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EDITORIAL

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Bienvenidos al Volumen 12, Número 1 de la revista *Latin-American Journal of Computing (LAJC).*

Me complace presentarles esta última edición, que reúne ocho artículos de investigación de alta calidad que abordan algunos de los desafíos más apremiantes en los campos de la computación y la tecnología. Estos estudios destacan la innovación y dedicación de investigadores comprometidos con el avance del conocimiento y la resolución de problemas del mundo real.

Este número cubre una amplia gama de temas relevantes y oportunos, que incluyen monitoreo ambiental, visualización de datos, revisiones sistemáticas, sistemas de energía renovable, arquitecturas de microservicios y soluciones para ciudades inteligentes. Cada artículo ofrece ideas valiosas y aplicaciones prácticas, reflejando la misión de la revista de fomentar investigaciones rigurosas y con impacto.

Entre las contribuciones de este número, los lectores encontrarán:

- Un innovador **sistema inalámbrico de geolocalización** diseñado para monitorear y reducir la contaminación en áreas urbanas.
- Un **marco sistemático de visualización de datos,** orientado a apoyar la toma de decisiones estratégicas en el comercio global.
- Perspectivas sobre los **mecanismos de defensa contra ataques de enrutamiento** en redes del Internet de las Cosas (IoT).
- Una **herramienta web fácil de usar para el dimensionamiento de sistemas fotovoltaicos**, alineada con los objetivos de energía renovable de Ecuador.
- Revisiones exhaustivas y metodologías que fomentan la **adopción de la computación en la nube, protección a los usuarios móviles y optimización de la gestión del tráfico urbano.**

Estas contribuciones subrayan la importancia de la colaboración interdisciplinaria para abordar problemas sociales complejos, tanto en América Latina como a nivel global.

En nombre del comité editorial, deseo expresar mi gratitud a todos los autores, revisores y al equipo editorial, cuya dedicación hace posible esta edición. Seguimos comprometidos en apoyar a nuestros colaboradores y lectores, brindando una plataforma para compartir investigaciones de vanguardia y fomentar la colaboración académica.

Esperamos que este número inspire nuevas innovaciones y conversaciones significativas dentro de la comunidad de la computación.

Gabriela Suntaxi

Editora en Jefe

Welcome to Volume 12, Issue 1 of the *Latin-American Journal of Computing (LAJC).*

It is a privilege to introduce this latest edition, which brings together eight high-quality research articles addressing some of the most pressing challenges in the fields of computing and technology. These studies showcase the innovation and dedication of researchers committed to advancing knowledge and tackling real-world problems.

This issue covers a diverse range of relevant and timely topics, including environmental monitoring, data visualization, systematic reviews, renewable energy systems, microservices architecture, and smart city solutions. Each article offers valuable insights and practical applications, reflecting the journal's mission to foster impactful and rigorous research.

Among the contributions of this issue, readers will find:

- An **innovative wireless geolocation system** designed to monitor and reduce pollution in urban areas.
- A **systematic data visualization framework** tailored to support strategic decision-making in global trade.
- Insights into **routing attack defense mechanisms** for Internet of Things (IoT) networks.
- A **user-friendly web-based tool for sizing photovoltaic systems** aligned with Ecuador's renewable energy targets.
- Comprehensive reviews and methodologies that enhance **cloud computing adoption, protect mobile users, and streamline urban traffic management.**

These contributions emphasize the significance of interdisciplinary collaboration in addressing complex societal issues, both in Latin America and on a global scale.

On behalf of the editorial committee, I want to extend my gratitude to all authors, reviewers, and the editorial team whose dedication makes this issue possible. We remain committed to supporting our contributors and readers by providing a platform for sharing cutting-edge research and fostering academic collaboration.

We hope this issue inspires further innovations and meaningful conversations within the computing community.

Gabriela Suntaxi

Editor-in-Chief

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We are most grateful to the following individuals for their time and commitment to review manuscripts for the Latin American Journal of Computing – LAJC

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Data Visualization Model for Multi-party Analysis and Strategic Decision-Making in International Trade

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***Abstract*—**This paper presents a detailed analysis of Ecuador's non-oil exports over ten years. The study was performed using the SPEM methodology and data-cleaning processes. The results highlight a notable coherence in analyzing the most relevant export items and the main trading partners, providing essential information for strategic decision-making. Furthermore, recommendations related to the technical conditions necessary to achieve precise and accurate communication through data visualization were considered, and adequate answers to the questions generated in the business knowledge stage contributed to the users' knowledge. Furthermore, the study suggests incorporating import data to enhance the analysis and provide a foundation for future research in this area.

