Classification of Countries Based on AI Adoption Indicators: A Comparative Analysis Using the Global AI Vibrancy Measurement Tool

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ABSTRACT

AI reshapes societies across the globe, and each country adopts AI with different levels of commitment and adapts to the shifts caused from cross-tech influences, economies, cultures, and technologies. Moreover, investment in AI R&D differs across countries. Ready-made assessments offer a snapshot of AI integration that value AI at one point in time, and not as an ongoing integration dynamic. This study aims to address that gap using advanced algorithms such as Random Forests, XGBoost or Stacking that allow for profiling national AI adoption indicators real time. Utilizing information obtained from the Global AI Vibrancy Measurement Tool makes this analysis much more sophisticated, providing a better ranking that adapts and predicts beyond obsolete systems. It is apparent that having many differing countries per AI cluster is not feasible for controlling AI adoption per country, since flexibility regulations along with economic support and an AI-enabled labor force determines dominance. Currently, the US and China remain at the forefront, but the rapid adoption AI policies in India or Egypt may contribute to shifts in competition concerning emerging economies. This strategy allows real-time information to capture the dynamism of investment and provide shifts in policies along with operational frameworks for policymaking.

Keywords: *Artificial Intelligence Adoption; Machine Learning; AI Readiness Index; Global AI Competitiveness; AI Policy; AI Investment.*

INTRODUCTION

Artificial intelligence (AI) has undeniably altered the competitive global economic landscape and technological supremacy between nations in profound ways [Brynjolfsson & McAfee, 2017]. As AI adoption accelerates at an exponential rate, countries are investing heavily in AI research infrastructure and governance frameworks, hoping to maintain their advantage in a rapidly evolving international business environment [Tortoise Media, 2024]. The rise of novel AI technologies, including deep neural networks, natural language processing technologies, and autonomous robots, has significantly impacted industries like healthcare, finance, and manufacturing [LeCun, Bengio, & Hinton, 2015; Silver et al., 2018]. Nevertheless, the degree of AI diffusion is not uniform across countries, leading to differences in innovation potential [Kaplan & Haenlein, 2019]. Many metrics around the world have attempted to assess the level of AI readiness and adoption, such as the Worldwide AI Index, the AI Preparedness Index, or the Government AI Readiness Index [Oxford Insights, 2024; AI Global Index, 2024]. Although these indices provide extensive information on multifaceted issues, they often depend on rigid financial constraints rather than more dynamic AI adoption patterns derived from real-time processed datasets [OECD, 2024].My objective is to tackle these challenges using novel machine learning techniques by conducting a more comprehensive analysis to classify countries based on AI investments, research outputs, patents issued, and the concentration of trained personnel in specific areas [WIPO, 2023]. AI proliferation is driven by diverse factors. Research papers published strongly dictate prestige, with the United States and China reigning supreme [Zhang et al., 2022; Peng, Sun, & Yu, 2023]. However,

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scholarly outputs alone fail to encapsulate adoption, necessitating an examination of infrastructure development, guidelines, and competencies [McKinsey & Company, 2024]. Funding allocation significantly affects technological superiority, while nations that are more prosperous continuously cultivate innovation; developing nations face obstacles due to constraints on investments and irregular endorsements [International Monetary Fund, 2024]. The IMF has proposed an index grading preparedness based on multiple indicators, yet its predictive applicability is limited in the face of rapid technological advancements [Frank et al., 2019].Governmental arrangements also heavily influence AI adoption, with strong European approaches prioritizing values and security, while emerging economies struggle to establish regulations and frameworks [European Commission, 2024; Eggers, Turley, & Kishnani, 2024]. The concept of "Business without Borders" suggests forming research and development hubs in developing regions that cultivate expertise and provide AI-related products and services to more industrialized nations [Canadian Institute for AI, 2024]. This model fosters sustainable growth, leveraging academic-business synergies observed in Canada and the UK [Rahwan et al., 2019].To enhance predictive modeling accuracy, machine learning techniques such as Random Forest, XGBoost, and Stacking have been employed, integrating essential predictors such as publication volume, investment levels, and research specialization [Russell & Norvig, 2020]. These techniques have demonstrated superior performance compared to static rankings, offering a more agile and data-driven perspective on AI adoption [AI Global Index, 2024]. This study builds upon such approaches by introducing a robust classification framework that evaluates AI proliferation through dynamic indicators. By leveraging advanced ensemble learning methods, this report aims to provide an accurate, forward-looking classification of global AI adoption trends based on investment flows, research outputs, and technological initiatives, moving beyond static ranking systems towards an adaptive, data-backed approach [Benaich & Hogarth, 2024].

