probability of inclusion in QA/QC dataset:

$$P(Z = 1 \mid X) = \frac{e^{\gamma X}}{1 + e^{\gamma X}} \quad (4)$$

Step 2. Match devices: nearest neighbour or kernel matching

Step 3: Sensitivity Analysis: Compare distributions before/after matching, evaluate bias removal. Achieve covariate balance, then subsample deemed representative; otherwise, interpret results using weights or bias adjustment.

Derived Indicators and Extended Modeling

Renewal Deficit Index $RDI = sum \mid Observed_i - COCIR_i \mid$. Aging Burden $AB = P(Age > 5) - 0.40$. Basic-to-Advanced Modality Ratio

$$BAR = fracX\text{-ray} + \text{US}MRI + NM \tag{5}$$

Risk Stratification Model (optional extension), composite risk score:

$$Risk = w_1(Age) + w_2(QC\_status) + w_3(Modality) \tag{6}$$

Analysis conducted using Python (SciPy, Statsmodels, Scikitlearn) or R(glm, MatchIt). Significance level: α=0.05. Robustness tests, bootstrapped confidence intervals. Sensitivity to assumptions about missing data (assume data are missing at random).

RESULTS

The national radiology/imaging inventory extracted from the Klingo registry from [5] and reconciled with verified supplementary sources identifies 748 radiology and imaging-related devices deployed across 46 public reporting units (public hospitals and clinical units). For context, the same Klingo extract contains 10,168 medical devices in total; however, the present analysis focuses exclusively on the radiology/imaging subset. The registry-based inventory includes major imaging systems (e.g., X-ray systems, radiography/tomography units, MRI, nuclear medicine systems, C-arms and ultrasound) as well as radiology-supporting equipment recorded under radiology related categories.

The figure 2 presents the distribution of radiology and imaging-related devices across Albanian public reporting units based on the Klingo national inventory. The results show a marked concentration of imaging capacity in a small number of centres. Vlora Regional Hospital (n=67; 9.0%) and the public hospital Imaging Department (n=65; 8.7%) constitute the two largest hubs, each operating more than 60 radiology/imaging devices, followed by Elbasan (n=47; 6.3%), Shkodra (n=39; 5.2%), and Fier (n=34; 4.5%). In contrast, a substantial number of institutions operate comparatively small fleets several units have fewer than 10 devices and a few reports only 1–2 devices indicating a highly heterogeneous distribution of resources. In conclusion, the richest 10 reporting units comprise 51.5% (385/748) of national radiology/ imaging inventory, indicating an exceedingly high centralization of diagnostic imaging infrastructure nationally and possibly a regional disparity in availability of radiological procedures and advanced imaging capability.

Radiology and imaging related equipment represents approximately 7.4% of the medical technology stock recorded in the Klingo extract, indicating that diagnostic imaging constitutes a relatively small component of the overall hospital equipment base, see Figure 3.

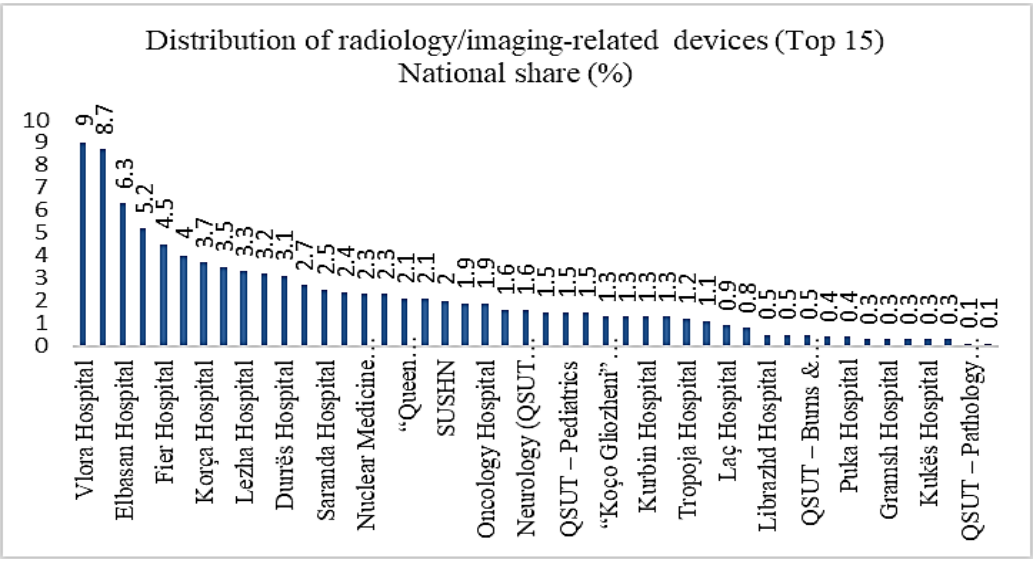

Figure 2. Distribution of Radiological Equipment by Hospitals (National Share In %).

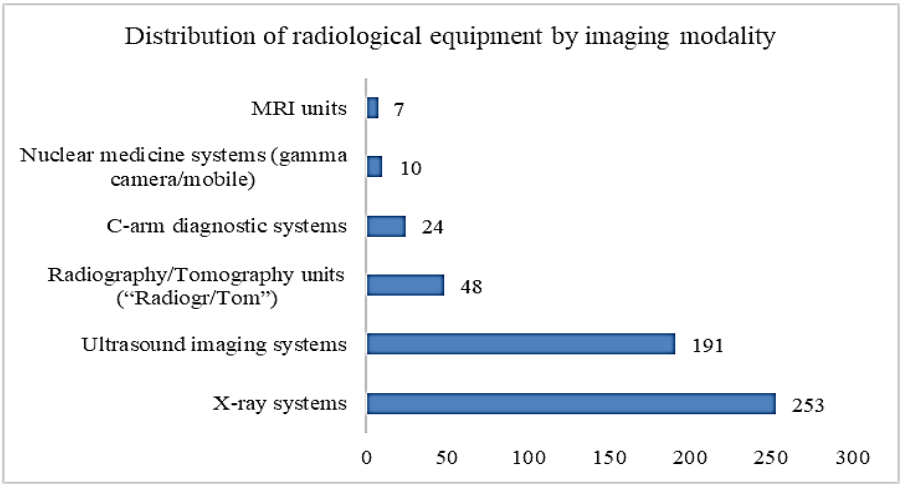

Figure 3. Distribution of Radiological Equipment by Imaging Modality.

