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# "*Healthcare Transformation in Europe: Cluster Analysis & PPP Solution*"

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# *1. Introduction*

The healthcare systems in Europe are currently navigating a period of unprecedented complexity, driven by demographic shifts, technological advancements, environmental challenges, and economic constraints. Healthcare systems are increasingly burdened with managing chronic diseases and age-related conditions. More than 20% of Europe's population is over 65 years old, a figure that is expected to rise substantially in the coming decades [1]. This demographic transition has intensified the prevalence of chronic conditions such as diabetes, cardiovascular diseases, and osteoporosis, placing additional strain on healthcare services [2]. The fragmented development and accessibility of treatments for these conditions further underscore the disparities that persist across European regions, posing challenges to the equitable delivery of care.

Climate change compounds these pressures, creating new health risks while exacerbating existing ones. Rising temperatures and the increasing frequency of extreme weather events have been linked to higher rates of respiratory and cardiovascular conditions, particularly in vulnerable populations. Furthermore, these environmental challenges disproportionately affect low-income and rural communities, magnifying healthcare inequalities across Europe. Despite these challenges, there is a growing recognition of the need for integrated policies that address both health and environmental resilience. Policy frameworks are critical in this context, yet translating scientific insights into actionable policies remains a significant hurdle [3].

Technological innovation offers a beacon of hope but also introduces new complexities. Artificial intelligence (AI) is at the forefront of this transformation, with the potential to revolutionize diagnostics, optimize treatment pathways, and reduce systemic inefficiencies [1]. However, the integration of AI in healthcare raises profound ethical and regulatory questions, particularly regarding data privacy, algorithmic bias, and equitable access [4]. The deployment of AI-powered tools, such as those used in endocrinology and pain medicine, demonstrates both the promise and the challenges of this technology [1]. Successful implementation requires not only technical innovation but also workforce training and regulatory adaptations to ensure these tools are used effectively and equitably.

Economic sustainability is another pressing concern for healthcare systems across Europe. Public spending on pharmaceuticals and other healthcare services constitutes a significant portion of national budgets, necessitating robust strategies to manage these costs. The increasing reliance on expensive treatments and innovative therapies adds further strain, particularly in countries with limited financial resources. Methods for forecasting and managing pharmaceutical spending are being explored, but these require careful balancing to ensure affordability without compromising innovation or access to essential treatments [5].

The organization and delivery of healthcare services also face substantial challenges. The transition from hospital-based care to community or home-based models, particularly for vulnerable populations such as children with complex medical needs, highlights gaps in continuity of care. Similar challenges arise in the development and support of specialized healthcare professions, where disparities in training and resources across regions create further inequalities in service provision. These systemic issues are compounded by the uneven distribution of healthcare infrastructure and personnel, with urban centres often enjoying more advanced facilities and services than rural or remote areas [2].

Over the decade 2010-2020, the Italian healthcare system has experienced a reduction in total available resources, with healthcare expenditure declining from 25.6% to 23% of total public social spending [6]. This trend contrasts with the European average over the same period, where healthcare expenditure remained at 29.47% of total social spending [6]. While public healthcare funding has decreased, private healthcare expenditure has risen, particularly in the form of out-of-pocket (OOP) payments, which increased from 20.55% to 21.13% of total healthcare expenditure [6]. A high out-of-pocket healthcare expenditure can have regressive effects on income distribution, disproportionately impacting lower-income individuals who may struggle to afford essential medical services. Additionally, the lack of an intermediary entity between the payer and the provider prevents risk distribution, leading to higher prices for private healthcare services. This dynamic further exacerbates health inequalities, as those who cannot afford private care may experience delayed or inadequate treatment, ultimately worsening public health outcomes.

The combination of aging populations, climate change, technological advancements, and economic pressures underscores the urgent need for sustainable and equitable healthcare strategies.

Public-Private Partnerships (PPPs) have emerged as a promising strategy for improving healthcare efficiency, modernizing infrastructure, and optimizing resource allocation. By leveraging private sector investment, expertise, and operational efficiency, PPPs enable public healthcare systems to benefit from advanced medical technology, streamlined hospital management, and improved patient care delivery [7]. European countries have implemented various PPP models, including hospital financing agreements, digital health collaborations, and long-term service contracts, to bridge gaps in service accessibility and infrastructure development. However, PPPs are not without challenges; concerns regarding financial transparency, cost-benefit distribution, and potential conflicts of interest require strong regulatory oversight and governance mechanisms [7].

A compelling example of successful PPP implementation is Siemens Healthineers' Value Partnerships model. The Stroke International Services (SIS) in Vietnam, as outlined in the case study "Value Partnerships in Southeast Asia: Innovating care delivery in a diverse region", exemplifies how these partnerships are tailored to regional needs, leveraging advanced technology, operational expertise, and capacity-building initiatives to create long-term impact [8]. This partnership underscores the versatility and effectiveness of the Value Partnership model in transforming healthcare delivery across diverse contexts. In Vietnam, the healthcare system has faced significant challenges, particularly in stroke care within the Mekong Delta region. Limited access to timely and specialized treatment due to infrastructural and environmental barriers has often prevented patients from receiving care within the critical "golden hour." Siemens Healthineers, through its Value Partnership with the SIS network, addressed these challenges by establishing Vietnam's first integrated stroke care network, launched in 2021 [8]. This initiative combines technological innovation, operational efficiency, and workforce development to provide a comprehensive solution to the region's healthcare needs. Central to the partnership is the deployment of advanced diagnostic and therapeutic technologies. Siemens Healthineers provided state-of-the-art equipment, including cutting-edge CT scanners, angiography systems, and robotic-assisted intervention technologies. These tools have significantly enhanced the diagnostic and therapeutic capabilities of the SIS network, enabling precise and timely interventions for stroke patients. By equipping healthcare facilities with these technologies, the partnership has not only improved immediate clinical outcomes but also strengthened the overall capacity of the healthcare system to handle complex medical cases. In addition to technological solutions, the Value Partnership emphasizes workforce development and knowledge transfer. Recognizing the importance of skilled healthcare professionals in ensuring the success of the initiative, Siemens Healthineers facilitated collaborations with international stroke care experts, including those from the renowned Inselspital Bern in Switzerland. These partnerships have allowed local clinicians to gain exposure to global best practices through initiatives such as the Asian Stroke Summer School. This annual event brings international expertise directly to Vietnamese healthcare providers, fostering skill development and encouraging the adoption of innovative treatment protocols. The partnership also focuses on operational and strategic planning to ensure the long-term sustainability of the SIS network. By co-developing customized strategies with local stakeholders, Siemens Healthineers has optimized resource allocation, streamlined workflows, and strengthened governance within the network. These efforts have allowed the SIS facilities to achieve internationally recognized standards of care. By 2022, the SIS network earned Diamond Status from the World Stroke Organization, reflecting its commitment to providing high-quality, patient-centered stroke care [8]. The results of this initiative are transformative, both in terms of patient outcomes and healthcare accessibility. Since the inception of the partnership, the percentage of stroke patients reaching care within the critical six-hour window has risen from 10% to 23% [8]. This improvement highlights the tangible impact of aligning innovative technology, training, and operational support with localized healthcare needs. Furthermore, the partnership's focus on sustainability ensures that these advancements are not short-lived but rather embedded within the system to benefit future generations. The case study of the SIS network exemplifies Siemens Healthineers' broader strategy of co-creating solutions that address specific regional challenges. By combining its technological expertise with a deep understanding of local healthcare needs, Siemens Healthineers has demonstrated the potential of Value Partnerships to drive meaningful change. The success of the SIS network in Vietnam serves as a model for replicating similar initiatives in other regions, showcasing the ability of public-private collaborations to bridge gaps in healthcare infrastructure, improve access, and deliver sustainable outcomes. In the broader context of this thesis, the SIS partnership reinforces the critical role of Value Partnerships in addressing systemic inefficiencies through innovation and collaboration. By leveraging technology, fostering education, and enabling operational transformation, Siemens Healthineers demonstrates how tailored solutions can align with regional contexts to deliver equitable and impactful healthcare outcomes. This case provides valuable insights into the effectiveness of the Value Partnership model, which will be further discussed in connection with other healthcare systems and public-private partnership frameworks.