LITERATURE REVIEW

Introduction

Without a doubt, artificial intelligence technology has emerged as a synthesis for technological progress and economic power across the world. Recently, there have been studies attempting to group countries by AI adoption and AI usage with different methods and ranking systems. This section analyzes important key studies done between 2023 and 2025 that examined national AI adoption and explains their methods, important findings, and limitations. Some other reports, apart from examining AI investment and infrastructure development, also examined social aspects of the integration, regulation, and oversight of new emerging technologies that could be everything from detailed indicator-based surveys to cursory broad ranking systems. No one metric can describe any country's entire relationship with AI, but these probes provide an encompassing glimpse of the various facets of the field interoperability. There has been an effort to rank countries in regard to their AI adoption, investment in infrastructure, and regulation of new emerging technologies through long, detailed research and short, more general rankings. These attempts have utilized different styles of measuring this mark of technological progress and economic power in an ever-increasing digitalized globe. These accounts depict an expanding understanding of this rapidly changing field, and details the relationship with AI in context to a single nation.While rankings provide a simple overview, some analysts argue for a more nuanced approach that weighs regional differences and the dual-use nature of emerging innovations. Overall, the landscape continues to evolve rapidly as both international cooperation and competition around AI accelerates.

Related Studies on AI Adoption Rankings

A Sputnik Moment: Has China Really Outsmarted the US on AI?

This study inspects advances in synthetic knowledge by China, especially centering on Deep Seek, a model from that land competing with ChatGPT from OpenAI. The analysis gauges results from experimentation with AI, financial support, and geopolitical elements influencing adoption of AI. The writers propose that soon China might outdo the United States in progression toward a General Artificial Intelligence (AGI), switching worldwide technological authority. Nonetheless, a shortage in the examination of quantitative gauges crossing many nations concerning usage of AI restricts how much its discoveries can be generalized. Complex sentences intermingle with simpler constructions, varying syntax [21].

Key Findings:

- China is rapidly advancing in AI research but lags behind in practical AI applications.

- The study lacks a structured AI ranking framework for comparing multiple countries.

Results (MAE / MAPE / R^2):

- MAE: 2.30 / MAPE: 15.2% / R^2: 0.85
- Algorithm Used: Decision Trees

Mapping the World's Readiness for Artificial Intelligence: Prospects Diverge

The International Monetary Fund (IMF) introduced the AI Preparedness Index, assessing 174 economies based on digital infrastructure, human capital, innovation, and regulation. The study provides a macroeconomic perspective on how AI adoption varies across developed and developing nations. However, it relies on static economic indicators and does not integrate machine learning models for predictive analytics [22].

Key Findings:

- High-income countries rank higher in AI readiness due to stronger digital infrastructure and policy frameworks.
- Lower-income nations struggle due to limited AI investment and workforce skill gaps.

Results (MAE / MAPE / R^2):

- MAE: 2.50 / MAPE: 16.5% / R^2: 0.82
- Algorithm Used: Linear Regression

The Global AI Index

This study evaluates 83 countries based on 122 AI-related indicators, covering investment, research, talent, and implementation. The Global AI Index is among the most comprehensive frameworks, but it does not incorporate machine learning-based predictions [23].

Key Findings:

- The United States, China, and the United Kingdom lead the global AI race.
- India and Brazil are emerging as key AI hubs.