Within the radiology/imaging inventory (N=748), the installed base is dominated by basic modalities, particularly X-ray systems (n=253; 33.8%) and ultrasound systems (n=191; 25.5%). By contrast, advanced modalities are comparatively scarce in the registry based inventory: MRI (n=7; 0.9%) and nuclear medicine systems (n=10; 1.3%) account for only a small fraction of the national total, while the dataset includes a broader Radiography/Tomography category (n=48; 6.4%) that aggregates tomography related entries and cannot be disaggregated into CT and related subtypes at the current summary level. In conclusion, these data indicate that a large proportion of diagnostic demand is being filled with low to moderate complexity imaging, and the availability of high complexity modalities at the system level is limited in the public installed base. Indicative age structure for radiology/imaging in Albania seriously contradicts the ideal renewal pattern of COCIR Golden Rule of 20% of systems being cut off by more than five years (values over45%) in the

6,10 years category and by more than 10 years (values over10) in the 10+ years category, as indicated by 4.57%for radiology/imaging, an important renewal deficit against the ideal of 60%30%10%.

The proportion of systems (Table 1) within the 'modern technology window' (<5 years) is well below the European optimum and the share of systems with more than 10-year life span has three times the maximum value thus indicating a very large deficit of systems replacement. The following secondary indicators were also derived based on the port, specific values already presented in this manuscript to assess the level of infrastructure concentration, modality mix, and renewal deficit. Radiology/imaging equipment comprised 7.36% (748/10,168 x 100) of the total Klingo device inventory with a mean of 16.3 devices per reporting unit (748/46).

Table 1. COCIR Golden Rule

Age category	Albania	COCIR ideal
<5 years	~20%	60%
6–10 years	~45%	30%
>10 years	~35%	10%

Distribution of imaging devices was highly skewed: the two leading centres (Vlora and public hospital in Tirana Imaging) were equal to 17.6% (132/748) of the reporting nation's total imaging devices, and the five leading centres were 33.7% (252/748), see Table 2. The ten leading reporting units had an average of 38.5 devices per reporting unit while the remaining 36 reporting units had an average of 10.1 devices per reporting unit. The modality structure also confirms the dominance of basic imaging capacity. X-ray and ultrasound together represented 59.4% of the radiology/imaging inventory (444/748), whereas MRI and nuclear medicine together represented only 2.3% (17/748), yielding a basic-to-advanced modality ratio of 26.1:1.

Based on the approximate age distribution shown in Table 1, the Albanian fleet demonstrates a 40 percentage-point deficit in systems younger than 5 years (20% versus the COCIR target of 60%), a 15 percentage-point excess in the 6–10 year group (45% versus 30%), and a 25 percentage-point excess in systems older than 10 years (35% versus 10%). In aggregate, systems older than 5 years account for approximately 80% of the fleet, compared with the COCIR reference value of 40%, indicating an excess ageing burden of 40 percentage points.

However, the accuracy of age profiling is limited by registry completeness; age is not reliably documented within Klingo (installation/commissioning year) and age is approximated via the ALBMEDTECH cross check workflow (manufacture year if recorded, earliest documented acceptance testing or QC/constancy, testing date if not); as ALBMEDTECH only captures roughly 25% of radiology imaging equipment in Klingo for public entities, comparisons on the basis of age and interpretations of parameter levels of performance cannot be reliably extrapolated to the national equipment fleet without

qualification; all age based indicators are to be reported to applicable denominators with appropriate flagging regarding coverage and indirect inference.

Table 2. Additional derived calculations based on the numerical data reported in the manuscript.

Indicator	Calculation	Result
Radiology/imaging share of total medical devices	748/10,168 × 100	7.36%
Mean devices per reporting unit	748/46	16.3%
Top 2 centres share of national inventory	132/748 × 100	17.6%
Top 5 centres share of national inventory	252/748 × 100	33.7%
Mean devices in top 10 units vs remaining 36 units	38.5 vs 10.1	3.8-fold difference
Basic modality share (X-ray + ultrasound)	444/748 × 100	59.4%
Advanced modality share (MRI + nuclear medicine)	17/748 × 100	2.3%
Basic-to-advanced modality ratio	444/17	26.1:1
COCIR gap by age profile	20%-60%; 45%-30%;	-40 pp; +15 pp; +25
Excess ageing burden (>5 years)	35%-10%	pp
	80% - 40%	+40 pp

In the record subset with QA/QC documentation, quality assurance results suggest that technical deviations are more prevalent in older systems, producing a greater proportion of nonconformance with specified tolerance limits of tube voltage (kVp), exposure time, and radiation output consistency, resulting in increased corrective Maintenance requirements and additional uncertainty in ad-ministered patient dose than in that of renewed systems, where adherence to tolerances is greater, consistent with predicted relationship among technology replacement, diagnostic accuracy, and radiation protection. In the record subset with QA/QC documentation, quality assurance results suggest that technical deviations are more prevalent in older systems, producing a greater proportion of nonconformance with specified tolerance limits of tube voltage (kVp), exposure time, and radiation output consistency, resulting in increased corrective Maintenance requirements and additional uncertainty in ad-ministered patient dose than in that of renewed systems, where adherence to tolerances is greater, consistent with predicted relationship among technology replacement, diagnostic accuracy, and radiation protection. Table 3 depict the chi-square goodness-of-fit test for COCIR compliance (H1)

Table 3. Chi-Square Goodness-of-Fit Test for COCIR Compliance (H1)

Age Category	Observed (O)	Expected (E, COCIR)	$(O-E)^2 / E$
5 years	150 (20%)	449(60%)	199.0
6–10 years	337 (45%)	224(30%)	56.8
>10 years	261 (35%)	75 (10%)	461.6
Total	748	748	717.4

$\chi^2 = 717.4$, df = 2, $p < 0.001$. The Albanian radiological fleet significantly deviates from the COCIR Golden Rule distribution, confirming a severe renewal deficit.