Healthcare systems across Europe face mounting pressures to balance equity, efficiency, and sustainability in the face of growing disparities, resource constraints, and demographic shifts. This thesis aims to explore how public-private partnerships (PPPs) can provide strategic solutions to these challenges by leveraging collaborative models that combine public accountability with private sector innovation and expertise. The objective is not only to analyse the theoretical potential of PPPs but also to assess their practical applicability within diverse European healthcare contexts. Central to this research is the use of cluster analysis as a quantitative approach to identify patterns and groupings among European regions based on key healthcare indicators. By examining factors such as healthcare expenditure, resource distribution, and patient outcomes, the analysis seeks to uncover clusters of regions with similar healthcare characteristics. This clustering provides a foundation for understanding where systemic inefficiencies exist and how PPPs might be tailored to address them effectively. Through this analysis, the thesis seeks to provide data-driven insights into the conditions under which PPPs can thrive, offering a nuanced understanding of their potential impact. Real-world examples, such as Siemens Healthineers' Value Partnership model, serve as practical illustrations of how PPPs have been successfully implemented to improve healthcare delivery and resource optimization. These examples anchor the research in practical relevance, bridging the gap between theoretical frameworks and actionable strategies. The goal of this thesis is to contribute to the broader discourse on sustainable healthcare innovation in Europe by offering evidence-based recommendations for policymakers, healthcare providers, and private sector stakeholders. By combining quantitative analysis with qualitative insights, the research aims to provide a roadmap for the strategic deployment of PPPs, ensuring that these partnerships are both effective and context-sensitive.

The thesis is structured into five core chapters, each addressing a critical aspect of the research objective. The second chapter provides a literature review, examining existing research on PPP models, regulatory frameworks, and their effectiveness in healthcare delivery. The third chapter outlines the methodology, detailing the data sources, principal component analysis (PCA) application, and clustering techniques used to analyse European healthcare systems. The fourth chapter presents the empirical analysis, interpreting the results of the clustering study and discussing potential PPP applications in different healthcare contexts. Finally, the fifth chapter synthesizes the findings, offering policy recommendations and future research directions

## 2. *Literature Review: Addressing Healthcare Inefficiencies through PPPs*

**2.1 Definition and Models of PPPs:**

Public-Private Partnerships (PPPs) have become an essential tool for addressing various public sector challenges by utilizing the strengths of both public and private entities. These partnerships provide a framework for shared responsibility in delivering infrastructure, services, and innovation while balancing efficiency with accountability. Traditionally associated with infrastructure projects, PPPs have evolved to encompass sectors such as resilience planning, digital transformation, and cultural heritage preservation [9]. PPPs are defined by contractual agreements in which private entities undertake roles such as financing, designing, implementing, and managing public services or projects, while the public sector provides regulatory oversight and ensures alignment with public interests [10]. In urban resilience projects, PPPs play a crucial role in enhancing community preparedness, risk mitigation, and disaster response by integrating private sector expertise, technological advancements, and financial resources [9]. Similarly, in library digitization projects, PPPs facilitate access to cultural heritage through private sector investments in technology and infrastructure, although concerns remain about transparency and control over digital assets [10]. Several models of PPPs exist, depending on the degree of private sector involvement and risk-sharing mechanisms. The Build-Operate-Transfer (BOT) model allows private entities to finance, develop, and operate infrastructure before transferring ownership to the public sector. This model has been widely used in resilience and infrastructure projects to ensure long-term sustainability [9]. Another approach, the Concession Agreement, enables private operators to manage public assets and generate revenue while maintaining service quality under governmental oversight [9]. The Joint Venture (JV) Model emphasizes shared decision-making and collaborative risk management between public and private partners, which is particularly useful in projects that require flexibility and continuous adaptation, such as large-scale digitization initiatives [10]. The theoretical underpinnings of PPPs derive from various economic and administrative theories. Principal-Agent Theory explains the dynamics between public institutions (principals) and private partners (agents), focusing on the need to align incentives and mitigate conflicts through contractual mechanisms [9]. Transaction Cost Economics highlights the importance of structuring PPPs to minimize inefficiencies and financial risks, ensuring long-term viability [9]. Additionally, Public Choice Theory suggests that involving private actors in service delivery can enhance efficiency by fostering competition and reducing bureaucratic constraints [10]. Despite their advantages, PPPs present notable challenges. Issues such as contractual ambiguities, uneven risk allocation, and differing stakeholder priorities can result in inefficiencies [9]. Moreover, in projects related to public assets, such as cultural heritage digitization, concerns over private sector influence, transparency, and long-term access to resources have been raised [10]. The governance of PPPs must, therefore, incorporate robust oversight mechanisms, clear performance-based contracts, and transparent evaluation metrics to ensure that public interests are safeguarded [9]. To enhance the effectiveness of PPPs, policymakers advocate for structured regulatory frameworks that emphasize value-for-money assessments, stakeholder engagement, and accountability mechanisms [9]. In the European context, PPPs have been increasingly recognized as a strategic approach to fostering sustainable development, particularly in areas requiring substantial investment and innovation [9].