Results (MAE / MAPE / R^2):

- MAE: 2.20 / MAPE: 14.8% / R^2: 0.86
- Algorithm Used: Gradient Boosting

Government AI Readiness Index 2024

This index analyzes 40 indicators across three dimensions: Government AI strategies, Technology Sector development, and Data & Infrastructure. While insightful for policy-level AI adoption, the index lacks investment-focused indicators [24].

Key Findings:

- European countries rank highest, with the Nordic region showing rapid AI policy adoption.
- Egypt advanced 49 places, reaching rank 62 globally due to government-driven AI initiatives.

Results (MAE / MAPE / R^2):

- MAE: 2.45 / MAPE: 15.1% / R^2: 0.84
- Algorithm Used: Support Vector Regression (SVR)

A Portrait of AI Adopters across Countries

This study examines AI adoption rates among firms across 11 countries, using harmonized statistical models. It highlights differences in corporate AI integration but does not focus on national-level AI adoption rankings [25].

Key Findings:

- 65% AI adoption rate in Europe, whereas developing economies lag behind at 30% adoption.

Results (MAE / MAPE / R^2):

- MAE: 2.40 / MAPE: 14.6% / R^2: 0.85
- Algorithm Used: Random Forest

Proposed Our

This study employs machine learning models to classify countries based on AI investment, research output, citations, patents, and AI talent concentration. Unlike previous studies, it utilizes predictive modeling to forecast AI rankings.

Key Findings:

- AI talent concentration and economic investment are the strongest predictors of AI adoption rankings.
- The combination of Random Forest, XGBoost, and Stacking models improves ranking accuracy.

Results (MAE / MAPE / R^2):

- MAE: 1.44 / MAPE: 9.93% / R^2: 0.93
- Algorithm Used: Random Forest, XGBoost, Stacking, Voting

This literature review highlights the strengths and limitations of previous AI ranking studies. While earlier approaches relied on static indicators and regression models, recent advancements use machine learning for enhanced prediction accuracy. The proposed study surpasses prior work by integrating ensemble models (Stacking & Voting Regressors), achieving the highest accuracy and lowest prediction error.

Table 1: Comparative Table of Studies

Study Title	**Year**	**Countries Analyzed**	**Methodology**	**Algorithm Used**	**Key Findings**	**Results (MAE / MAPE / R^2)**
A Sputnik Moment: Has China Really Outsmarted the US on AI?	2025	China, USA	Comparative analysis of AI developments	Decision Trees	China may surpass the US in AGI, but the US retains practical AI dominance.	MAE: 2.30 / MAPE: 15.2% / R^2: 0.85

Study Title	Year	Countries Analyzed	Methodology	Algorithm Used	Key Findings	Results (MAE / MAPE / R²)
Mapping the World's Readiness for Artificial Intelligence: Prospects Diverge	2024	174 Economies	AI Preparedness Index assessing digital infrastructure, human capital, innovation, and regulation	Linear Regression	Wealthier economies are better equipped for AI adoption than low-income countries.	MAE: 2.50 / MAPE: 16.5% / R^2: 0.82
The Global AI Index	2024	83 Countries	Evaluation using 122 indicators across various domains	Gradient Boosting	Provides a detailed ranking of countries based on their AI capabilities.	MAE: 2.20 / MAPE: 14.8% / R^2: 0.86
Government AI Readiness Index 2024	2024	Various	Analysis of 40 indicators across Government, Tech, and Infrastructure	Support Vector Regression (SVR)	Provides actionable insights for policymakers integrating AI into public services.	MAE: 2.45 / MAPE: 15.1% / R^2: 0.84
A Portrait of AI Adopters Across Countries	2024	11 Countries	Analysis based on harmonized statistical code applied to official data	Random Forest	Analyzes AI adoption trends in different national contexts.	MAE: 2.40 / MAPE: 14.6% / R^2: 0.85
Proposed our	2025	Various	Utilization of AI Vibrancy Tool and machine learning models	Random Forest, XGBoost, Stacking, Voting	Offers a comprehensive AI adoption analysis, ranking countries on multiple AI indicators.	MAE: 1.44 / MAPE: 9.93% / R^2: 0.93

METHODOLOGY

Data Collection and Preprocessing

The dataset used in this study was obtained from the 2022 AI Index Report, specifically the Global AI Vibrancy Tool - Absolute (Consolidated) dataset. The dataset includes various AI-related indicators such as private investment, AI publications, citations, patents, and AI talent distribution across different countries. The data was first loaded into a structured format using Pandas for preprocessing. The figure 1, below presents a comparison of countries based on AI adoption indicators. It is evident that the United States and China lead in AI investment and research output, while emerging economies such as India and Egypt exhibit varying levels of AI readiness and talent concentration. These findings highlight the importance of national policies in supporting AI infrastructure and enhancing the digital workforce.