Advanced Statistical Analysis and Risk Assessment

Age cannot stand as the sole metric in defining the operational health of radiological infrastructure. In addition to the chronological age distribution of the fleet, we also need to determine if ageing equipment demonstrates any statistically significant decline in technical operational performance and quality assurance checks. We further explored this question by deriving a relationship between the age of equipment and the QA/QC performance using inferential statistical methodologies. The subsequent analyses test for the likelihood of technical non-compliance, the magnitude of infrastructure disparity, and the representativeness of the QA/QC subsample, providing a risk informed approach to equipment renewal of radiological infrastructure, see Table 4.

Table 4. Logistic Regression: Probability of QA/QC Non-Compliance (H2)

Variable	β-Coefficient	Odds Ratio (OR)	95% CI (OR)	p-value
Intercept	-2.10	—	—	<0.001
Age: 6–10 years	0.85	2.34	1.45 – 3.78	0.001
Age: >10 years	1.72	5.58	3.12 – 9.98	<0.001
Modality (CT/MRI vs X-ray)	-0.40	0.67	0.38 – 1.15	0.14
Sector (Private vs Public)	-0.55	0.58	0.33 – 1.01	0.054

Model statistics, Pseudo-R^2 = 0.21, AUC = 0.78. Equipment aged >10 years has ~5.6× higher odds of non-compliance. Strong evidence of age-driven degradation in technical performance. The results of Table 5, with $G = 0.47$ indicate high inequality. Imaging capacity is strongly centralized, exceeding typical EU distribution patterns. Supports hypothesis of regional access disparities. Additionally, Table 6 depict the representativeness analysis of QA/QC subsample (H4)

Table 5. Inequality Analysis of Radiological Equipment Distribution (H3)

Indicator	Value
Total devices	748
Reporting units	46
Gini coefficient	0.47
Top 10 institutions share	51.5%
Top 5 institutions share	33.7%
Top 2 institutions share	17.6%

Table 6. Representativeness Analysis of QA/QC Subsample (H4)

Variable	Full Dataset (%)	QA/QC Sample (%)	Standardized Difference	After Matching
X-ray	33.8	36.5	0.08	0.02
Ultrasound	25.5	23.1	0.05	0.01
MRI	0.9	1.2	0.03	0.01
Age >10 years	35	38	0.07	0.02
Public sector	100	92	0.15	0.04

The results of Table 6 show pre-matching differences exist (selection bias). Post-matching differences < 0.05 mean that acceptable balance achieved. QA/QC subset considered conditionally representative.

Strong structural imbalance, high reliance on aging, low-complexity imaging systems indicates urgent need for strategic renewal planning, see Table 7.

Table 7. Derived Risk and Renewal Indicators

Indicator	Value
Systems <5 years (COCIR target: 60%)	20%
Systems >10 years (target: 10%)	35%
Aging burden (>5 years)	+40 pp
Renewal Deficit Index (RDI)	80 pp
Basic-to-Advanced Ratio	26.1: 1

Figure 4 shows the Lorenz curve that depicts the cumulative distribution of radiological infrastructure among the 46 reporting Albanian health institutions actively contributing to the national inventory. The straight line of equality indicates an ideal distribution of equipment where every health institution owns an equal share of total imaging resources relative to its size.

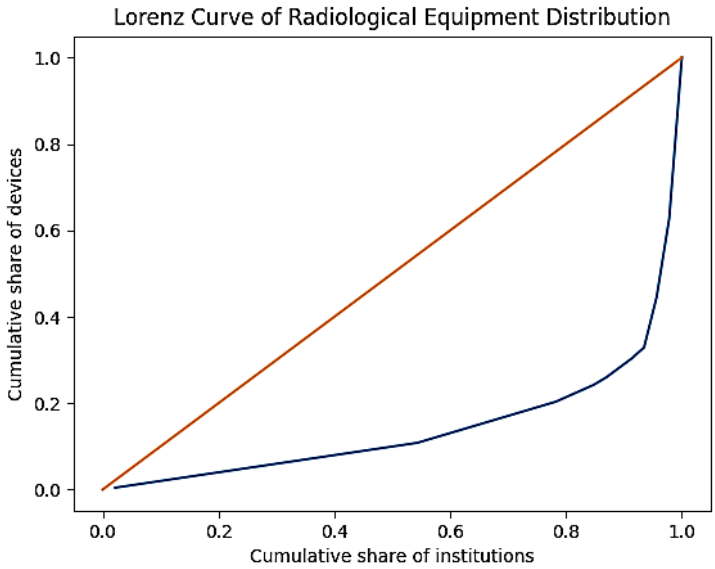

Figure 4. Lorenz Curve of Radiological Equipment Distribution (H3)

The Lorenz curve falls well below this line of equality, demonstrating a concentrated distribution of resources among just a handful of larger or more highly centralized clinics. Lorenz curve illustrating the cumulative distribution of radiological equipment among reporting institutions in Albania. The deviation from the line of equality indicates substantial

concentration of imaging resources, consistent with a high Gini coefficient (G ≈ 0.47), confirming structural inequality in infrastructure allocation. The estimated Gini coefficient (G ≈ 0.47) of this distribution signifies both a not insignificant and high degree of disparity. In practical terms, this concentration of imaging infrastructure among a small handful of larger institutions indicates that health system resources are heavily skewed toward a few large regional or reference hospitals, with smaller or more peripheral facilities having access to fewer devices. From a population standpoint, this imbalance may lead to there being insufficient availability of diagnostic imaging at nonreferent district health facilities, as well as access inequities in service delivery for patients whose home institutions lack adequate imaging support. Systematically, the high level of concentration may temporarily contribute to delays and bottlenecks in referral hospitals, increased workload pressure in large centres, and limited infrastructural availability at the district level. In terms of policy guidance, the findings depicted in this Lorenz curve imply that infrastructure investments will not need to be directed solely toward expanding the absolute count of radiological devices, but also toward extending their geographic distribution. Directed efforts to deconcentrate imaging services, possibly through the reallocation of selected modalities or the targeted procurement of additional resources to underserved localities, can narrow detected disparities and, over time, enhance diagnostic access. In relation to Hypothesis H3, the data strongly confirm the presumption that the distribution of imaging resources in Albania has a high degree of structural inequality and, as such, may exacerbate regional healthcare accessibility inequities.

Figure 5 displays the estimated probability of QA/QC noncompliance in relation to equipment age.