### 2.2 Benefits, Challenges, and Key Regulations in Healthcare

Public-Private Partnerships (PPPs) have become a fundamental strategy in addressing the growing challenges faced by healthcare systems, particularly in Europe, by leveraging private sector expertise while maintaining public oversight. These collaborations have been crucial in infrastructure modernization, resource optimization, and service accessibility, ensuring that public healthcare systems can adapt to increasing financial and operational pressures [11]. As economic constraints continue to strain public budgets, PPPs provide an effective alternative by combining public sector objectives with private investment and innovation. One of the primary contributions of PPPs to healthcare is the modernization of infrastructure and service delivery. Through these partnerships, European countries have been able to construct technologically advanced hospitals, implement digital healthcare solutions, and develop specialized care programs tailored to their populations' needs [12]. Digital transformation has been particularly impactful in elderly care, where PPPs have introduced technology-driven solutions that enhance accessibility and efficiency. By fostering collaboration between the public and private sectors, these initiatives have ensured long-term sustainability in healthcare service delivery [12]. In addition, PPPs have played a significant role in crisis response, particularly during the COVID-19 pandemic, where collaborations between governments, pharmaceutical companies, and research institutions accelerated the development and distribution of vaccines [13]. The successful execution of these partnerships underscores their potential in mobilizing resources effectively during healthcare emergencies. Beyond infrastructure, PPPs have enhanced healthcare accessibility in regions where public healthcare services face financial and operational constraints. In several European countries, including Portugal, Spain, and Germany, private sector involvement has facilitated the construction of modern hospitals, reduced patient wait times, and improved healthcare service efficiency [11]. The Alzira Model in Spain exemplifies a successful PPP initiative where a private consortium managed public hospitals, leading to cost reductions and improved patient outcomes [11]. Similarly, Germany has relied extensively on PPPs to modernize hospital infrastructure and expand specialized medical facilities, ensuring better access to advanced healthcare services [11]. PPPs have also addressed the challenge of medical workforce shortages, a growing concern across Europe. The increasing demand for healthcare professionals has led to the implementation of PPP-driven training programs and cross-border collaborations aimed at improving workforce retention rates and attracting medical professionals to underserved regions [14]. France and Italy, for example, have used PPP initiatives to establish joint medical education institutions and scholarship programs, mitigating workforce shortages and ensuring the long-term sustainability of healthcare services [14]. PPPs align with broader European healthcare objectives, including the European Union's Sustainable Development Goals (SDGs) and the European Health Union's initiatives. These partnerships foster improved governance, transparency, and accountability, addressing inefficiencies in healthcare service delivery [14]. Stakeholder participation in local healthcare governance ensures that PPPs are implemented effectively, aligning with public health priorities to strengthen healthcare systems through multi-level collaboration [14]. Despite their advantages, PPPs present challenges that must be managed carefully. Financial sustainability is a primary concern, as long-term PPP contracts often require substantial public investment. Poorly structured agreements have led to cost overruns and financial inefficiencies in some cases, raising concerns about the long-term affordability of such projects [11]. Furthermore, issues of equitable access arise, as some privatized healthcare services have prioritized high-revenue treatments over essential public health initiatives, leading to disparities in access for low-income populations [11]. Regulatory inconsistencies across Europe further complicate PPP implementation. While countries like Germany and France have established robust PPP regulations to ensure accountability and service quality, others struggle with fragmented policies that create inefficiencies [11]. Standardizing regulatory frameworks across EU member states could mitigate these issues by ensuring uniform guidelines for contract structures, financial risk assessments, and performance monitoring [11]. To enhance the effectiveness of PPPs, policymakers should adopt a balanced approach that integrates efficiency with financial sustainability and equitable healthcare access. Strengthening regulatory oversight is essential, with independent bodies ensuring transparency in financial reporting and contract enforcement [11]. Cross-border collaborations could further optimize PPP effectiveness by pooling resources among EU member states for healthcare infrastructure projects, shared digital health platforms, and joint medical research programs. Such initiatives would not only enhance healthcare resilience but also reduce the financial burden on individual national budgets, ensuring a more coordinated European response to healthcare challenges [13]. Despite their challenges, PPPs remain a valuable tool for achieving sustainable healthcare improvements in Europe. Their ability to introduce innovative solutions, optimize resource allocation, and enhance system efficiency underscores their importance in modern healthcare systems. However, their long-term success depends on the establishment of well-defined regulatory frameworks, transparent governance mechanisms, and a balanced approach that ensures private sector involvement aligns with public health priorities [11]. By adopting a strategic approach that includes robust oversight, tailored implementation strategies, and enhanced cross-border collaboration, PPPs will continue to play a pivotal role in addressing systemic inefficiencies, fostering healthcare resilience, and improving service accessibility across Europe.

# 3. Methodology

## 3.1 The European Healthcare System

The European healthcare system encompasses a diverse range of models and structures, reflecting the economic, political, and cultural contexts of different countries. While each nation operates its own healthcare system, common trends and principles, such as universal access and government involvement, are evident across Europe. The European Union (EU) plays a coordinating role, ensuring healthcare quality, accessibility, and efficiency through regulatory frameworks and cross-border healthcare policies [15]. Although healthcare policy primarily falls under the jurisdiction of individual states, the EU plays a vital role in standardizing and improving healthcare systems across its member states. The EU promotes cooperation through initiatives such as the European Health Insurance Card (EHIC), which allows citizens to receive medical care across member states under the same conditions as locals [15]. Furthermore, the EU has implemented regulations on cross-border healthcare, ensuring that patients can seek treatment in other member states and be reimbursed by their home country's healthcare system [15]. The European healthcare system is characterized by diversity yet unified by common principles of accessibility, quality, and efficiency. While countries adopt different models, the role of the EU in ensuring healthcare cooperation and regulatory oversight continues to grow. However, challenges such as cost containment, workforce shortages, and healthcare disparities require continuous policy reforms and innovation. Digital transformation presents an opportunity to enhance healthcare delivery, making systems more resilient and sustainable for the future.

## 3.2 Introduction to the Methodology and Data Source

The foundation of this study is an analysis of the European healthcare system, conducted using a dataset compiled from Eurostat. The objective of this analysis is to classify countries into distinct clusters based on these indicators, enabling the identification of shared healthcare characteristics and systemic disparities. This classification will serve as a basis for exploring the strategic implementation of public-private partnerships (PPPs) to address inefficiencies and improve healthcare outcomes across Europe. This research employs a quantitative methodology to assess the role of PPPs in European healthcare by analysing key healthcare performance indicators. The study utilizes Principal Component Analysis (PCA) to reduce the dimensionality of the dataset while retaining the most critical healthcare system variations, followed by K-Means Clustering to categorize European countries into groups based on healthcare expenditure and efficiency. These methods provide a structured classification of European healthcare systems, enabling an evaluation of the conditions under which PPPs may be most effective. The dataset used for this study is sourced from Eurostat, the statistical office of the European Union. The dataset includes healthcare indicators across 27 European Union member states, capturing fundamental aspects of healthcare financing, accessibility, and system performance. The variables considered include total healthcare expenditure, long-term care expenditure, practicing physicians per 100,000 inhabitants, hospital beds per 100,000 inhabitants, healthy life years at birth, and self-reported unmet medical needs. These indicators provide a comprehensive view of both financial inputs and healthcare system outputs, allowing for an evaluation of efficiency and performance across countries. Before conducting the analysis, data preprocessing techniques were applied to ensure consistency and statistical validity.

