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ORIGINAL

Prediction of ICT Usage in Ecuador Through Machine Learning: impact of Education Level, Age, and Income on Digital Inclusion

Predicción del uso de TICs en Ecuador mediante aprendizaje automático: impacto del nivel educativo, edad e ingresos en la inclusión digital

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ABSTRACT

The progress of digital technologies in Ecuador during 2023-2024 was analyzed using data from the ENEMDU and machine learning models, processing 56 941 records that were carefully cleaned, normalized, and organized. Most notably, there was an increase in ICT usage across all age groups: usage among young people aged 18-29 rose by 1,7 %, among adults aged 30-49 by 1 %, and among those over 50 by 1,2 %. Education level emerged as the most decisive factor, showing a strong correlation of 0,69, although improvements were observed across all income levels. However, the gap between urban and rural areas remains significant, highlighting the need for more inclusive policies. The results suggest that this growth is expected to continue through 2025 and begin to stabilize between 2026 and 2027.

Keywords: ICT; Ecuador; Machine Learning; Digital Divide; Projections.

RESUMEN

Se analizó el avance de las tecnologías digitales en Ecuador durante 2023-2024 usando datos de la ENEMDU y modelos de IA, procesando 56 941 registros que se limpió, normalizó y organizó cuidadosamente. Lo más interesante es que se encontró un aumento en el uso de TIC en todos los grupos de edad: los jóvenes de 18-29 años subieron un 1,7 %, los adultos de 30-49 un 1 % y las personas mayores de 50 años un 1,2 %. El nivel educativo resultó ser el factor más determinante, con una fuerte correlación de 0,69, aunque se vio progresos en todos los niveles económicos. Aun así, las diferencias entre zonas urbanas y rurales siguen siendo notorias, lo que indica que hacen falta políticas más inclusivas. Los resultados proyectan que, este crecimiento debería mantenerse hasta 2025 para luego empezar a estabilizarse entre 2026 y 2027.

Palabras clave: TIC; Ecuador; Aprendizaje Automático; Brecha Digital; Proyecciones.

INTRODUCTION

Information and communication technologies (ICT) have clearly influenced how people interact today. They have transformed education, employment, and entertainment, enabling faster and more efficient ways of accessing, interpreting, and disseminating information.[1]

However, its adoption has not been equitable, and even countries with high rates of technology use, such as the United States, are not immune to this problem. Although 85 % of American adults have smartphones and 77 % of households have high-speed internet, nearly a third of the population still has trouble connecting. This inequality highlights the stark differences in income and educational attainment. In contrast, China has made significant progress in reducing this gap. By 2023, it had reached 1,092 billion internet users, with 66,5 % growth in rural connectivity, representing an increase of 4,6 percentage points compared to the beginning of that year.[2,3]

In Ecuador, the digital divide goes beyond simple access to information and communication technologies (ICTs); it also has environmental consequences stemming from increasing digitalisation. According to figures from the National Survey of Employment, Unemployment and Underemployment (ENEMDU), socioeconomic and geographical factors not only restrict the use of these tools but also impact critical areas such as education and the labour market.[4,5]

On the other hand, the UN's Digital Economy 2024 report warns that the increase in the use of digital devices and the growth of technological infrastructure already account for up to 3,2 % of global greenhouse gas emissions. Therefore, in developing countries such as Ecuador, digitisation strategies must address two simultaneous challenges: reducing the digital divide and promoting sustainable practices that minimise environmental impact.[6,7,8]

The acceleration of the digital economy in developing countries is an urgent necessity, as noted in the United Nations Conference on Trade and Development report. Although digital trade and connectivity have grown in many regions, countries like Ecuador face serious barriers to accessing digital infrastructure and e-commerce. In less developed economies, only 6 % of the population shops online, compared to 62 % in advanced economies, highlighting a digital divide that significantly limits opportunities in the labour market and trade. Digital transformation in Latin America has been an accelerated process in recent decades. However, it faces significant challenges in countries such as Ecuador, where inequalities in access to technology persist. Digitalisation has grown considerably in several sectors, but economic barriers and insufficient infrastructure remain obstacles to the equitable adoption of digital technologies. Understanding how socio-demographic characteristics related to age, educational level, and income influence access to and use of ICTs is necessary to address these inequalities, particularly in developing countries where disparities tend to be more pronounced.[9,10]