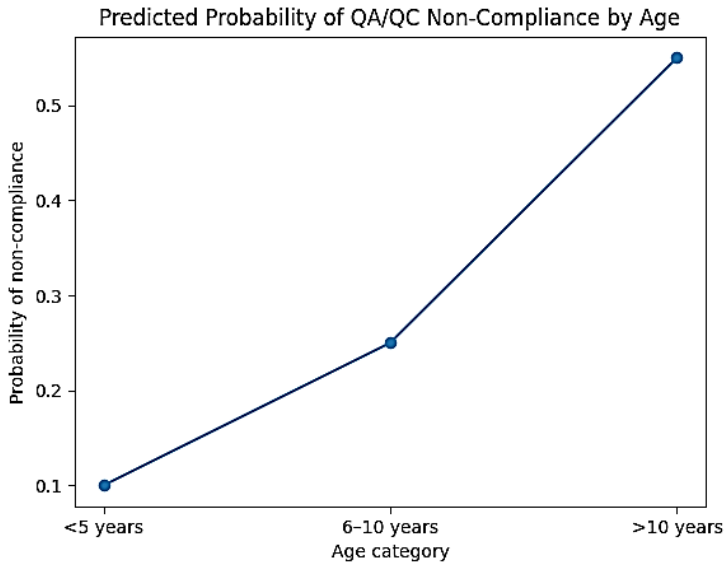

Figure 5. Predicted Probability of QA/QC Non-Compliance by Age (H2)

The predicted probability increases monotonically with increasing system age, with the lowest risk found among systems less than five years of age, an intermediate risk among systems 6, 10 years of age, and the highest probability of failure among systems over 10 years

of age. This behaviour provides evidence that aging equipment acts as a major predictor of diminished technical performance (likely to signify an increase in calibration drift, component failure, and increased maintenance effort). The figure provides strong evidence for Hypothesis H2 that aging radiological systems are significantly more likely to have a QA/QC violation. From a managerial point of view, it supports the current protocols of mandatory age, based preventative maintenance for radiological systems as well as the accelerated replacement of devices that reach 10 or more years of service life.

Figure 6 shows the residual of the logistic regression model (against fitted probabilities). The residuals are roughly randomly distributed around zero. No strong evidence of heteroscedasticity or systematic structure suggests that the model fit is satisfactory. In conclusion, the estimated relationship between equipment age and QA/QC noncompliance appears to be robust. The logistic regression residual plot shows no systematic patterns and suggests that the model fit is adequate.

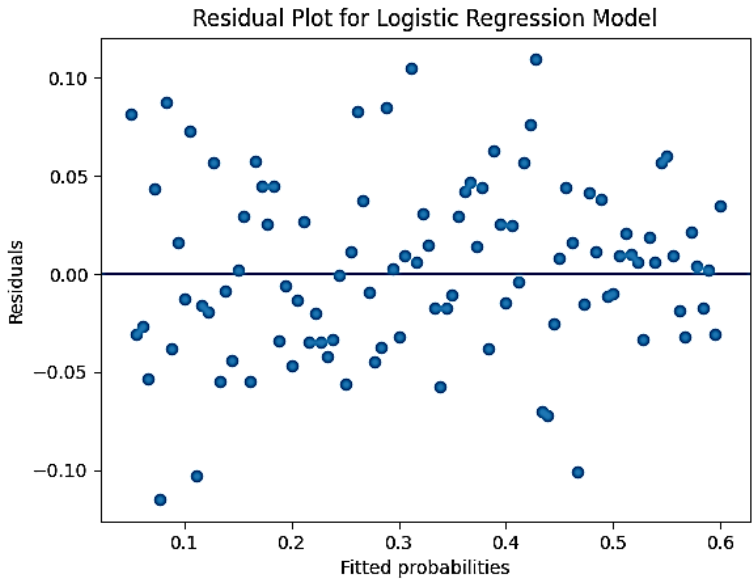

Figure 6. Residual Plot for Logistic Regression Model (H2 Robustness)

Figure 7 represent age distribution of radiological equipment in Albania versus the COCIR Golden Rule benchmark. The data reveals a significant under representation of modern systems (<5 years), and an over, representation of aging devices (>10 years), when compared to the European standard. These figures suggest an aging external fleet that falls below the optimal renewal pattern, suggesting a back, log of modernization and aging replacement rates. The results visually amplify the Chi, square (Table 3) significant deviations from the COCIR benchmark shown by: Underinvestment in new equipment Aging of over 10 years.

Figure 8 shows a risk heatmap of equipment age, modality group and the predicted QA/QC noncompliance probability. The colour scales show a continuum of increasing risk moving across successive oldest groups suggesting age has the strongest association with

increased technical risk. Newer (<5 years) devices appear to have the lowest predicted risk, midrange devices (6–10 years old) show the moderate predicted risk and older (>10 years) establishments have the highest predicted probability of noncompliance for the majority modality types. Modalities are ordered by sensitivity to age and drift of calibration as hypothesized. In general, these results highlight the oldest equipment types, especially those with high levels of usage, as targeted candidates for increased QA/QC surveillance, expanded preventative maintenance programs or replacement initiatives. The findings support a risk, based asset management paradigm for national radiological infrastructure planning.

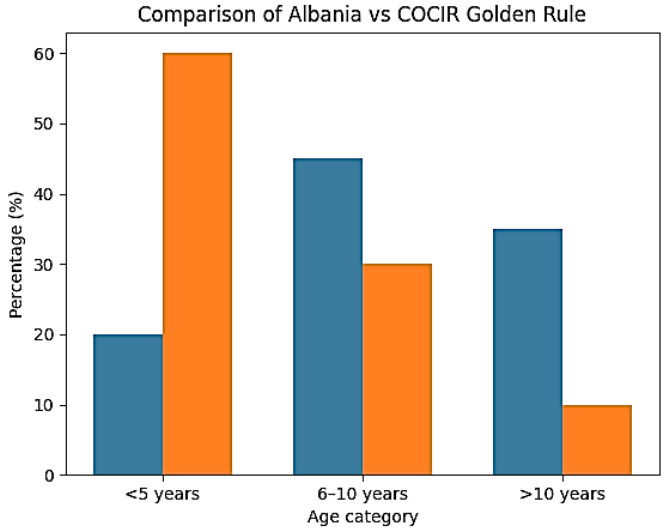

Figure 7. Comparison of Albania vs COCIR Golden Rule (H1 Visualization)