### 3.3 Data Preprocessing, Cleaning Techniques, and Statistical Models

This study employs a quantitative research methodology to investigate similar characteristics among European countries when it comes to healthcare factors. The analysis follows a structured approach that includes data collection and preprocessing, descriptive statistical analysis, principal component analysis (PCA), clustering techniques, and data visualization. The objective is to identify key healthcare-related factors among European countries and to categorize them into clusters in order to understand where the PPPs model could apply the best. The dataset used in this study is stored in an Excel file and contains 7 variables related to healthcare investment, healthcare infrastructure, and population health outcomes of the 27 countries of the European union. The first variable is population size (pop) reported for 2021, serves as a contextual variable for understanding the scale of healthcare systems and the magnitude of resource demands [16]. Countries such as Germany, with a population exceeding 83 million, demonstrate different system needs and capacities compared to smaller nations like Malta, with just over half a million residents. The inclusion of population size provides critical context for interpreting other variables and understanding how system resources are distributed. The second variable is self-reported unmet need for medical examination and care (u_need), recorded as a percentage in 2022, measures accessibility to healthcare services [17]. This indicator reflects the proportion of individuals aged 16 and over who were unable to access medical care due to financial constraints, waiting lists, or geographical barriers. This variable highlight systemic challenges faced by different regions in ensuring equitable healthcare access. Variability in unmet needs, ranging from 0.2% in Malta to 6.5% in Finland, underscores significant disparities across the EU [17]. The third and fourth variables are total healthcare expenditure (hc_exp) and long-term care (health) expenditure (ltc_exp), expressed in millions of euros for 2022, quantify the financial investments made by each country in their healthcare systems [18] [19]. Total healthcare expenditure reflects the overall commitment to healthcare services, excluding capital investments, while long-term care expenditure focuses specifically on medical and personal care for individuals with chronic conditions or long-term dependencies. Germany, with the highest total healthcare expenditure at €488.7 billion, exemplifies the substantial investments required to support a large and complex healthcare system [18]. In contrast, smaller nations such as Luxembourg allocate significantly lower amounts, reflecting differences in population size, system priorities, and economic capacity [18]. The fifth variable is practising physicians per 100,000 inhabitants (Pp), reported for 2020, as a measure of healthcare workforce availability [20]. The density of practising physicians provides a critical perspective on system capacity, as higher densities often correlate with better accessibility and quality of care. For instance, Austria, with 534.6 practising physicians per 100,000 inhabitants, demonstrates a robust healthcare workforce, whereas Latvia, with 333.9 practising physicians, highlights potential resource shortages [20]. The sixth variable is hospital beds per 100,000 inhabitants (Hb), recorded for 2022, capture the physical infrastructure available for inpatient care [21]. Germany leads in this metric, with 766 hospital beds per 100,000 inhabitants, compared to Sweden's 189 beds per 100,000, reflecting stark differences in system readiness to address acute and chronic health needs [21]. The last variable is Healthy life years (Hly), an outcome-based indicator for 2022, measures the average number of years an individual is expected to live in good health, free from chronic illness or disability [22]. This variable provides a holistic perspective on the effectiveness of healthcare systems, emphasizing not only longevity but also quality of life. Disparities in healthy life years, such as Malta reporting over 70 years compared to less than 60 years in Latvia and Finland, underscore the importance of addressing systemic inefficiencies and inequalities [22]. Each variable in the dataset captures a key aspect of healthcare system performance from an economic perspective. Population (pop) represents healthcare demand, as larger populations require greater resource allocation and infrastructure. Self-reported unmet need (u_need) reflects healthcare accessibility, indicating barriers such as financial costs and waiting times. Total healthcare expenditure (hc_exp) measures investment in medical services, while long-term care expenditure (ltc_exp) highlights support for aging populations and chronic conditions. Practicing physicians per 100,000 (Pp) represents workforce availability, affecting service capacity. Hospital beds per 100,000 (Hb) indicate hospital capacity, crucial for inpatient care. Healthy life years (Hly) measure public health efficiency, linking healthcare quality to economic productivity. To ensure the dataset is suitable for statistical analysis, a series of preprocessing steps were applied. Variable names were standardized to maintain consistency, non-numeric values were converted into numerical format where necessary, missing values were either omitted or imputed, and data types were checked and corrected to facilitate mathematical operations. These steps ensured that the dataset was structured appropriately for further statistical analysis. Descriptive statistical analysis was conducted to summarize the key characteristics of the dataset. Measures of central tendency and dispersion were computed, including the mean, defined as:

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

and the standard deviation, computed as:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

These descriptive statistics provided a comprehensive understanding of the distribution, central tendency, and variability of the dataset before further analyses were conducted. To reduce the dimensionality of the dataset while retaining key variance, Principal Component Analysis (PCA) was applied. The dataset was normalized to ensure that all variables, measured on different scales, have equal weight in the analysis. Since the dataset includes heterogeneous metrics, such as healthcare expenditure in millions of euros and percentage-based indicators, normalization using z-scores

$$Z_i = \frac{x_i - \overline{x}}{\sigma_x}$$

allows for comparability and prevents variables with larger values from dominating the PCA. This transformation ensures that the principal component analysis is based solely on the relationships between variables, improving the interpretability of the results. In order to proceed with the Principal Component Analysis, a normalization of the dataset PCA transforms the original variables into new uncorrelated principal components that capture the maximum variance in the data. Each principal component is a linear combination of the original variables, defined as:

$$PC_j = w_{j1}X_1 + w_{j2}X_2 + \cdots + w_{jp}X_p$$

where $PC_j$ is the $j$th principal component, $w_{ji}$ are the eigenvectors (weights), and $X_i$ are the original variables. The variance explained by each component was determined using eigenvalues, defined as $\lambda_j = Var(PC_j)$. A scree plot was used to determine the optimal number of components to retain by identifying the point where variance begins to level off. Additionally, variables contribution to principal components were analyzed using squared cosine values, computed as:

$$cos^2(X_i) = \frac{Squared\ Loading\ of\ X_i}{\sum Squared\ Loadings}$$

where higher values indicate stronger contributions to the principal components. This allowed for the identification of the most influential variables in the principal components. To categorize countries based on healthcare characteristics, K-Means clustering was applied. This method minimizes the sum of squared distances between data points and their assigned cluster centroids, defined as:

$$\sum_{i=1}^{k} \sum_{x_{j \in C_i}} ||x_j - \mu_i||^2$$

where k is the number of clusters, $x_j$ is a data point, and $\mu_i$ is the centroid of cluster $C_i$. The optimal number of clusters was determined using the Elbow Method, which involves plotting the within-cluster sum of squares (WCSS) against different values of k and identifying the point where the decrease in WCSS starts to level off. The clustering results allowed the identification of distinct groups of countries, with one cluster characterized by high healthcare investment and better health outcomes, another by moderate investment and average health outcomes, and a third by low investment and poorer health outcomes.

This methodology integrates descriptive statistics, regression analysis, PCA, and clustering to provide a comprehensive assessment of the relationship between healthcare investment and life expectancy. The results highlight the critical role of healthcare expenditure in improving life expectancy and categorize countries into distinct groups based on their healthcare policies and outcomes. This study provides valuable insights for healthcare policymakers, researchers, and planners aiming to optimize resource allocation and improve public health outcomes.

### 3.4 Limitations of the Methodology

While this study employs robust statistical methods, several limitations must be considered. The reliance on secondary data from Eurostat introduces constraints, as the accuracy and completeness of findings depend on the quality of publicly available statistics. Some important healthcare system characteristics, such as patient satisfaction, regional healthcare disparities, and institutional governance structures, are not captured in the dataset. Additionally, the choice of clustering method affects results, as K-Means requires a predefined number of clusters, which introduces a degree of subjectivity in model selection. Another limitation arises from PCA's dimensionality reduction, which, while improving interpretability, may exclude minor but relevant trends that could contribute to policy analysis. Finally, the study's focus on European Union member states limits the generalizability of its findings, as healthcare policies and PPP structures in non-EU countries may differ significantly. By acknowledging these limitations, this study aims to provide a balanced and data-driven perspective on the role of PPPs in European healthcare. The findings contribute to ongoing discussions on sustainable healthcare financing and service delivery models, offering insights that can inform policymakers, healthcare providers, and researchers in their efforts to improve healthcare system efficiency and accessibility.

# 4. *Empirical Analysis*

## 4.1 Presentation of Results

This section presents the empirical results obtained from the statistical analysis, following the methodology outlined in Chapter 3. The objective is to systematically examine the healthcare characteristics of European Union member states through three key analytical steps: descriptive statistics, Principal Component Analysis (PCA), and K-Means Clustering. It has been computed the mean and standard deviation for the selected healthcare indicators, providing an initial overview of how healthcare investment, accessibility, and system efficiency vary across countries. PCA is then applied to identify the main dimensions driving differences between healthcare systems, reducing the dataset's complexity while preserving its key informational content. Finally, K-Means Clustering groups countries based on healthcare similarities, allowing for a structured classification of different healthcare models in Europe. Each step builds upon the previous one, offering a progressively deeper understanding of the underlying healthcare structures across EU countries.