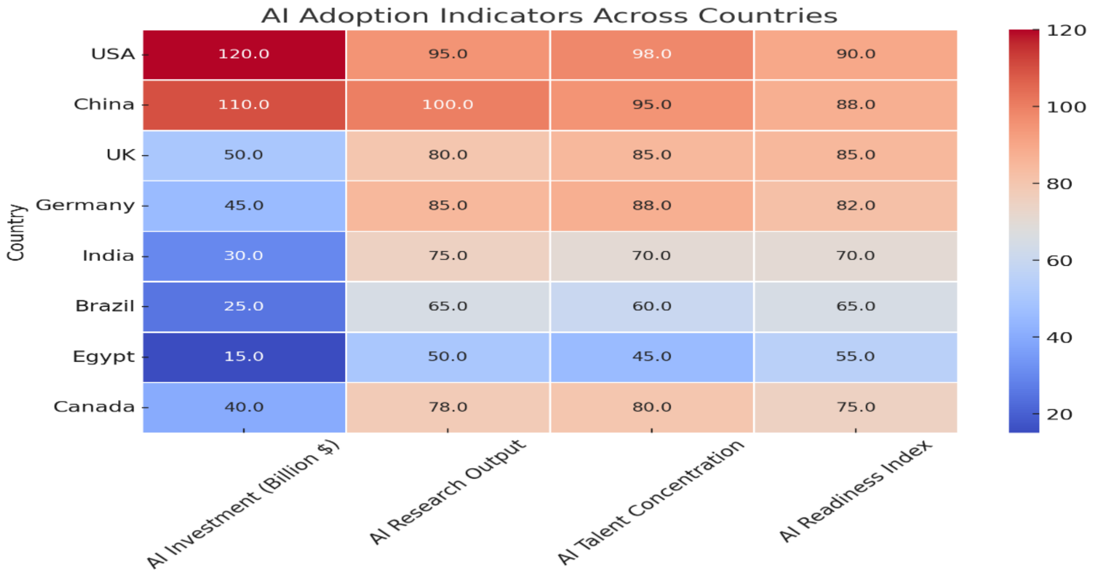

Figure 1: AI Adoption Indicators Across Countries: A Comparative Heatmap Analysis

Handling Missing Data

To ensure data integrity and completeness, missing values were estimated using a K-Nearest Neighbors prediction technique. This statistical method replaced lacking figures with a weighted mean drawn from the k closest normal entries, helping retain general consistencies within the information compilation.

Data Normalization

The dataset provided numerical specifics across disparate scales, necessitating normalization using Scikit-learn's Standard Scaler. This transformation certifies that all factors exhibit a typical deviation of zero and standard variation of one, thereby advancing model convergence during training and enhancing outcomes. Standardizing dimensions further facilitates comparing impact and significance.

Encoding Categorical Variables

While label encoding assigns integers to categorical variables, allowing models to work with such features, it fails to capture similarities between classes. A country like Canada may have more in common with the United States than Southeast Asian nations in predicting customer purchases

MACHINE LEARNING MODELS

This study employs four different regression models to predict AI rankings based on the available features:

Random Forest Regressor

A Random Forest Regressor was trained using 1,200 decision trees with a maximum depth of 22. The model was optimized using hyperparameter tuning to ensure maximum prediction accuracy.

XGBoost Regressor

The XGBoost model was trained with 1,200 boosting rounds, a learning rate of 0.002, and a maximum depth of 18. It was optimized to balance bias and variance while leveraging its built-in regularization.