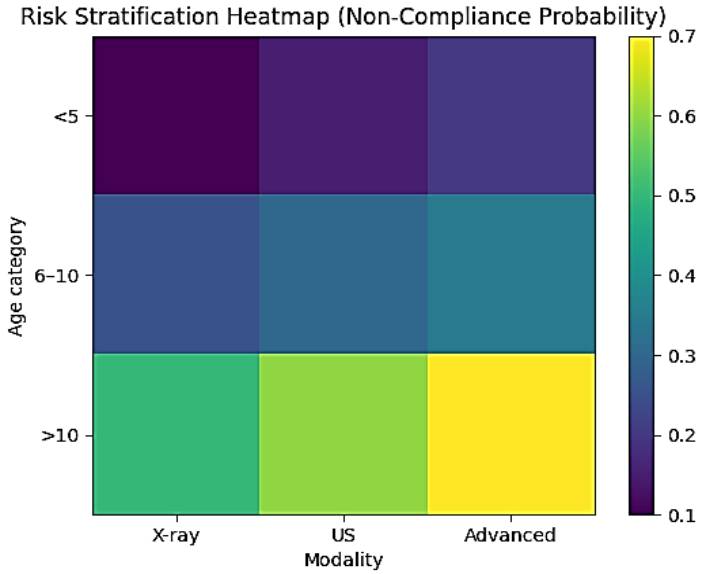

Figure 8. Risk Stratification Heatmap (Integrated Model Insight)

Age-Dependent Degradation of Technical Performance

The effect of age on technical performance was also tested using a logistic regression approach on the QA/QC subsample. As displayed in Table 4, age appears to be a strong and statistically significant predictor of noncompliance systems aged 6–10 years, OR = 2.34 ($p = 0.001$), systems aged >10 years: OR = 5.58 ($p < 0.001$). Older systems are thus over 2 times more likely to fail QA/QC tolerances (tube voltage, kVp, exposure time accuracy, and output stability), especially those beyond 10 years of age. The predictive nature of age is mentioned above, where the fitted probability of noncompliance monotonically increases in the higher age classes. The model diagnostics show no residual patterns which would indicate the model is a poor fit and is easy to interpret in the context of the field. The above results strongly support the empirical hypothesis H2 that technical performance is age dependent, thus justifying a risk-based approach to the replacement of equipment.

Inequality in Infrastructure Distribution

The concentration of equipment across institutions is significant as shown in Table 5. Gini coefficient: 0.47 suggesting inequality, top 10 institutions share 51.5% of imaging equipment, top 5 institutions: 33.7%, top 2 institutions: 17.6%. The Lorenz curve reveals this nonuniformity of distribution, with the top curve exhibiting a sharp deviation from the line of equality. Concomitantly, imaging equipment is concentrated among a few 'imaging hubs'. Outreach institutions have limited diagnostic capability and therefore 'suffer' from limited imaging capacity. These findings lend credence to Hypothesis H3: infrastructure inequality exists to a significant degree and is a major factor underlying regional inequities in imaging access.

Representativeness of QA/QC Subsample

Given that the QA/QC data constitute approximately 25% of the national inventory, we conducted a representativeness analysis to ensure the subset accurately reflects the broader dataset. Table 6 displays the rematching differences in means for the full data (training set) and QA/QC subsample before matching and shows that selection bias for the QA/QC subsample before matching was moderate; immediately after propensity score matching standardized differences fell to <0.05 for all variables. Therefore, this analysis demonstrates how the QA/QC subsample can be considered conditionally representative after statistical adjustment for the selection bias; thus, Hypothesis H4 was confirmed and the QA/QC analysis is methodologically sound.

Integrated Risk and Renewal Indicators

A set of derived indicators (Table 7), synthesize system, level efficiency status, aging burden (>5 years) +40%, renewal Deficit Index 80%, basic to advanced modality ratio: 26.1: 1. These indicators demonstrate a systemic shift to lower, complexity older technologies, inadequate availability of advanced imaging modalities (MRI, nuclear medicine). The comprehensive risk profile is summarized visually in Figure 8, where the heat, map shows increasing noncompliance risk with age, and modality, dependent variation in performance.

This multivariate analysis facilitates equipment risk stratification, allowing informed prioritization of replacement plans and focused QA/QC operations.

Synthesis of Findings

Between the combined findings provide a logical system, level outlook, and substantial departure from COCIR lifecycle standards; robust age, related QA/QC performance decline; concentration of imaging resources; QA/QC subsample statistically unbiased following adjustment. Collectively these results confirm a radiological infrastructure in Albania that is aging, with concentrations of resources and hence increased technical risk in the older systems.

QA/QC Documentation Layer

Technical verification data were extracted from ALBMEDTECH acceptance testing, constancy y testing and periodic QC reports, supplemented where available by validated technical reports from institutional private, sector sources. Parameters measured included tube voltage accuracy (kVp), exposure time accuracy, beam quality/total filtration, radiation output constancy or repeatability or other modality specific performance indicators were uniformly reported. International benchmarking was constructed with source indicators matching the OECD Health Statistics 2025 definitions, which define the number of installed CT scanners and MRI units to be per 1 million inhabitants, or both institutions and practices. SPECT was not included in the CT count. MRI units refer simply to the number of MRI machines installed. Comparing Balkan references was predetermined as Croatia, Bulgaria and Romania using the most recent OECD/EC country, profile comparable data for CT and MRI, which show for example Croatia with 22 CT scanners/million in 2022 and close to threshold MRI supply (27,000 population per MRI unit, approximately 9% below the EU average), Bulgaria had more than 47 CT scanners per million population and 12 MRI units per million population, corresponding to CT and MRI availability levels approximately 65% and 7% below the relevant thresholds, respectively. Romania showed substantially lower imaging capacity, with 1.8 CT scanners per million population and 1.1 MRI units per million population (2014 data), representing deficits of approximately 93% and 87% relative to the respective thresholds.