ICTs have radically transformed organisational and social communication, significantly impacting the labour market. The rapid development of technologies such as robots, artificial intelligence, and software is digitising information and changing production processes. Science and technology, comprising research, development, and innovation, are key economic progress tools. Technological advances generate debate about their impact on employment. While automation can lead to unemployment, it can create new businesses, sectors, and professions requiring highly skilled specialists. Despite advances in global digitalisation, countries like Ecuador face significant challenges in adopting ICTs. Research conducted in other countries has confirmed that factors such as education level, income, and even age directly influence access to and use of information and communication technologies (ICTs). However, there is still a need to analyse how these variables interact in Ecuador, especially during the rapid digital transition process that took place between 2023 and 2024.[11,12]

This study used data from the ENEMDU (2023 and 2024) to see how Ecuadorians are adopting digital technologies. The aim is to understand how they use the internet and devices and what helps or hinders them in accessing these technologies. By comparing these results with previous research and examining annual changes, the study provides an updated view of the challenges and opportunities in terms of digital inclusion. The study's main objective is to analyse factors such as age, educational level, and income that determine the type and frequency of activities carried out on the internet to assess how these dynamics have changed between 2023 and 2024.[13,14]

This study hopes to provide practical input for designing effective public policies that reduce digital divides and promote equitable access to ICTs. Key questions addressed in this study include: How have ICT usage patterns evolved among different age and educational groups over the last year? What role have socioeconomic conditions played in the use of digital technologies? Answering these questions is essential for advancing toward more inclusive societies in the digital age and adapting public policies to current and future needs.[15,16]

METHOD

This study is based on data from ENEMDU Ecuador for the years 2023 and 2024. This database contains information related to sociodemographic characteristics and patterns of use of information and communication technologies (ICT).

Data sources

This analysis includes 56 941 records and 171 variables from urban and rural clusters in the provinces of Ecuador, except Galápagos, related to access to digital technologies, the geographical distribution of the population, and sociodemographic data such as age, level of education, per capita income, and employment for the years 2023 and 2024. Information about ICT use is available on the frequency and type of online activities, such as education, leisure, and communication. It includes housing and household identifiers for analysis at the individual and family level.

Data management processing

To ensure the quality of the dataset, errors, inconsistencies, and problems were identified and corrected. To avoid bias, incomplete observations in key variables such as age and educational level were excluded, and statistical imputation (mode or median) was used in secondary variables.

In addition, duplicate records and inconsistent data between 2023 and 2024 were removed. In terms of variable transformation, One-Hot Encoding 17 was applied to categorical variables such as educational level and type of ICT activity instead of Label Encoding to avoid assigning artificial ordinal relationships that could bias the results, and income and age were normalised 18 to a range between 0 and 1 to ensure compatibility in the models.[17]

Furthermore, a 'year' column was added to distinguish between records from 2023 and 2024, allowing for comparative analysis.[18]

In addition, the variable 'uso_tic' was generated to quantify the level of interaction with digital technologies. To this end, variables related to access and use of devices, Internet, and digital skills were selected, including mobile phone ownership and number, smartphone use, connectivity, online services, Internet and computer use frequency, and basic and advanced digital skills. Each variable was transformed into a numerical format; outliers were replaced and normalised by their maximum value. The percentage of ICT use was then calculated by adding the normalised values of all variables and dividing them by the total number of indicators considered, obtaining a relative index between 0 and 100. This new variable allows for the evaluation of patterns of technology adoption and their relationship with other sociodemographic characteristics.

Methods of analysis

Spearman's correlation analysis [19] was performed to identify key relationships between variables such as age, educational level, and income with ICT use. In addition, visualisations such as bar charts and heat maps [20] were generated to show changes in ICT usage patterns and highlight strong correlations, respectively. Regarding year-on-year comparison, variations in ICT use by age, education, and economic group were assessed between 2023 and 2024, identifying new trends such as teleworking and digital training.

Due to the 171 variables available, machine learning models were used to select the variables most relevant to ICT use. Among the techniques applied were decision trees[21] and Random Forest[22] which can handle heterogeneous data and non-linear relationships typical in sociodemographic studies, and which made it possible to determine that among the variables most related to ICT use are income, age, and educational level. Deep learning techniques such as long short-term memory (LSTM) neural networks were also used, employing a two-layer architecture with 64 neurons each to model temporal trends in ICT use based on the variables obtained in 2023 and 2024.