Keywords: *data integrity; multi-party analysis, international trade, strategic decision-making, tableau*

I. Introduction

In the current era, analyzing large volumes of data is crucial for making informed decisions in various sectors, including foreign trade. Data visualization emerges as a powerful tool for converting complex information into understandable graphical representations, allowing patterns, trends, and areas for improvement to be identified.

Sosa [1] highlights the usefulness of data visualization in understanding the evolution of the export sector in countries such as Ecuador, where the economy depends mainly on exporting primary products. This tool allows us to explore changes in export patterns over time, identify the main product categories and destination countries, and evaluate the effectiveness of export policies and strategies.

Traditional analyses of the export sector often focus on a single product or category, limiting the possibility of comprehensive comparisons and evaluations. In conjunction with data mining techniques such as those proposed by Kirk [2], data visualization allows us to overcome these limitations.

The present work proposes a visualization model that uses data visualization and data mining to provide diverse users with convincing, clear, and attractive results. This model is based on cleaning, consolidating, summarizing, and presenting large amounts of Ecuadorian export data using data mining techniques and visualization tools to improve decision-making in the export sector.

This approach is evident in several publications, such as Araque & Arguello [3], Tercero et al. [4], and Tonon Ordóñez et al. [5] who have analyzed cocoa, copper, and banana, respectively. However, this unitary approach uses extensive data visualization tools and data mining and cleaning techniques. The potential benefit of this research is that it simplifies the use of data, aiding end users and businesses to make more informed decisions through enhanced data visualization. With these tools, it is possible to interact with them and extract valuable information without the need to restart from the data preparation phase for each product or item [6], [7]. This can save significant time and effort and allow the user to perform benchmarking and evaluations more efficiently and effectively.

The work methodology is represented by Systems Process Engineering Metamodel 2.0 (SPEM 2.0). The process was performed in four steps: data preprocessing, labeling and inclusion of valuable fields for the analysis, application of the visualization model, and finally, the validation of the model. The items analyses are denominated by the Harmonized System, as recommended in the United Nations Department of Economic and Social Affairs [8] report, since comparability of information between countries is allowed.

This article is structured as follows: Section II contains the related works that influenced this research. Section III describes the methodology and theoretical framework used in this research. Then, Section IV presents the results that were obtained in the study. Likewise, Section V presents the discussions regarding similar works and our contribution, and finally, Section VI presents the conclusions of this research.

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II. Related work

Throughout history, many people have contributed to the development of data visualization. Thus, some of the pioneers in data analysis are presented, such as William Playfair, who was the first to use graphs to represent economic data, contributing to the popularization of bar, line, and sector graphs [9]. In the 1850s, Florence Nightingale (1820-1910) shared her professional vision as a nurse using data visualization techniques to show the importance of sanitary conditions in the care of soldiers during the Crimean War [10]. At the end of the 19th century, Karl Pearson (1857-1936) introduced the concept of correlation coefficient, which measures the relationship between two variables. Pearson also pioneered statistical techniques in genetics and created the chi-square test [11]. Ronald Fisher (1890-1962) is the father of modern statistics. In the 1920s, Fisher developed statistical techniques for data analysis in genetics and biology and was one of the first to use the maximum likelihood method to estimate parameters [12]. John Tukey (1915-2000) was one of the first to use data visualization for exploratory analysis, creating techniques such as the box-and-whisker plot and the matrix scatterplot [13]. Another pioneer was Jaque Bertin (1918-2010), who, using computers, produced the publication Semiologie Graphique, which showed the link between data and its visual function, the science of graphical representation of data, and the basis for visual data analysis [12].

Concerning the visualization of foreign trade data, there are interpretations from several decades ago, focusing on the graphical representation of economic data through graphs and maps, such as "The Atlas of United States Exports," published by the United States Department of Commerce. A wide range of data on United States exports was presented as maps, graphs, and tables with that Atlas. The data were presented by country and sector, which allows the identification of foreign trade trends and patterns. Another graphical representation is "Comtrade Data Visualization", an international trade database managed by the United Nations. This data visualization tool allows users to explore global trade by country and product. The visualization uses interactive charts and maps to show trade trends and exchange patterns [8]. Finally, TradeMap is a data visualization tool developed by the European Commission that allows users to explore international trade between the European Union and other countries. The tool uses interactive graphs, charts, and maps to show trading trends and patterns [14]. These findings underscore the importance of data visualization as a fundamental component in understanding trade data.