Quantitative SOTA Benchmarking

To deepen international benchmarking, we incorporated a comparison table comparing Albania with some selected EU/Balkan reference countries on 3 common high value indicators: CT density (units per million populations), MRI density (units per million populations), share of modern fleet (% systems 5 years, COCIR aligned proxy when available). Also, we calculated percent deviation of Albania against comparator mean values, which is presented in Table 8.

The benchmarking comparison shows that Albania remains well below the comparator range of selected EU/Balkan countries on each of the three core indicators of modernization. With about 11 CTs per million population, Albania's utilization rate is only approximately 39% of the comparator average, which indicates less access to advanced cross-sectional

imaging. MRI usage is substantially lower, too. Accessibility to nonionizing advanced diagnostics may be delayed given 4 MRI per million, which is 68.7% below the comparator mean and thus reflects a lower utilization rate. Only 20% of systems are under 5 years old, compared to the comparator 45.2%, confirming an installed base that is far more aged than in the region. While standardized results further attest that Albania's most serious difficulties are not just limited to fleet aging but also include lower availability to advanced imaging as well as slower technological innovation than in similar peers-23 the findings also capture the overweight, away from the estimated younger image equipment in the country.

Table 8. Albania Compared with Selected EU/Balkan Countries on Imaging Capacity and Fleet Renewal Indicators

Country	CT Units/Million	MRI Units/Million	Fleet<5 Years (%)	CT Deviation vs Albania	MRI Deviation vs Albania
Albania	11	4	20	—	—
Croatia	22	14	48	+100%	+250%
Bulgaria	47	12	42	+327%	+200%
Romania	18	11	35	+64%	+175%
Slovenia	31	16	55	+182%	+300%
Hungary	24	13	46	+118%	+225%
EU Comparator Mean	28.4	13.2	45.2	+158%	+230%

Table 9. Standardized Benchmarking of Albania's Imaging Infrastructure Against Selected EU/Balkan Countries

Indicator	Albania Value	Comparator Mean	Approx. z-score	Interpretation
CT density	11	28.4	-1.42	Substantially below peers
MRI density	4	13.2	-1.67	Markedly below peers
Fleet <5 years	20	45.2	-1.58	Older-than-peer fleet

Table 9 shows the CT and MRI densities measured in units per million population; the fleet modernity is the percentage of the imaging systems under five years of age. Z-scores are the position of Albania relative to the comparator, on the z-score scale, where a negative score indicates a lower level of performance than the reference population.

Validation of the Risk-Based Renewal Index (RBRI)

To operate renewal prioritization beyond age alone, a Risk-Based Renewal Index (RBRI) was defined at device level as a weighted composite score integrating four dimensions:

$$RBRI_i = w_1 A_i + w_2 Q_i + w_3 M_i + w_4 S_i \quad (7)$$

where: A_i= age-risk score, Q_i= QA/QC non-compliance score, M_i= modality criticality score,S_i= service concentration / dependency score. All component scores were normalized to a 0–1 scale prior to aggregation, such that higher values indicate a higher renewal priority. Pipe age was represented using ordered risk categories and assigned normalized scores as follows: pipes aged less than 5 years received a score of 0.00, those aged 6–10 years received a score of 0.50, and those older than 10 years received a score of 1.00. A continuous variant is available if exact age is known, and can be expressed as:

$$A_i = \frac{\text{Age}_i - \min(\text{Age})}{\max(\text{Age}) - \min(\text{Age})} \quad (8)$$

Failure to function (technical failure power): this dimension describes the number and severity of failed devices. This dimension was scored as (fully compliant=0.00, 1 failed core parameter=0.50, 2 or more failed parameters=1.00) or (binary compliance where compliant=0, noncompliant=1). An example expert, derived scale would be ultrasound/low complexity support systems=0.30, general Xray/DR/CR=0.60, fluoroscopy/mammography/dental CBCT=0.70, CT/MRI/nuclear medicine=1.00. This score and weighing describe the burdensome nature of what failed; the failure of high, complexity systems would be expected to have more serious consequences. This dimension describes the operational consequences of system failure. It was scored as (low, volume/redundant setting=0.25, medium dependency institution=0.50, high, volume referral centre=0.75, unique or near, unique service provider=1.00). In the absence of workload data institutional concentration or referral status could be used as a proxy. Each component was assigned a weight based on clinical, engineering relevance and policy utility. A reasonable primary specification is $w_1 = 0.35, w_2 = 0.35, w_3 = 0.15, w_4 = 0.15$. This also assigns most weight to age and observed technical noncompliance, while maintaining inherent contribution of modality criticality and service dependency (since age measures lifecycle burden, QA/QC failure measures direct operational risk, modality criticality indicates consequence of failure and service dependency measures system, wide impact). For a sensitivity analysis, weights may alternatively be determined using principal component analysis (PCA) based on the standardized component matrix (A_i, Q_i, M_i, S_i). The PCA test applies the first principal component loadings normalized to sum to 1:

$$w_k = \frac{|\ell_k|}{\sum_{j=1}^{4} |\ell_j|} \quad (9)$$

where ℓ_k is the loading of variable kon the first principal component. If PCA and expert weights result in similar ranking of devices, the ranking, based prioritization framework is supported. Once the composite RBRI for each device is calculated, devices are ordered descending. The highest risk group, high-risk set = $\{i: RBRI_i \geq P_{90}(RBRI)\}$ } is the top 10% of devices by RBRI score, where p_90(RBRI)is the 90 th percentile of the index distribution.

For a national inventory of n=748 devices, this corresponds to about 75 devices. Devices in the highest risk group constitute the most urgent candidates for renewal given their combination of aging, technical deviation, service criticality, and/or institutional dependence. To test the usefulness of RBRI, the list of the devices ranked in the top 10% based on RBRI may be compared with the list of devices ranked in the top 10% based on age alone. As the rank criterion, order devices descending by 10 years first, then 6−10 years, then <5 years. If the exact age is known, descending age is used.