Model evaluation

The Mean Square Error (MSE) evaluation metric was used to measure the model's accuracy in projecting ICT use due to its sensitivity to significant errors, which is particularly relevant for public policy applications. The data was divided into training (80 %) and testing (20 %) to ensure generalisation and avoid overfitting, ensuring both sets maintained the original proportion of demographic groups. In addition, normalisation was implemented with MinMaxScaler to stabilise model convergence and improve the representativeness of the variables. Regularisation techniques such as Dropout (0,2) were incorporated to prevent overfitting. The Adam optimiser dynamically adjusted the learning rate, improving model stability. In addition, EarlyStopping was used to interrupt training if validation loss stopped improving, ensuring a more accurate and efficient model. In addition, the adjusted R^2 (0,72) was reported, indicating that the model explains 72 % of the variance in ICT use, along with balanced accuracy (0,81) and F1-score (0,79) to evaluate performance in minority groups.

RESULTS

The comparative analysis between 2023 and 2024 helps to understand how ICT use has changed in Ecuador. When reviewing the data, certain significant advances are noted, although inequalities persist and new trends appear that are worth monitoring closely.

Evolution of participation in ICT-related activities

Participation in ICT-related activities has grown in all age groups (figure 1). Among young people aged 18 to 29, use rose by +1,7 percentage points from 62,6 % to 64,3 %, reflecting how digital platforms continue to be a key part of their daily lives, academically, socially, and at work.

The 30-49 age group also grew slightly by +1 percentage point, rising from 55,6 % to 56,6 %, mainly because ICTs have become essential for teleworking, continuing education, and online shopping.

For people aged 50 and over, the increase was +1,2 percentage points, from 37,3 % to 38,5 %. Although growth is slower, it reflects certain advances that could be linked to digital literacy programmes. Even so, obstacles, such as a lack of access to suitable devices or difficulties learning how to use them, cannot be ignored.

Young people and adults of working age are leading the way in ICT adoption, using them in their academic activities (distance learning), professional activities (teleworking, job searching), and social networking. Strategies need to be implemented to enable older adults to use digital technologies and thus reduce the technology gap.

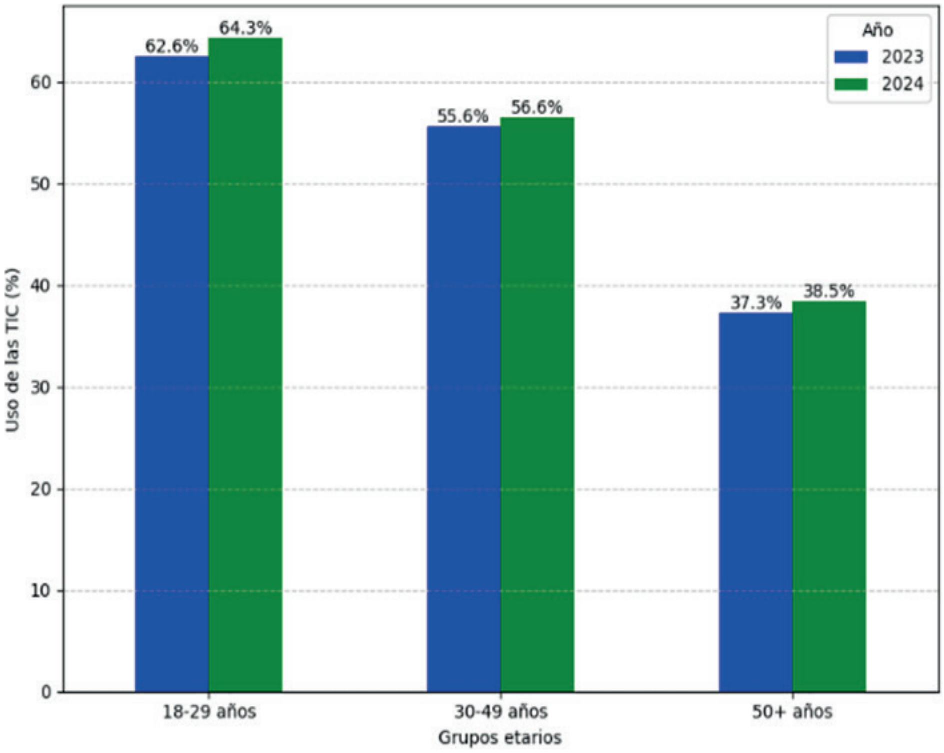

Figure 1. Evolution of ICT activities by age group (2023 vs. 2024)

Use of ICT by educational level

As seen (figure 2), there is widespread growth at almost all educational levels, although significant differences exist in using digital technologies.