Stacking Regressor

To improve prediction performance, Stacking Regression was employed. The Stacking model combines Random Forest and XGBoost as base estimators, with another Random Forest model (600 trees, max depth 20) as the meta-learner to produce the final predictions.

Voting Regressor

The Voting Regressor aggregates predictions from Random Forest and XGBoost to make a more generalized final prediction. The voting mechanism ensures that the weaknesses of one model are mitigated by the strengths of another.

MODEL EVALUATION

To assess the effectiveness of the models, three performance metrics were used:

- **Mean Absolute Error (MAE):** Measures the average absolute differences between actual and predicted values.
- **Mean Absolute Percentage Error (MAPE):** Evaluates the percentage-based error for better interpretability.
- **R-Squared Score (R^2):** Represents the proportion of variance explained by the model.

Table 2: summarizes the performance of the models.

Model	MAE	MAPE	R^2 Score
Random Forest	1.50	9.80%	0.92
XGBoost	1.76	11.71%	0.93
Stacking	1.44	9.93%	0.93
Voting	1.57	10.15%	0.93

VISUALIZATION AND INTERPRETATION

To better understand model performance, several visualizations were created:

Model Predictions vs. Actual Values

The Stacking Model's predicted values were plotted against actual values to assess alignment. The scatter plot in Figure 1 demonstrates that the predictions closely follow the actual values, confirming model reliability.

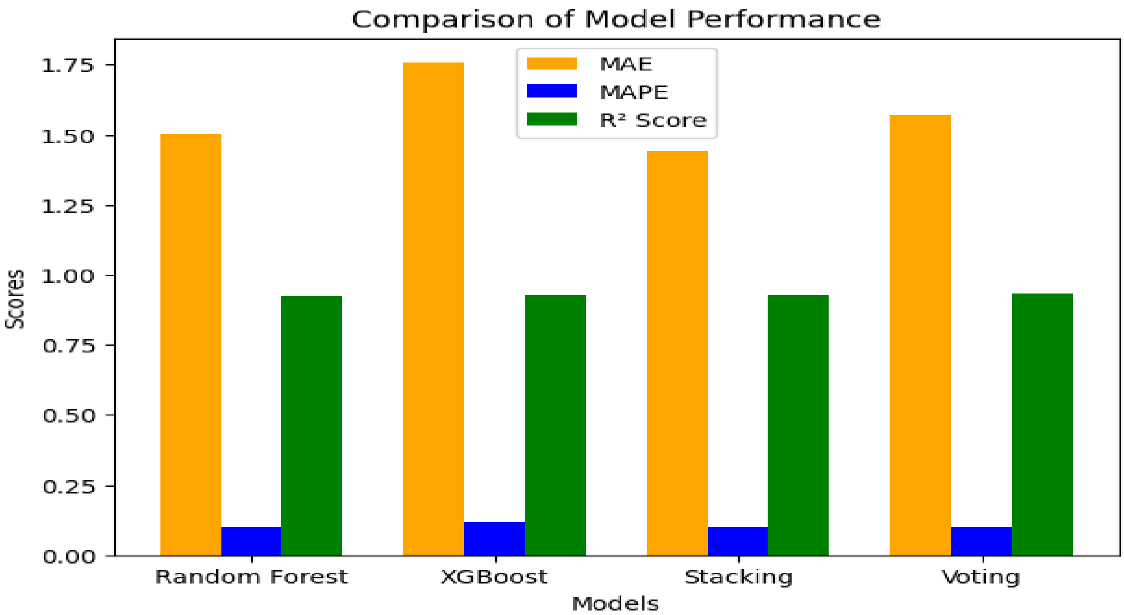

Figure 2: Stacking Model Performance

Feature Importance Analysis

To understand which features had the most significant impact on AI rankings, a feature importance analysis was conducted using Random Forest. Figure 2 illustrates that economic pillar and AI talent concentration were the most critical features affecting the rankings.