Over the past years, we have witnessed a transformative leap in data visualization technology. This leap has allowed the development of more sophisticated and practical data analysis and interpretation tools, expanding new horizons for researchers and professionals [15]. Data visualization tools are not just about visual appeal but practicality and functionality. They allow exploration in different dimensions and the visualization of complex patterns and relationships that would be difficult to detect otherwise. Several studies, such as that by Skender & Manevska [16], note in their review that various tools exist for visualization and visual data analysis. New techniques and approaches, such as K-means cluster, Gravity Equation, and 3D data visualization, have practical applications in analyzing trade and economic data [17]. These new options have allowed greater flexibility and creativity in data presentation and analysis [18] and led to valuable insights and recommendations.

Regarding data visualization research, there is a plethora of scientific literature available in the field, including theoretical, applied, and evaluation studies of visualization tools. Durán, J. & Zaclicever, D. [18] used the grouping of countries by region with trade agreements: Andean Community of Nations (CAN), Caribbean Community (CARICOM), Southern Common Market (MERCOSUR), Central American Common Market (CACM) and analyzed the amounts of regional exports. In the study by Tercero et al. [4], copper trade flows between countries were examined, generating representations on maps and direction arrows, where the thickness of the lines was used to identify the transaction amounts and the grouping of countries by region, which quickly detected the movement between origin and destination.

In the work of Morrison et al. [14], the health of a country's economy was measured based on the number of exported items; they analyzed the complexity of the products produced and described complex economic systems with networks connected by points whose central location denotes importance. The non-linear iterative evaluation of complexity was described as a specialized process and very susceptible to the variation in the number of games studied and data cleaning. Finally, the recommendation does not analyze tariff items at a four-digit level but at six for greater detail. Straka et al. [19] obtained an algorithm that allows for the measurement of the similarities between export products and the level of technological advance of the countries through the bipartite representation of the International Trade network, using the calculation of the entropy and projective models. They exported information from 1995 to 2010, identifying country communities with color keys on a world map and analyzing specific sections of years to validate their estimates. Dong et al. [20] studied global wheat consumption, verifying the influence of climate patterns in each region studied. The information came from the United Nations database, and they segmented the countries as protagonists and peripherals concerning world trade. They used bar graphs, choropleth maps, and line graphs. They recommended studying the other variables not considered, such as oil price, water availability, and socio-political conditions.

Dar et al. [21] made visualizations and an estimate of the commercial profile of the South Korean economy based on the growth that its products have in the world market to serve as a guide in the policies and business decisions made by the government. They found a positive evolution in their trade relationship with other Asian countries. They recommended viewing the country's trade profile for a greater understanding of trade, as it can provide detailed and easily accessible information, which allows precise estimates to be made. In the context of analyzing bilateral trade data involving more than two hundred countries, together with China, Ye et al. [23] proposed a geospatial analysis methodology known as the Digital Trade Feature Map (DTFM). This methodology offers a broad and detailed vision for analyzing the characteristics of specific products and their relationships with other products. The authors used the import and export values in Cartesian coordinates to implement this approach. Then, they calculated the differences between these values and plotted them as a line on a Cartesian plane. Subsequently, they evaluated the volume

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of commercial exchange and its range-size distribution based on the criterion of transaction amount versus frequency. In this way, they identified rare or high-trade products located at the top of the distribution and low-trade or repetitive products at the bottom. The authors concluded that the DTFM method is a valuable tool for analyzing trade trends, especially when information on imports and exports is available. This approach is a fundamental preliminary step before the statistical data analysis, providing a solid and meaningful perspective. Qaiser et al. [22] measured South Korea's economic complexity index, using time series to identify patterns and make trade estimates. They considered that the visualization and forecasting of imports, exports, Gross Domestic Product (GDP), and GDP per capita benefit international trade. The analysis, visualization, and forecasting of global trade must be determined in an increasingly detailed and precise manner. They managed to identify the main trading partners and make estimates of the country's imports and exports, establishing a positive correlation with GDP and GDP per capita. In other studies, such as that of Kim et al. [23], considering several fundamental aspects when designing data visualizations is essential. This includes knowing the type of user, the specific objectives of the visualization, and the size of the device on which the information is presented so that the appropriate tools are used to display the content without distortion, avoid loss of meaning, and optimize the user's interaction experience. For this purpose, they validated 378 pairs of visualizations from various sources and data. They defined 76 characterizations that align with the specific objectives sought with visualization to satisfy the users' needs and expectations.