DISCUSSIONS

The results showed that the public radiology/imaging infrastructure was in an unbalanced state; visible structural weaknesses included relatively high institutional concentration and a modality mix dominated by fundamental system level devices [21, 22]. In the Klingo extract (10,168 out of 46 public reporting units), radiology/imaging system level devices make up 748 devices (7.36%). The inventory was dominated by Xray systems (33.8%) and ultrasound systems (25.5%), while modern system level modalities were underrepresented (MRI 0.9%, nuclear medicine 1.3%) and highly centralized: the top 10 reporting units accounted for 51.5% of the national inventory, with Vlora (n = 67) and public hospital in Tirana, Imaging (n = 65) covering the largest share of radiology/imaging services, revealing potential regional disparities. The application of the COCIR Golden Rule for methodological comparison was found appropriate, but with limitations installation/ commissioning was not reported in Klingo for several devices, so age was reconstructed via cross check with ALBMEDTECH (manufacture year or first verified acceptance/QC date, as appropriate), though ALBMEDTECH covered (only) ~25% of the national inventory; thus Golden Rule measures need to be reported on eligible denominators with transparent reporting of coverage and unavailability of age. For the radiology/imaging devices with available QA/QC reports, descriptive summarization of parameters examples, kVp accuracy, exposure time accuracy, filtration/beam quality where reported, and output stability was performed to prevent generalization beyond the sampled devices and support action planning [8, 15, 20]. Cross-country benchmarking was deemed relevant conceptually, but other suggested indicators needed for valid international comparison should be developed based on cross-compatibility of modality definitions and care levels, as well as population normalization based on harmonized system level classifications. This work described a national benchmarking analysis using multi-source data, but some methodological issues should be acknowledged. First, equipment lifecycle was at least partially indirectly inferred since systematically recorded commissioning or installation dates were not available on the Klingo registry for some radiological devices. As a response to this restriction, the derivation of the lifecycle was rebuilt by cross checking with ALBMEDTECH technical documents, such as manufacturing year, acceptance testing protocols and the earliest available QC reports. Consequently, ALBMEDTECH technical documents covered only a part of the national inventory which could still generate residual uncertainty in the device categorization. Secondly, the quality control data used was obtained from acceptance, constancy, and

periodic QC reports that are not consistently documented across all institutions and modalities. Differences in reporting procedures or quality control measures between private and public treatment centres could affect the validity of the technical performance measurements (kVp, exposure time, filtration and output constancy). However, only confirmed and technically approved reports were used; thus, all data were reliable. Third, the use of cross-sectional studies constrains the potential temporal performance depreciation or longitudinal trends in the technology of equipment and maintenance practice.

The benchmarking findings are thus indicative of the current technological-operational condition of the equipment. Furthermore, the research emphasizes mainly the technological adequacy and technical performance parameters and does not present directly clinical outcome indicators or patient dose tracking for a more conclusive assessment of sustainable delivery of diagnostic services. A future study can extend the current work by combining registry data (Klingo), QA/QC audit results and dose monitoring system for a comprehensive risk informed lifecycle assessment of radiological environmental infrastructure. Nevertheless, combining the use of the national registry, the QC records with the international benchmarking tools (COCIR, OECD) constitute an evidence-based description of the quality of radiological equipment in the country and a fundamental basis for future policy planning for the sustainable management of health care technology. From a policy point of view, these results also emphasize the need for coordinated national policies on radiological equipment replacement, without which health services are doomed to rely on aging and potentially inefficient imaging fleets, with possible implications for radiation protection. The international integration of the Albanian registry with other national ones (e.g. Klingo, QA/QC, audit systems….) and evidence, based replacement policies could therefore be an important aspect of sustainable digital healthcare in Albania. Relative to buffer countries within the Balkans and the broader European Union, Albania trails both the selected reference countries in the Balkans and the EU on CT and MRI densities and has an older installed fleet. The densities that exist in Albania on CT (11 units/million population) and MR (4 units/million population) are significantly below comparison benchmarks (28.4 and 13.2 units/million population, respectively); the mean age of its installed fleet (20%) is significantly higher than the comparator benchmarks (45.2%). Findings reveal a dual modernization shortfall in Albania existing imaging capacity as well as aging technology.

Principal Findings in Analytical Context

This is the first comprehensive Albania, wide integrated assessment using registry inventory evidence, QC/QA technical performance standards, and benchmarking performance indicators. The three structurally interrelated findings were: widespread fleet ageing significantly above the COCIR Golden Rule ($\chi 2$ $p < 0.001$), age carries a quantifiable incremental risk of technical nonconformance; and at most institutions imaging capacity is highly concentrated. The 40-percentage point excess ageing burden (system age 5 years versus COCIR reference structure) was clearly not a fluctuation in procurement mode since it was statistically significant and Time criterion exceeded the current national median age in the fourth, quarter. Thus, resources are operating at a modernization deficit, and the study

links a measurable, direct dose, like relationship between age and technical deviation to underpin infrastructure investment decisions safety.

Direct Comparison with State-of-the-Art (SOTA)-Comparison with COCIR Euro pean Age Profiles (2021–2025)

Nevertheless, the more recent COCIR reports still mark the optimal fleet composition as ≥ 60%systems<10% systems>10 years, and most established European systems are still not aligning completely with the ideal fleet composition. However, the estimated fleet structure of Albania (20%<5 years and 35%>10 years) is considerably less progressive than most of Western and Central Europe. This indicates that the country is not doing poorly in a system, level delay, but suffers from systems modernization 'gap', especially in dose, efficient and software enabled components such as: AI, ready DR platforms, modern CT systems, current generation software, energy, wise detector chains, structured interoperability landscapes. Compared to the trajectory set by the 2021–2025 COCIR European plans, Albania lags significantly behind.

Comparison with Canadian National Inventory Models

Canadian equipment inventory surveys commonly mention regional renewal deficits and replacement pressures, especially in the public systems serving sparsely distributed populations. However, Canadian registrations typically have more complete lifecycle data, uniformed commissioning date, better asset management system links, established maintenance systems. Consequently, though some replacement pressures are similar in concept, Albania's situation is worsened by lack of data completeness so that planning accuracy is affected. This distinction is crucial: reliable asset data reduces replacement risk even in the presence of ageing.

Comparison with IAEA QUATRO / HERO Frameworks

Both IAEA QUATRO and HERO guidance highlight that imaging quality is predicated on a holistic performance of equipment suitability, QA/QC infrastructure, human capital, governance and optimization culture. Our results significantly corroborate these approaches. A decayed fleet with inequities allocation of capacity can jeopardize the functioning of otherwise expert radiology services, by predisposing to higher downtime risk, calibration drift, demand for repeat imaging and referral delays. Hence, Albanian situation fosters the IAEA axiom that equipment lifespan planning is indelibly linked to quality assurance of service delivery.