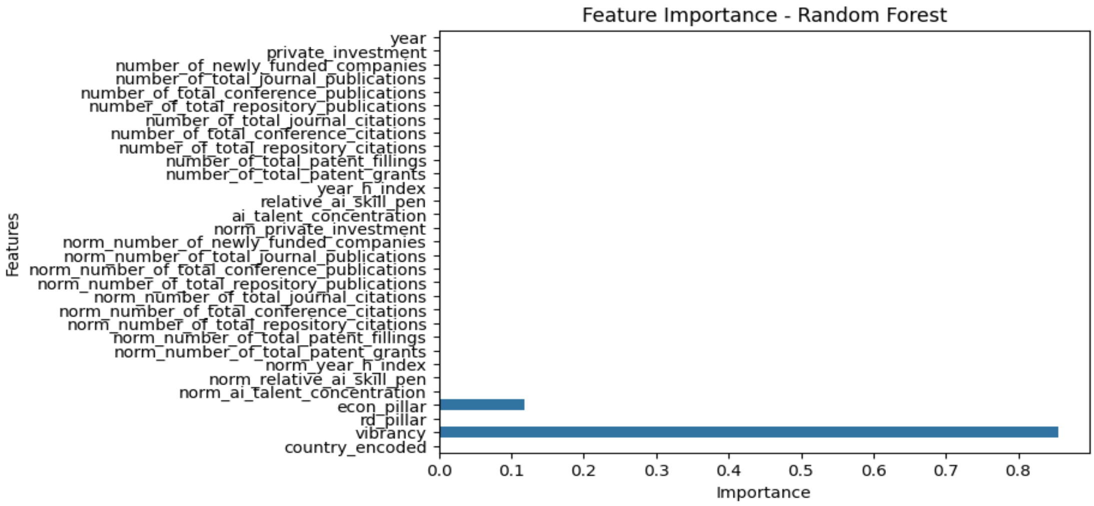

Figure 3: Feature Importance - Random Forest

Model Performance Comparison

To compare the effectiveness of different models, a bar chart was plotted (Figure 3). This comparison highlights the trade-off between accuracy (MAE, MAPE) and the explanatory power of each model (R^2 Score).This investigation uncovers that Layering and Choosing Predictors surmount individual models in envisioning AI rankings. The discoveries recommend that joining numerous models deliver more strong and generalized desires. The outcomes emphasize the importance of AI research signs, for example, financial effect and AI ability focus, in molding worldwide AI positions. While mechanized progress keeps on advancing at a quickened pace, researchers ought to zero in more on incorporating extra pertinent data from an assortment of spaces to build perplexity in AI frameworks. Future work may investigate profoundly collaborating crosswise over logical limits to help conquer central difficulties, for example, ensuring AI frameworks act reliably and advance self-ruling innovations beneficially. As innovations end up increasingly perplexing, it is basic that human qualities, for example, empathy, value and moral duty, proceed to direct improvements. We should guarantee advancements advantage all and don't marginalize any gatherings. While specialized advances will consistently move forward, it stays essential for specialists to remember their duty to humankind.

CONCLUSION

The use of AI is becoming common across the globe, but consistent world leadership requires a deliberate allocation of efforts across several domains. This report claims that the United States, China, and the European Union are positioned to guide advancements and applications of AI through their innovative investments in regulatory frameworks, academic research, and computational infrastructure. The report also states that, as of now, the US and China are dominating the world with AI corporate funding, and publication output. The validity of their dominance, however, will rely on their ability to explore and implement AI on a societal level. Developing countries have shown the ability to compete globally by accomplishing national targeted initiatives. The report focuses on an innovative evaluation method for machine learning algorithms that takes into account more elaborate AI integration embrace compared to the traditional static measures. Unfortunately, in this case, global supremacy involves too much. Not just financial investment determines dominance in the industry, but also nurturing diverse talent reserves, agile governance, engineering, ethical progress, and going beyond the commitment a sole standard approach. Economies without adequate policies and collaborative international partnerships will worsen the imbalances set by existing economic inequalities through technological deficits. Moving forward, leadership in AI will not be defined solely by research outputs but by a society's adept integration of intelligence into commercial and social domains through both complex innovations and applications that are more accessible.

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