Descriptive statistics provide an initial understanding of the distribution and variability of key healthcare indicators across European Union member states. The mean represents the average value of each variable, while the standard deviation measures how much individual country values deviate from the average, indicating the extent of heterogeneity among healthcare systems (CFR Table 1). The large standard deviation in healthcare expenditure (hc_exp) and long-term care expenditure (ltc_exp) suggests that some countries allocate substantially more resources to healthcare than others, reflecting differences in government priorities, economic capacity, and demographic structures. Similarly, the variation in self-reported unmet needs (u_need) highlights disparities in healthcare accessibility, which may be influenced by insurance coverage, waiting times, and regional healthcare availability. The relatively high standard deviation in practicing physicians (Pp) and hospital beds (Hb) indicates different healthcare system models across Europe. Some countries maintain high hospital bed capacity (e.g., Germany) as part of an inpatient care model, whereas others focus more on primary care and outpatient services, requiring fewer hospital beds but more physicians per capita. The dispersion in healthy life years (Hly) demonstrates that healthcare investment alone is not a sufficient predictor of health outcomes. Lifestyle factors, preventive care policies, and social determinants of health all contribute to variations in life expectancy and quality of life across Europe.

Principal Component Analysis (PCA) is applied to reduce the dimensionality of the dataset while preserving the most critical sources of variation among European healthcare indicators. By transforming correlated variables into a smaller set of uncorrelated components, PCA allows for a structured interpretation of the underlying healthcare system differences across EU countries. The first step in PCA involves analyzing the variance explained by each principal component (CFR Table 2). Principal Component 1 accounts for 42.0% of the total variance, followed by Principal Component 2 (19.1%) and Principal Component 3 (16.0%). Together, the first three components explain 77.1% of the total variance, indicating that they capture most of the meaningful variation in the dataset. The cumulative variance surpasses 88% when including Principal Component 4, suggesting that a four-component solution provides a reasonably comprehensive summary of the data. Since Principal Component 1 and Principal Component 2 together explain over 61% of the total variance, they are retained as the primary dimensions for visualization and interpretation. The scree plot of principal components (CFR Graph 1) further supports this selection, as the eigenvalues drop significantly after the second component, indicating that additional components contribute progressively less explanatory power. The sharp decline after Principal Component 2 suggests an "elbow point," indicating that the first two Principal Components capture the most critical information. Additional Principal Components contribute progressively less variance, reinforcing the decision to focus on Principal Component 1 and Principal Component 2 for further analysis. To understand how each variable contributes to the principal components, it is analysed the loading scores (CFR Table 3) . The loadings indicate the correlation between the original variables and the principal components, helping to define their meaning and interpret the patterns emerging from the PCA. Principal Component 1, which explains 42% of the variance, has high positive loadings for population size (pop) (0.93), Healthcare Expenditure (hc_exp) (0.98), and Long-term care Expenditure (ltc_exp) (0.95). This suggests that Principal Component 1 primarily represents healthcare investment and system scale, with higher values indicating countries that allocate substantial resources to their healthcare systems and have larger populations.

Countries scoring high on Principal Component 1 tend to have greater healthcare expenditure, more developed long-term care services, and overall larger healthcare infrastructures. Principal Component 2, accounting for 19.1% of the variance, is strongly influenced by Practising Physicians (pp) (0.81) and Healthy life years (Hly) (0.47), while it is negatively correlated with Hospital beds (Hb) (-0.66). This component appears to capture healthcare workforce availability versus hospital-based infrastructure. Countries with high values in Principal Component 2 emphasize primary care and physician accessibility, whereas countries with lower values rely more on hospital-based care, with fewer physicians per capita. The PCA variable plot (CFR. Graph 2) confirms these relationships by visually displaying the contribution of each variable to Principal Component 1 and Principal Component 2. Variables closely aligned along an axis have a stronger influence on that principal component. The strong clustering of Total healthcare expenditure (hc_exp), Long-term care expenditure (ltc_exp) and population size (pop) along Principal Component 1 reinforces its interpretation as a measure of healthcare investment and system scale, while the opposite positioning of Hospital beds (Hb) and Practising physicians (pp) along Principal Component 2 highlights the contrast between hospital capacity and physician density. By reducing the dataset to these two principal components, it is retained 61.1% of the total variance, capturing the primary healthcare system differences across European countries. These results serve as the foundation for the K-Means Clustering analysis, which will group countries based on their PCA-derived characteristics.

K-Means Clustering is applied to classify European countries into distinct groups based on their healthcare system characteristics. This method partitions the dataset into clusters that minimize the within-cluster variance, ensuring that countries within the same group share similar healthcare profiles. The first step in the clustering process is to determine the optimal number of clusters (k), using the Elbow Method (CFR Graph 3). The plot shows a sharp decrease in within-cluster variance as "k" increases, followed by a levelling-off, indicating the optimal number of clusters is three. Once the optimal number of clusters is selected, K-Means clustering is performed using three clusters. The results (CFR Graph 4), display the distribution of countries across the first two principal components (Principal Component 1 and Principal Component2). Each colour represents a different cluster, with countries sharing similar healthcare expenditure, accessibility, and system structure grouped together. The clusters reveal distinct patterns in European healthcare systems: Cluster 1 (Red) represents countries with higher healthcare expenditure and long-term care spending, associated with well-developed systems but also higher costs, Cluster 2 (Green) includes countries with moderate healthcare investment and relatively balanced system structures, suggesting a mix of public and private healthcare models, Cluster 3 (Blue) contains countries with lower healthcare expenditure and higher unmet medical needs, indicating challenges in accessibility and resource allocation. To facilitate the interpretation of the K-Means clustering results, it is essential to refer to the complete list of the countries included in the analysis (CFR Table 4).

## 4.2 Economic Interpretation of the Results

The cluster analysis conducted in this study has provided valuable insights into the structural and financial disparities among healthcare systems in the European Union. By segmenting countries based on healthcare expenditure, infrastructure, and accessibility, three distinct clusters have emerged, each representing unique characteristics and systemic attributes. This analysis offers a more granular understanding of how national healthcare systems are structured, enabling a deeper exploration of the disparities that exist within the EU. These distinctions are not merely theoretical; they have significant implications for public health policy, funding allocation, and long-term planning for healthcare systems across the continent.

The first cluster includes countries such as Sweden, Portugal, and Greece, positioned in the upper left quadrant of the principal component space. These nations exhibit moderate to high healthcare investments but also present particular structural limitations or differences in accessibility. Their positioning along the second principal component suggests that variations in hospital infrastructure and long-term care expenditure are key distinguishing factors. Sweden, for instance, stands out in this cluster due to its strong emphasis on long-term care rather than hospital-based care. The Swedish healthcare system prioritizes home-based and community-based care models over large-scale hospital infrastructure, leading to a system that focuses more on chronic disease management and elderly care rather than acute medical interventions. Portugal and Greece, while investing considerably in healthcare, may face structural inefficiencies or accessibility challenges that differentiate them from countries with more comprehensive system integration. For example, Portugal has a strong public healthcare system but still struggles with long waiting times and uneven regional distribution of resources, particularly in rural areas. Greece, on the other hand, has a high proportion of out-of-pocket healthcare expenses compared to other EU nations, indicating potential inefficiencies in its public healthcare funding model.

The second cluster is composed of countries such as Germany, France, Italy, and Spain, positioned on the far right of the principal component space. These countries are characterized by a strong financial commitment to healthcare, evident through high expenditures and well-developed medical infrastructures. Their placement along the first principal component suggests that financial capacity and workforce availability are the primary differentiating factors. Germany, which contributes the most to the explained variance, exemplifies a nation with high healthcare expenditure, a robust workforce, and an extensive hospital infrastructure. With one of the highest hospital bed densities in Europe and a well-distributed healthcare system, Germany serves as a model for accessible and well-funded care. France follows closely, with a similarly well-funded system that ensures accessibility and efficiency through a mix of public and private healthcare providers. The French healthcare system is recognized for its universal coverage, high physician density, and generous reimbursement schemes that minimize out-of-pocket costs for citizens. Italy and Spain, while not reaching the expenditure levels of Germany and France, maintain balanced and well-organized healthcare systems that provide extensive coverage and quality services. Italy, for example, has a highly decentralized system where regional governments play a crucial role in healthcare delivery, leading to variations in quality but also allowing for localized decision-making. Spain, with its strong primary care network, ensures that a majority of healthcare needs are met at the community level, reducing the burden on hospitals and emergency departments. The countries within this cluster represent the most developed and resource-rich healthcare systems in the European Union, serving as benchmarks for best practices and comprehensive healthcare models.