The segment with no educational level showed a minimal increase of +0,5 percentage points, rising from 4,5 % to 5,0 %, confirming its technological lag; primary education, driven by digitisation programmes in schools after the COVID-19 pandemic, increased significantly, from 80,5 % to 82,5 %, while secondary education, driven by the use of digital technologies in schools, rose from 85,5 % to 87,5 %.

From 4,5 % to 5,0 %, confirming its technological lag; primary education, driven by digitisation programmes in schools after the COVID-19 pandemic and greater access to technological devices in homes, showed a more notable increase of +1,4 percentage points, from 29,1 % to 30,5 %.

Secondary education saw moderate growth of 0,8 percentage points (from 53,2 % to 54,0 %), confirming that technology adoption is already well established. This contrasts with higher education, which is the only level that recorded a slight decrease of 0,3 percentage points, from 73,6 % to 73,3 %, probably due to its proximity to saturation levels in the use of these technologies.

A positive correlation has been found between educational level and the adoption of digital technology. Although progress at basic levels is encouraging, low penetration among the unschooled population highlights the urgent need for digital inclusion policies. On the other hand, the slight decline observed in higher education requires further research to determine whether it is due to methodological factors or stagnation in adoption.

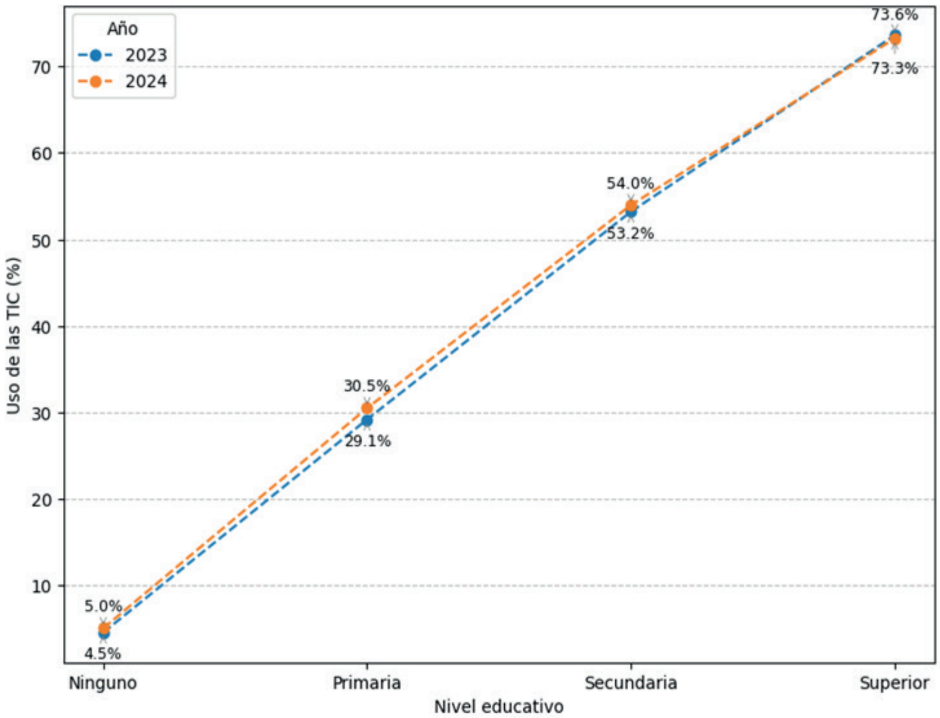

Figure 2. Relationship between educational level and ICT use

The box and whisker plot (figure 3) shows the dispersion of ICT use according to educational level, revealing greater variability at lower levels, especially in primary education and among those with no educational attainment, where there are significant differences in access to and use of technologies within each group. However, higher education distribution is more homogeneous, with values concentrated at higher use levels. The presence of outliers in primary education and among those with no schooling suggests that some individuals in these segments have achieved significant access to ICT, possibly through specific digital literacy programmes. The general trend confirms that educational level determines technology adoption, reinforcing the need for strategies that promote digital equity at lower academic levels.