According to Wu et al. [26], the world economy is becoming more interconnected, and there is a growing need to understand industry trends better. For this reason, Wu et al. introduced VIEA, a web-based system with various views and interactive features. VIEA lets us know the critical economic trends, where those issues are produced, trade patterns, and the economic comparison between industries. Medina López et al. [17] studied about Ecuadorian exports to create a knowledge base for trade specialists. To achieve this, a data visualization tool examines data from 2008 to 2018. The well-established CRoss Industry Standard Process for Data Mining (CRISP-DM) method for data mining projects was used as a foundation. This method involves five steps adapted to develop the mining and visualization model. The result is an interactive tool that allows users to explore key trade variables for Ecuador. This user-friendly interface makes it easier to analyze exports and ultimately supports informed decision-making in foreign trade.

According to Ren, D. [24], the Tableau Desktop software was recognized as configurable in the form of shelves due to its referent types of representations that obey the creation of different internal rules of the program and allow the combination of several attributes on the same screen. It has multiple representations for the measurements and dimensions of the data. It was also indicated that the flexibility for creating graphs is limited by the control at a high level of granularity of the data and the need for more options to combine different screens.

III. Materials and Methods

In the methodological process, the SPEM 2.0 approach methodology effectively represented each stage of the data analysis process. The methodology was divided into four consecutive steps, as shown in Fig. 1.

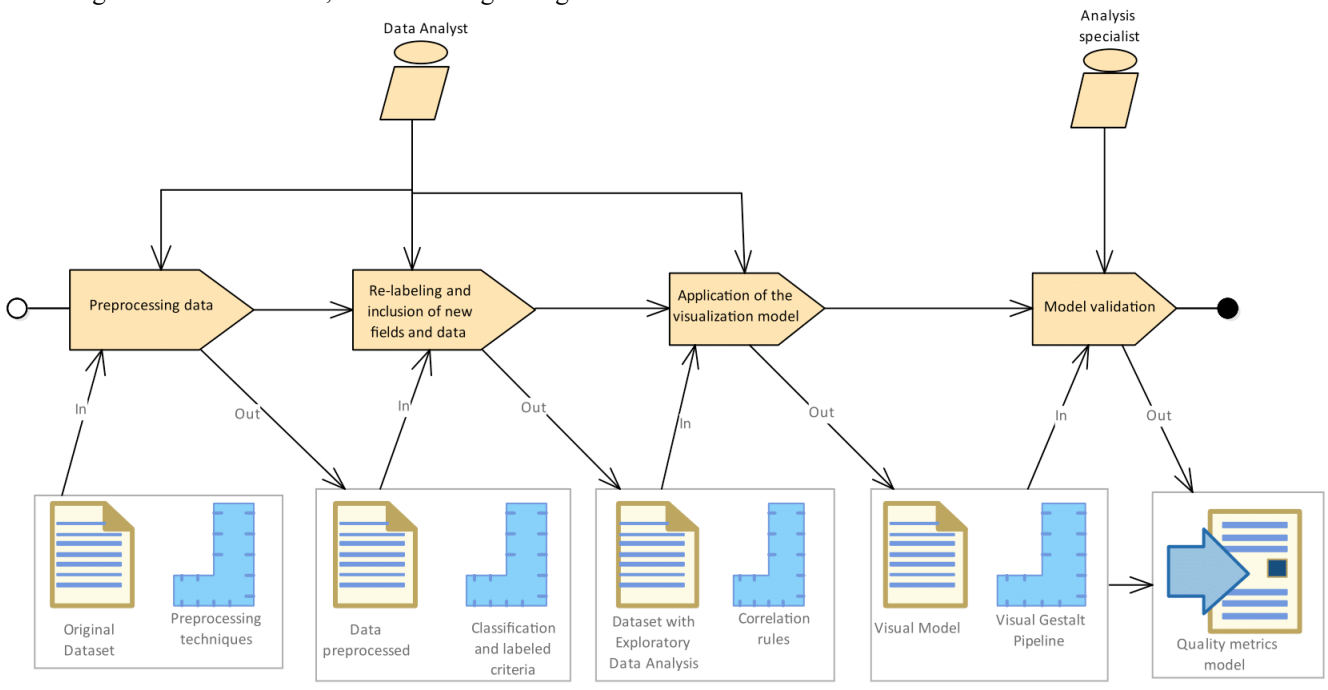

Fig. 1. The methodology used in the research

Thus, according to Fig. 1, the execution responsibilities are established in different methodology stages: the data analyst is responsible for the execution from steps 1 to 3, and the analysis specialist is accountable for the last step. The dataset of this study is obtained from the Central Bank of Ecuador, corresponding to the annualized export records performed between 2008 and 2018.