The third cluster groups Romania, Bulgaria, Latvia, and Estonia, positioned in the lower left quadrant. These nations are characterized by lower healthcare expenditure, fewer hospital beds, and significant accessibility limitations. The compact nature of this cluster indicates a high degree of similarity among its members, suggesting systemic challenges in resource allocation and healthcare delivery. Romania and Bulgaria, for instance, struggle with underfunded healthcare systems, often resulting in lower accessibility and quality of care. In Romania, healthcare infrastructure is outdated, and many rural areas suffer from severe shortages of medical professionals, leading to disparities in healthcare access between urban and rural populations. Bulgaria faces similar challenges, with low physician density and high out-of-pocket expenses that create barriers to care for lower-income populations. Latvia and Estonia, while slightly better positioned, still face difficulties in workforce availability and infrastructure investment. Estonia, for example, has made significant strides in digital healthcare innovation, with electronic health records widely implemented, yet financial constraints continue to limit the overall capacity of the system. The countries in this cluster represent healthcare systems with fewer resources, where systemic inefficiencies and financial constraints contribute to disparities in health outcomes and service provision. These healthcare systems often struggle to retain medical professionals due to lower wages and limited career opportunities, leading to medical brain drain, where doctors and nurses migrate to wealthier EU countries in search of better working conditions.

The spatial distribution of these clusters underscores the disparities in healthcare system capacities across the European Union. The most significant gap exists between Cluster 2, representing wealthier nations with well-funded and structured healthcare systems, and Cluster 3, comprising countries with fewer resources and greater accessibility challenges. Cluster 1 occupies an intermediate position, suggesting that some nations adopt unique healthcare system models that do not strictly align with the trends observed in the other two groups. This segmentation highlights the need for tailored policy approaches to address the specific healthcare challenges faced by different countries. While Cluster 2 countries may continue to refine their healthcare systems with technological advancements and efficiency-driven reforms, Cluster 3 nations require targeted interventions to address structural weaknesses and financial constraints.

From a policy perspective, the clustering results emphasize the need for strategic interventions to reduce systemic disparities. Countries in the third cluster, which exhibit financial and infrastructural limitations, would benefit from targeted investments in hospital infrastructure and workforce expansion to enhance accessibility and service provision. Additionally, financial aid programs and policy frameworks aimed at improving healthcare efficiency could help mitigate the disparities observed within this group. For example, increased EU funding could support modernization initiatives in Romania and Bulgaria to improve hospital infrastructure and expand medical training programs to address workforce shortages. The countries in the first cluster may need to focus on optimizing healthcare accessibility and efficiency, particularly in streamlining resource allocation and ensuring equitable service distribution across their populations. In Sweden, for instance, efforts could be made to improve access to specialized hospital care, which remains centralized in larger cities, creating barriers for rural populations. Meanwhile, the second cluster, which represents the most advanced healthcare systems in the EU, serves as a model for best practices. The policies and healthcare frameworks implemented in Germany and France, for example, could provide valuable insights for nations striving to enhance their healthcare systems. These nations could further lead cross-border collaborations, sharing expertise and resources to assist lower-performing healthcare systems in achieving better outcomes.

The findings of this cluster analysis reinforce the importance of evidence-based decision-making in healthcare policy. By identifying structural differences and financial disparities among EU countries, this segmentation provides a foundation for designing targeted interventions that align with the specific needs of each group. The results suggest that healthcare reforms should not adopt a one-size-fits-all approach but should instead focus on the unique challenges and strengths of each cluster. The analysis further highlights the role of healthcare expenditure, infrastructure development, and workforce availability as key determinants in shaping healthcare outcomes and accessibility across Europe. Addressing these disparities through well-designed policies and investments will be essential in ensuring that healthcare systems across the European Union can provide equitable and high-quality care to all citizens. Moreover, understanding these clusters allows for more precise forecasting of future healthcare demands, ensuring that national governments and EU policymakers can implement proactive strategies to enhance healthcare resilience, particularly in the face of challenges such as aging populations, pandemics, and economic crises.

This cluster analysis serves as an essential tool for assessing healthcare system performance, identifying areas for improvement, and shaping policy recommendations tailored to the specific needs of each country. The disparities highlighted in this study suggest that healthcare equity remains an ongoing challenge in the European Union, requiring continued collaboration between national governments and EU institutions to bridge the gap between high-resource and low-resource healthcare systems. Ensuring that all citizens, regardless of their country of residence, have access to high-quality and equitable healthcare services should remain a fundamental priority for European policymakers.

## 5. *Conclusions and Future Research*

The transformation of healthcare systems in Europe is being shaped by demographic, economic, environmental, and technological factors that place significant pressures on national healthcare frameworks. The increasing prevalence of aging populations, chronic diseases, and economic constraints has necessitated innovative approaches to healthcare financing and delivery. This thesis explored the role of Public-Private Partnerships (PPPs) as a potential solution to these challenges, leveraging private sector expertise, efficiency, and investment to enhance public healthcare services. Through a combination of Principal Component Analysis (PCA) and K-Means Clustering, this research categorized European healthcare systems into three clusters based on expenditure, accessibility, and system efficiency. The results indicate that Cluster 1 consists of countries with moderate-to-high healthcare investment, yet some systemic inefficiencies in infrastructure and service accessibility. Cluster 2 includes high-expenditure, well-structured systems, such as Germany and France, characterized by strong infrastructure and extensive workforce availability. Cluster 3 encompasses lower-investment healthcare systems, often facing accessibility limitations and workforce shortages, highlighting systemic inequities in European healthcare. These findings emphasize that while some European countries have robust healthcare frameworks, significant disparities exist, particularly in access to care and long-term sustainability. The research highlights the need for tailored policy interventions to address healthcare disparities across different clusters. For Cluster 1 countries, optimizing resource allocation and reducing inefficiencies in healthcare service delivery should be a priority. PPPs can be leveraged to introduce digital healthcare solutions and modernized infrastructure to enhance accessibility. For Cluster 2 nations, the focus should be on technological innovation and long-term sustainability, with PPPs facilitating advancements in AI-driven diagnostics, robotic-assisted surgeries, and value-based healthcare models. For Cluster 3 countries, strategic investment in infrastructure development, workforce training, and cross-border collaborations can help bridge healthcare accessibility gaps. PPPs should be designed to improve basic healthcare services and regional healthcare equality. Furthermore, regulatory frameworks must be reinforced to ensure transparency, accountability, and equitable distribution of PPP benefits. Stronger governance mechanisms are essential to prevent cost overruns, privatization risks, and inequalities in service provision. While this study provides a data-driven approach to analysing European healthcare systems, certain limitations must be acknowledged. The reliance on Eurostat data means that some qualitative aspects, such as patient satisfaction and regional healthcare disparities, are not fully captured. The PCA-based dimensionality reduction, while useful, may obscure some minor yet relevant trends within healthcare indicators. The K-Means Clustering approach, while effective, requires a predefined number of clusters, which introduces some degree of subjectivity. Future research could expand on these findings by conducting longitudinal studies to assess the long-term impact of PPPs on healthcare efficiency and equity, exploring alternative financing models such as blended financing and outcome-based contracting, to enhance the effectiveness of PPPs, and evaluating cross-border healthcare collaborations to understand how EU-wide initiatives can improve healthcare resilience and accessibility. This research underscores the importance of strategic public-private collaboration in ensuring sustainable, efficient, and equitable healthcare systems in Europe. By identifying healthcare system clusters and assessing the role of PPPs, this study provides valuable insights for policymakers, healthcare providers, and industry stakeholders. As healthcare challenges continue to evolve, the successful integration of innovative financing mechanisms, regulatory oversight, and technological advancements will be crucial in shaping the future of European healthcare. Strengthening cross-sector cooperation and evidence-based policy development will ensure that healthcare systems across Europe remain resilient, inclusive, and capable of meeting the demands of future generations.