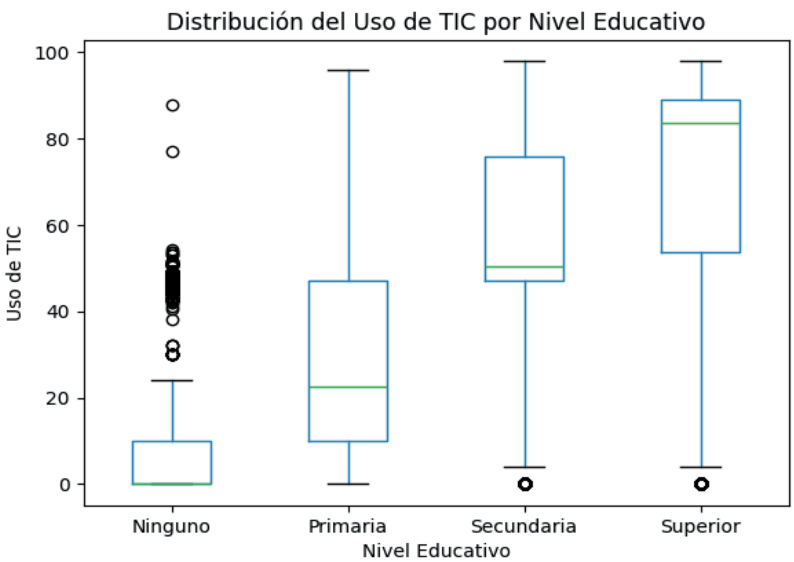

Figure 3. Distribution of ICT use by educational level

The ANOVA to evaluate ICT use among different educational levels showed an F statistic of 17 746,36 and a p-value of 0,0000, indicating highly significant differences between the groups. Since the p-value is less than 0,05, the null hypothesis 'There are no significant differences in ICT use between different educational levels' is rejected, confirming that educational level significantly influences ICT use. This conclusion is consistent with the box and whisker plot, which shows that individuals with higher educational levels have a more homogeneous distribution concentrated at high values of ICT use. In comparison, the dispersion is greater at lower levels, with outliers reflecting inequalities in access to and adoption of digital technologies.

ICT use by income level

Figure 4 shows the evolution of ICT use by income level between 2023 and 2024, showing a progressive increase in all economic segments, with more marked growth in the lower income sectors, where participation rose from 42,4 % to 44,1 % in the low-income group, reflecting an increase of 1,7 percentage points associated with digital inclusion programmes and access to more affordable devices, while in the middle-income group, ICT use increased by 1,2 percentage points, rising from 55,6 % to 56,8 %, driven by the expansion of digital tools in work and educational environments. In the high-income group, where ICT adoption is already high, growth was 0,9 percentage points, rising from 66,1 % to 67,0 %, suggesting that this segment has reached a phase of saturation in access to and use of technologies, confirming that although the digital divide is gradually narrowing, differences in access between different income levels remain significant, especially in lower-income sectors.