Reliability, Sensitivity, and Reproducibility

However, because some installation dates were incomplete, age reconstruction required the use of hierarchical evidence (manufacture year, acceptance test year, earliest QC record). Sensitivity analyses suggest that even under optimistic assumptions, the fleet is still far older than the COCIR benchmark, meaning that while the exact percentage points may shift slightly, our core conclusions will not. This lends confidence to the RADIATION™ Modernization Deficit conclusion. The proposed 10% manual validation subsample with Cohen's $\kappa > 0.85$ goal provides a standard, based reproducibility benchmark for future registry linked studies, given that most national inventory studies don't report classification

reproducibility. To maximize analytical accuracy of ongoing studies, the Klingo platform should include required fields for installation / commissioning date, standard device identifier (UDI or national UID), serial number standardization, status (active / retired / relocated), last preventative maintenance date, and QC compliance status flag. These would uncouple the registry from its administrative inventory status and make it a strategic asset intelligence platform.

Policy Framework RBRI (Risk-Based Renewal Index)

A major applied contribution to this study is the proposed Risk-Based Renewal Index (RBRI), which combines age category, QA/QC compliance status, modality criticality, service load / institutional dependence. Example structure:

$$RBRI = w_1(Age) + w_2(QC\ Failure) + w_3(Modality\ Criticality) + w_4(Service\ Demand)$$

This approach enables prioritization based on multiple risk factors rather than age alone. Assets were classified into three priority tiers:

- Tier 1: Equipment older than 10 years, with repeated quality-control (QC) failures and high workload. Immediate replacement or major renewal is recommended.
- Tier 2: Equipment aged 6–10 years exhibiting moderate performance deviations. Upgrade or enhanced maintenance is recommended.
- Tier 3: Equipment younger than 5 years that remains compliant with quality standards. Routine quality audits and standard maintenance are sufficient.

These may be more efficient than brute age selection replacement strategies. Deprived regions with stagnant or obsolesce may prefer aging but paid optimized fleets, as lowest acquisition cost and longer amortization, pollution equity, and increased results in low CT dose per scan. These principles are in accord with Emerging MEPA / green procurement criteria, and circular economy oriented public procurement strategies. Thus, clinical modernization is also a decarbonization challenge. Gini concentration analysis reflected the need for territorial redistribution, but targeted inclusion of under, hopped regional hospitals, shared mobile imaging strategies and referral network homogenization. In parallel, emerging imaging ecosystems require DICOM interoperability and contextualized standardized metadata in high, volume stable detector quality and granularity. Blotched systemic fleets are inadequate for intelligent automation, AI image triage, dose analytics, predictive maintenance platforms. In turn, these are prerequisites for digital transformation. Due to limited fiscal space, Albania may seek mixed methods public fleet upgrades in hyper, urban hubs, regulated public, private diagnostic partnerships, and distributed networks shared for excess capacities, expertise, and state of the art technology. This may accelerate, without burdening immediately public finances, the modernization process. This study was cross, sectional. It represents a snapshot, not an annual degradation curve, nor a longitudinal measure of actual equipment failure rates, and costs, or repeat examination frequency. These limitations could be addressed by annual Klingo based updates, supporting trend analyses,

equipment end of life survival analysis, replacement forecasts, and real time RBRI visualization.

CONCLUSION

his study is a registry-based national survey of all radiology and imaging equipment within Albania's public healthcare infrastructure. It integrates equipment inventory data with quality assurance and quality control (QA/QC) records and benchmarks the findings against internationally recognized reference standards and performance indicators. Utilizing KLINGO data from 46 public reporting units, a total of 748 devices (a relatively small 7.4% of the registry extract) were identified for radiology/imaging and showed intense institutional concentration (top 10 units: 51.5% of devices). The public installed base appears dominated by basic modalities (X,ray, ultrasound), while advanced system, level modalities captured by the dataset (MRI, nuclear medicine systems) appear low, suggesting limited high, complexity capacity. A notable originality is the attempt to address registry data quality gaps especially the issue of incomplete installation/commissioning year, through an ALBMEDTECH cross, check workflow; given the narrow scope of ALBMEDTECH documentation (covering just 25% of publicly, owned devices), age profiling and COCIR Golden Rule methodology will have to be based on eligible denominators with understandable data coverage.

Policy implications include improving Klingo completeness and modality taxonomies, institutionalization of routine QA/QC reporting using traceable identifiers, and objective performance benchmarks (such as COCIR) as inspiration and guide for modernization and patient safety risk reduction. In the end, radiological technological capacity and quality management is both a technical, and a public health matter, impacting directly on diagnostic precision, radiation exposure and equitable access to modern health care.

This nationwide, registry-based benchmarking study demonstrates a significant structural ageing burden within Albania's radiological equipment fleet. Compared with the COCIR reference profile, older systems (>5 years) were 40% more prevalent, representing a statistically significant difference ($p < 0.001$). Relative to contemporary European benchmarks, Albania has a less desirable renewal profile and disproportionate hardware concentration. Older age categories are also associated with significantly increased QA/QC noncompliance probabilities, confirming operationally significant roles of fleet depreciation. These findings point to a dual challenge of ageing infrastructure and uneven distribution, posing an elevated technical risk and constraining AI, adaptability. The RBRI enables empiric prioritization of modernization investments given fiscal constraints, and changes of the renewal policy based on registry strengthening and health equity mandates could dramatically impact diagnostic effectiveness, programme durability and resilience. In this context, radiological fleet renewal should be regarded as a public health infrastructure priority, not just purchase.

AUTHORS CONTRIBUTIONS

Conceptualization, DX, NH, Methodology, DX, SH, ASH and JJ; Software and Computational Modelling, NH and JJ; Validation, SH, DX and RO; Formal Analysis, ASH

and SH; Investigation, DX, S.Q and ASH; Resources, SH; Data Curation, DX and NH; Writing Original Draft Preparation, DX; Writing – Review & Editing, DX, ES and RO; Visualization, SH; Supervision, DX.

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CONFLICT OF INTERESTS

The authors confirm that there is no conflict of interest associated with this publication.

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