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## 7. Exhibits

**Table 1: Descriptive Statistics of Healthcare Indicators**

| Variable | Mean | Standard Deviation |
|---|---|---|
| Population size (pop) | 16,505,519 | 22,267,144 |
| Self-reported unmet need (u_need) | 0.03 (3%) | 0.02 (2%) |
| Total healthcare expenditure (hc_exp) | 61,055.06 million € | 109,250.23 million € |
| Long-term care expenditure (ltc_exp) | 9,900.99 million € | 20,095.03 million € |
| Practicing physicians (Pp) | 410.69 per 100,000 | 102.48 per 100,000 |
| Hospital beds (Hb) | 474.72 per 100,000 | 178.64 per 100,000 |
| Healthy life years (Hly) | 62.10 years | 3.98 years |

**Table 2: Importance of Principal Components**

| Component | Standard Deviation | Proportion of Variance | Cumulative Proportion |
|---|---|---|---|
| Principal Component 1 | 1.715 | 0.42 | 0.42 |
| Principal Component 2 | 1.1569 | 0.1912 | 0.6112 |
| Principal Component 3 | 1.0587 | 0.1601 | 0.7714 |
| Principal Component 4 | 0.8762 | 0.1097 | 0.881 |
| Principal Component 5 | 0.81129 | 0.09403 | 0.97508 |
| Principal Component 6 | 0.41 | 0.02401 | 0.99909 |
| Principal Component 7 | 0.0797 | 0.00091 | 1 |

***Graph 1: Scree Plot of Principal Components***

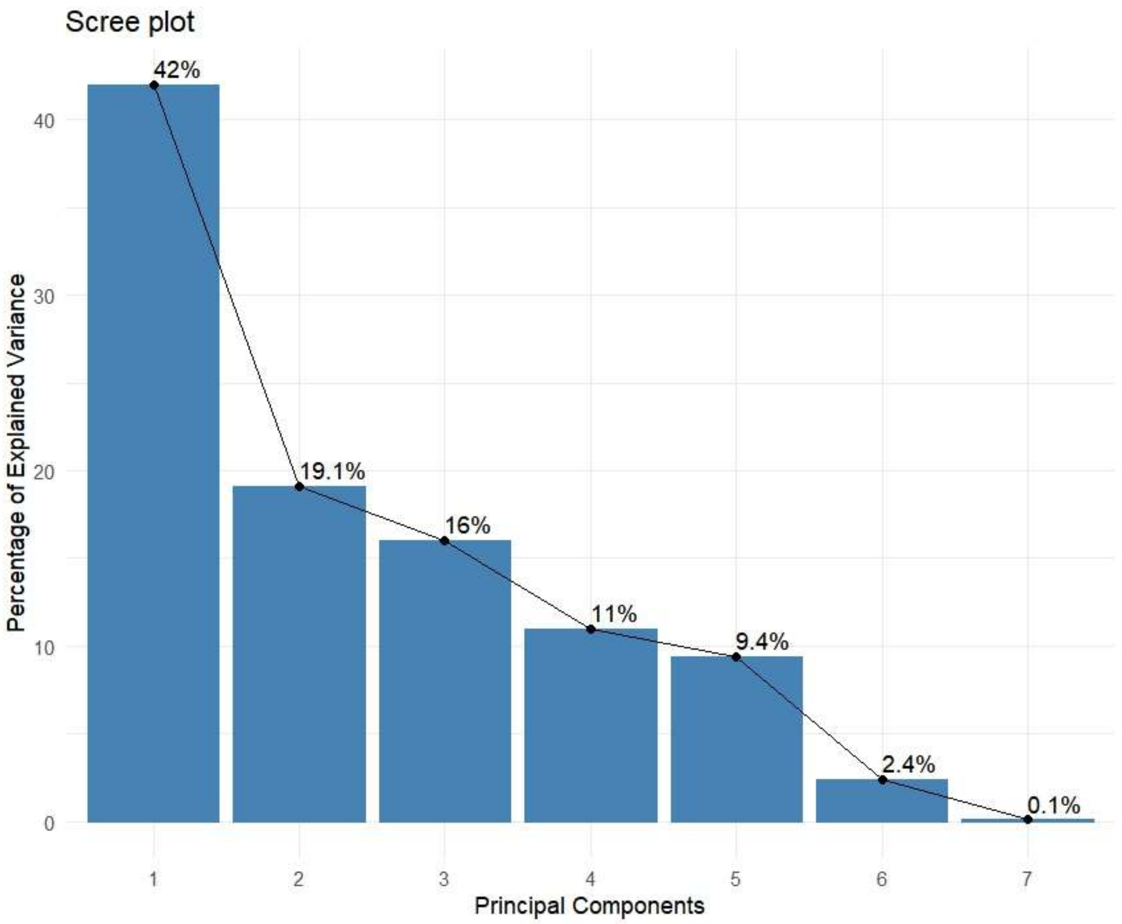
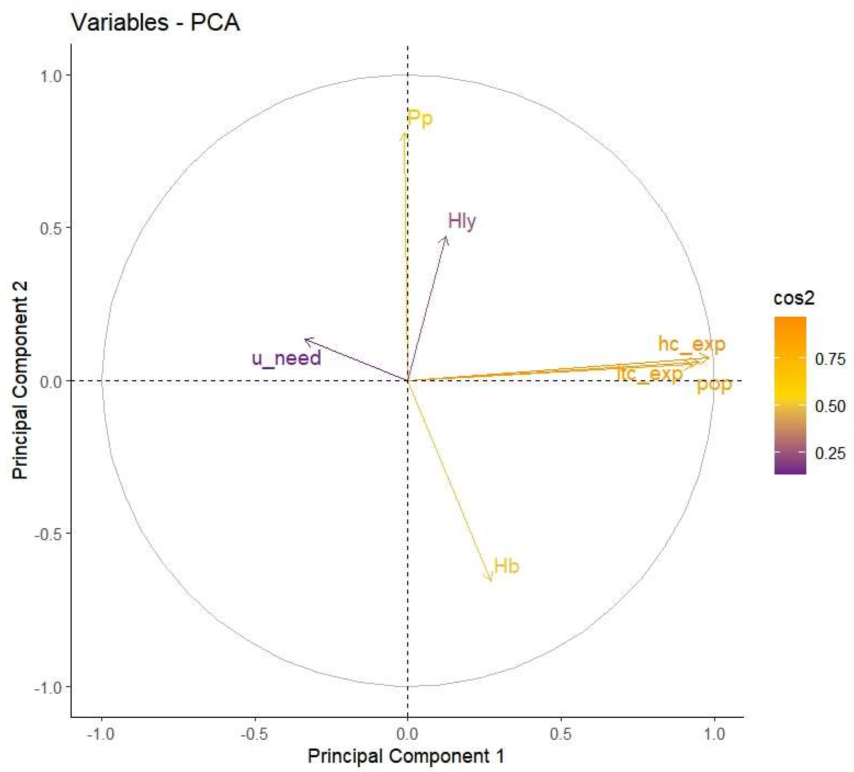