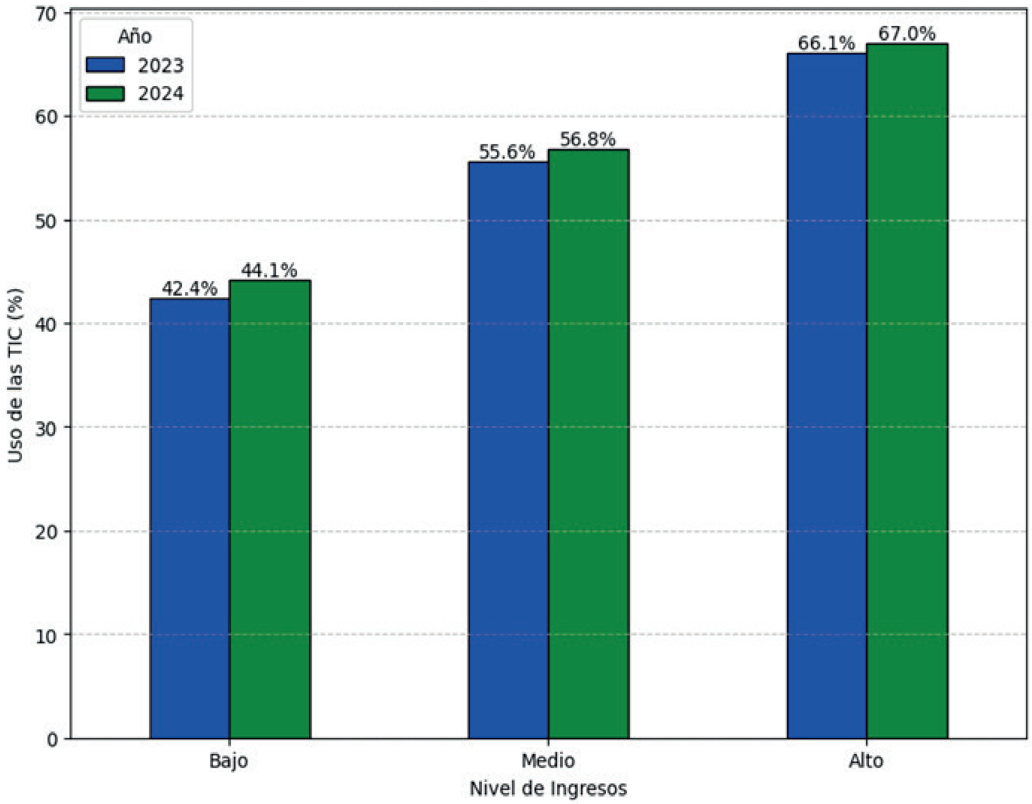

Figure 4. ICT usage by income level

Correlation analysis of sociodemographic variables with ICT use

Figure 4 shows the correlation matrix between various sociodemographic variables and ICT use, highlighting the relationship between structural factors and technology adoption, where the level of education shows the strongest positive correlation (0,69), indicating that as the level of education increases, the use of ICT intensifies, followed by the qualification obtained with a coefficient of 0,46, suggesting that achieving a higher academic degree significantly influences access to and use of digital tools. In contrast, per capita income shows a positive correlation of 0,19, reflecting that although income level influences ICT adoption, its impact is lower than that of educational level. In contrast, variables such as place of Internet use (-0,23) and different activities carried out on the Internet show weak negative correlations, suggesting that certain digital practices may be unrelated to general access to ICT. Furthermore, age (0,03) does not show a significant relationship with ICT use, indicating that, although technological adoption may be influenced by age, this effect is not as relevant as educational and economic level, confirming that access to education remains the main factor associated with digitalisation, surpassing the influence of age or income level, which reinforces the need for policies that prioritise digital literacy and the integration of ICT at different educational levels.

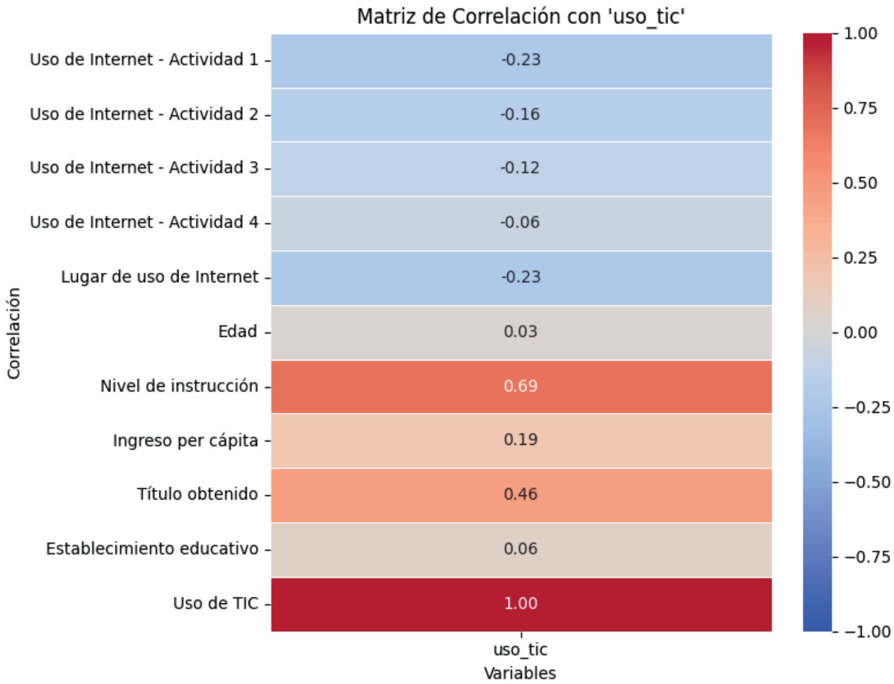

Figure 5. Correlations between key variables

Projected ICT use in 2027

Figure 5 shows the projected ICT use for the period 2025-2027, revealing a trend of continuous growth based on data from 2023 and 2024, which shows a progressive increase in the adoption of digital technologies, with a notable acceleration between 2024 and 2025, when ICT use rises from approximately 44,8 % to 46,8 %, reflecting more pronounced growth compared to previous years, followed by relative stabilisation from 2026 onwards, with a more moderate increase bringing the share to around 48 % in 2027, suggesting that digitisation will continue to expand, albeit at a slower pace as the market becomes saturated and the adoption of new technologies reaches maturity, highlighting the importance of strategic interventions to maintain the pace of growth and ensure that sectors with less access are not left behind in this digital transformation process.

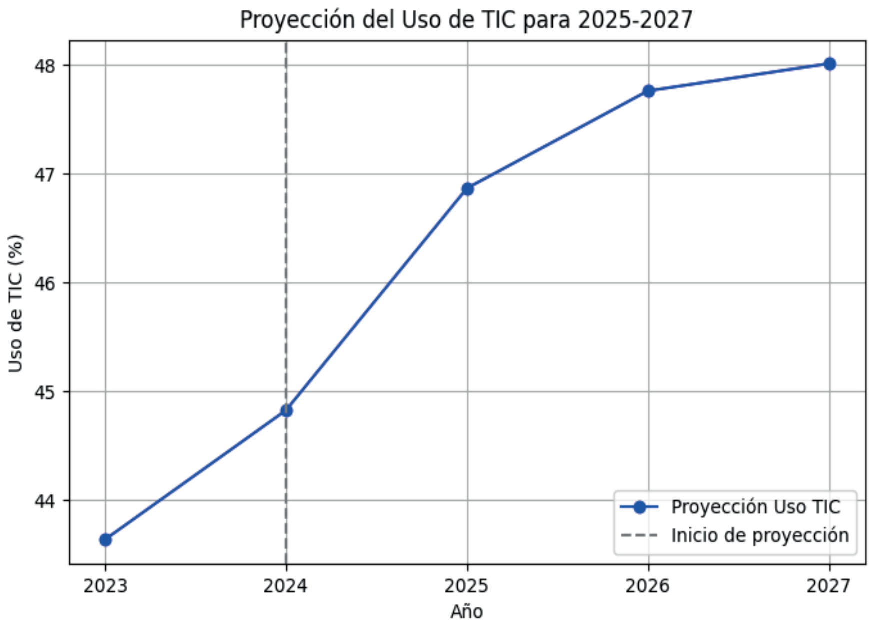

Figure 6. Projected advanced ICT usage by educational level (2023-2027)

DISCUSSION

The data analysed from the survey conducted by ENEMDU during 2023 and 2024 identified the progress and challenges that Ecuadorians have faced in using digital technologies. The comparison reveals that there has been progress in digital inclusion, although disparities related to socioeconomic, educational, and geographical situations have been observed.[23]

Secondary and university education levels have made progress in the use of ICT, as demonstrated by the results of this study and corroborated by the National Institute of Statistics and Census (INEC), which recorded an increase from 25,7 % in 2008 to 55,6 % in 2016 in internet use, which has been a fundamental pillar for the expansion of digital technologies in the Ecuadorian education system. Ecuador. This growth in the use of ICT could also be linked to government programmes such as the 2017-2021 National Development Plan, which promotes educational equity and emphasises the integration of ICT in teacher training so that they can use technology in their classrooms. It also refers to improving infrastructure, but as can be seen in the results of this study, primary education lags behind other levels of education in Ecuador.

Although primary school teachers are familiar with ICT, the effective integration of these digital technologies into classroom teaching practice remains limited. The main reason for this is students' lack of individual access to computers. This is confirmed by Martínez-Serrano, who indicates that only 40 % of students use ICT regularly in schoolwork, despite mastering basic digital activities. Berrett et al. point out that the mere availability of tools such as computers, laptops, tablets, etc., is no guarantee that they will be appropriately used, because it is necessary to provide early digital literacy training to students, with adequate teacher training and access to devices with internet connection, especially in rural and peri-urban areas, as emphasised by Matamala.[24,25]

Similarly, income level continues to be a determining factor in access to advanced ICTs in Ecuador. Low-income families, some of whom earn less than the minimum wage, have lower technology adoption rates, reflecting significant economic barriers. Nyika proposes the creation of rural sectoral networks to promote the use of digital technologies in disadvantaged communities.[26,27]

Geographical segmentation in Ecuador shows that urban areas are better positioned regarding access to and use of ICTs. In contrast, rural areas face significant gaps due to a lack of internet connection. Braesemann et al's suggestion to introduce online work platforms to integrate rural areas into the digital labour market and prevent migration to cities could be considered if they are provided with this technological tool.[28,29,30]