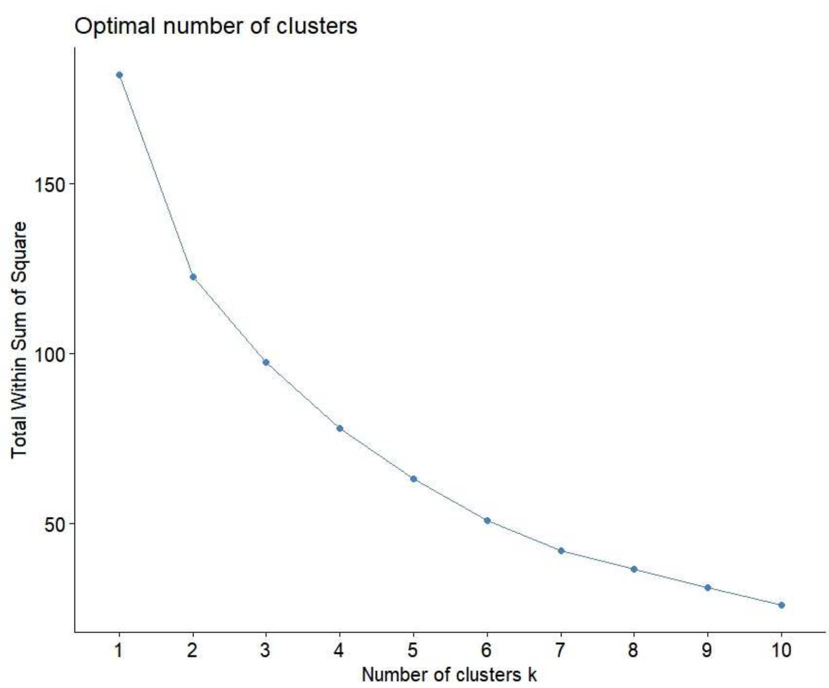

***Table 3: Variable Loadings for Principal Components:***

| Variable | Principal Component 1 | Principal Component 2 | Principal Component 3 | Principal Component 4 | Principal Component 5 | Principal Component 6 | Principal Component 7 |
|---|---|---|---|---|---|---|---|
| Population size (pop) | 0.9309 | 0.0509 | -0.1089 | -0.0413 | 0.1392 | -0.312 | 0.0228 |
| Self-reported unmet need (u_need) | -0.3389 | 0.1343 | -0.7252 | -0.4643 | 0.3525 | 0.0382 | 0.0009 |
| Total healthcare expenditure (hc_exp) | 0.9822 | 0.0723 | -0.1417 | 0.0239 | 0.0441 | 0.0584 | -0.063 |
| Long-term care expenditure (ltc_exp) | 0.9516 | 0.0596 | -0.1465 | 0.0675 | -0.0239 | 0.2498 | 0.0431 |
| Practicing physicians (Pp) | -0.0118 | 0.8082 | -0.1229 | -0.2168 | -0.5325 | -0.0332 | 0.0001 |
| Hospital beds (Hb) | 0.2706 | -0.6576 | 0.1713 | -0.6105 | -0.3067 | 0.0061 | -0.0004 |
| Healthy life years (Hly) | 0.1225 | 0.4727 | 0.7053 | -0.3542 | 0.3692 | 0.0475 | 0.0008 |

## ***Graph 2: PCA Variable Loadings Plot***




## ***Graph 3: Elbow Method for Optimal Cluster Selection***



***Graph 4: K-Means Clustering of European Healthcare Systems***

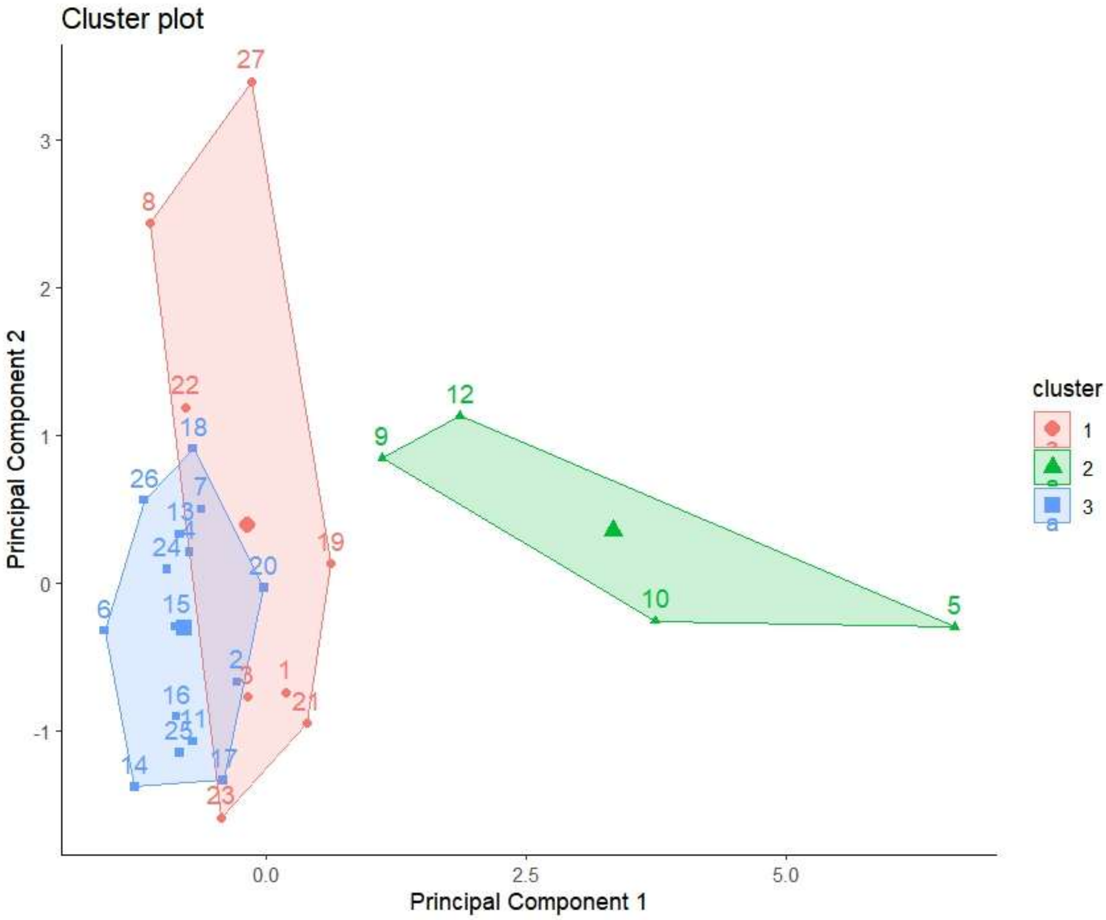



***Table 4: List of European Countries in the Dataset:***

| # | Country | # | Country | # | Country |
|---|---|---|---|---|---|
| 1 | Belgium | 10 | France | 19 | Netherlands |
| 2 | Bulgaria | 11 | Croatia | 20 | Austria |
| 3 | Czechia | 12 | Italy | 21 | Poland |
| 4 | Denmark | 13 | Cyprus | 22 | Portugal |
| 5 | Germany | 14 | Latvia | 23 | Romania |
| 6 | Estonia | 15 | Lithuania | 24 | Slovenia |
| 7 | Ireland | 16 | Luxembourg | 25 | Slovakia |
| 8 | Greece | 17 | Hungary | 26 | Finland |
| 9 | Spain | 18 | Malta | 27 | Sweden |