Older adults have shown modest progress in ICT adoption, as they are a group that faces barriers such as a lack of technological skills and restricted access to devices adapted to their needs. Gonzales et al. point out that older adults use mobile phones mainly to communicate with their families and as a therapeutic means of reducing loneliness. However, this does not fully meet their digital needs, as indicated by Park et al., who highlight the daily difficulties older adults face in interacting with modern technologies such as social networks, audio reading, etc. In Ecuador, strategies that include adapted technology training and simplified devices are needed to facilitate the inclusion of this group.[31,32,33]

The Random Forest machine learning algorithm facilitated the identification of patterns related to Ecuadorians' educational level and income. This algorithm is also used in international studies, such as the work of Satria et al. in East Java province, Indonesia, which highlights the need for public policies that prioritise digital literacy in vulnerable groups.[34]

Estimates up to 2027 suggest that the digital divide in Ecuador will narrow if government intervention in the most vulnerable sectors is strengthened through digital literacy policies starting in primary education, prioritising rural and peri-urban areas to ensure early access to basic digital skills. Strengthening technological infrastructure through subsidies for devices and connectivity is also essential, especially in rural regions with limited access. In addition, awareness campaigns can be developed for young people and adults on the responsible and ethical use of ICTs, promoting their application in education, work, and social development. Furthermore, public-private collaboration is essential to ensure the sustainability and scalability of digital inclusion programmes.[35,36]

The experience of other countries offers valuable lessons that can be adapted to the Ecuadorian context to improve digital inclusion. Some notable strategies include: the Malaysia Netbook programme, which distributed more than 1,5 million subsidised laptops to students from low-income families, reducing digital inequalities in rural areas and promoting the educational use of ICTs. A similar programme could focus on rural students and households in Ecuador to improve access to technological tools. Similarly, BharatNet in India connected 250,000 rural villages to high-speed internet, enhancing access to digital services in marginalised communities. Expanding internet access in Ecuador through collaboration with local operators and expanding public networks could replicate this model significantly. Estonia uses big data and artificial intelligence to monitor the impact of its digital inclusion policies, allowing for real-time strategic adjustments. Ecuador could implement a similar system to continuously evaluate progress in digital inclusion and adjust interventions according to emerging needs.[37,38]

The German Digital Pioneers programme trains workers to use advanced digital tools and recognised certifications, improving their employment opportunities in education. In Ecuador, a similar initiative could focus on sectors such as e-commerce and teleworking, areas of high demand in the digital market. The Spanish programme Mayores Conectados teaches older adults basic and advanced digital skills, offering ongoing technical support and adapted devices. Developing similar programmes in Ecuador could facilitate the inclusion of this group in educational and social activities. Furthermore, eLimu in Kenya offers interactive digital educational content in multiple languages for rural communities, improving access to education in marginalised contexts. A similar platform in Ecuador could address rural populations' cultural and linguistic needs. Finally, Plan Ceibal in Uruguay implemented educational campaigns on the use of ICT, benefiting both rural and urban communities. Ecuador could design similar strategies to increase knowledge and responsible use of ICT among its citizens.[39]

CONCLUSIONS

There is sustained growth in ICT adoption when comparing 2023 with 2024 and projecting to 2027, indicating a favourable trend for the use of digital technologies. Although digitisation will continue to expand, the data suggest that growth will be more pronounced at levels with greater access to infrastructure and technological training, while progress will be slower in sectors with lower levels of education and economic resources.

The main factor in ICT adoption is the level of education, with a positive correlation of 0,69. This correlation surpasses variables related to income and age in Ecuador, showing that there is greater adoption of digital technologies in higher education.

While the group with the highest level of education shows more widespread use of ICT due to the availability of resources and better access to infrastructure, primary and secondary levels still face barriers that limit their digital integration, including a lack of devices and teacher training. Older adults show more moderate progress, reflecting the need for specific strategies to improve their digital inclusion.

Lower-income sectors are seeing an increase in ICT adoption. Still, a lack of computer education and access to the latest devices makes it difficult for them to efficiently use the various applications that could help them in their work or find better employment opportunities.

The results suggest that, although digitisation will continue to increase, the pace of growth will slow down from 2026 onwards, highlighting the importance of sustainable government policies that promote the expansion of digital access without creating exclusion.

Using neural network models, growth and technological saturation dynamics were identified, demonstrating their ability to model complex temporal patterns and generate reliable projections, enabling efficient ENEMDU data management.

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CONFLICT OF INTEREST

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