This data added the name of the receiving country, the International Organization for Standardization (ISO) Code, and values exported as Free on Board (FOB) and Metric Tons

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(MT). Computer Science Research & Development Laboratory (LIDI) researchers preprocessed the data set provided at the University of Azuay. These researchers included columns with information on Population GDP, GDP per capita [25], distance to Ecuador from other countries, and force of attraction [17], [26].

The columns of the dataset have the following characteristics.

- Number of variables: 40
- Data set type: static
- Categorical: 19
- Numerical: 21
- Number of observations: 318,629
- Missing cells: 860,207
- Dataset size: 39.1 MB

A. Data preprocessing

In this initial phase, cleaning and transformation tasks were performed on the original data set in Comma Separated Values (CSV) format to ensure quality and consistency. This included standardizing formats and correcting missing data. The process started with identifying the data types present in the initial set, including specific data types. A detailed description of each type can be found in Table I.

TABLE I. DATASET DESCRIPTION

Field name	Description	Type of variables
Exp_region	Container name	Categorical
Exp_Cou_iso 3	Export country code (3-digit ISO format)	Categorical
Cou_Name_e sp	Export destination country name (Spanish)	Categorical
Exp_Year	Export year	Real
Pbi_Value	GDP value of export year	Real
Pop_Value	Population in export year	Real
Pbi_Percap_ Value	GDP per capita value in export year	Real
Pbi_Ecu_Val ue	Ecuador's GDP value in export year	Real
Exp_Subpnan	NANDINA subheading of export	Integer
Exp_Descnan	NANDINA description of export	Categorical
Exp_Ton	Quantity of tons exported	Real
Exp_Fob	FOB value in millions of dollars	Real
Par_code	Current heading code	Integer
Par_code_Na n	Heading code according to NANDINA codification	Integer
Par_code_Ec u	Local heading code (Ecuador)	Integer
Par_Desc	Local heading description (Ecuador)	Categorical
Par_Desc_Co mplete	Complete heading description up to the las level	Categorical
Par_Uf	Tariff heading unit measure	Categorical
Par_Section	Section code where heading belongs	Integer
Par_Section_ Desc	Description of section where heading belongs	Categorical
Par_Cod_Lvl 1	Tariff heading level 1 code	Integer
Par_Desc_L1	Tariff heading level 1 description	Categorical
Par_Cod_Lvl 2	Tariff heading level 2 code	Integer
Par_Desc_L2	Tariff heading level 2 description	Categorical
Par_Cod_Lvl 3	Tariff heading level 3 code	Integer
Par_Desc_L3	Tariff heading level 3 description	Categorical
Par_Level	Level of detail to which heading belongs	Integer

This step was performed with the Tableau Prep Builder tool; the changes applied sought to adjust to the requirements of the data analyst and the program that was subsequently used in the visualization stage [27]. The pre-processing stages were i) renaming headers and cleaning fields, ii) changing the type of fields, iii) cleaning and trimming fields, and iv) filling empty fields.

B. Re-labeling and inclusion of new fields and data

At this stage, Tableau Desktop was used to load and prepare the data for visualization. Previous adjustments were made, including the geographic coordinates of the four countries mentioned in Table II. This table details countries whose location was not automatically recognized by the software and was manually populated with relevant geographic information.

TABLE II. RE-LABELING AND FIELD INCLUSION

Country	Initial Value	Final Value
Bermudas Islands	N/A	Lat. 32.33 Long. -64.75
United States Minor Outlying Islands	N/A	Lat. 5.875 Long. -162.057
United State Virgin Islands	N/A	Lat. 18.33 Long. -64.8963
Trans-boundary waters	N/A	Data from this location is filtered because its physical location cannot be determined.

It is essential to clarify that we applied a filter to exclude data corresponding to the location of international waters or Transboundary waters during the initial data load. This decision was based on the challenge of pinpointing a fixed geographical point for its representation on the map. Additionally, crucial information such as population, GDP, and other valuable data were unavailable for this location visualization.

Table III details the calculation formulas used to create additional fields, such as the Average Price, MT, and the Number of Items. These formulas allowed us to answer critical questions through descriptive statistical analysis, such as: How much does each country sell? What products are sold? With which country are the most transactions performed?

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Additionally, given that the analysis focused on Ecuador's nonoil exports, answers were sought to the following questions: How much does each country buy? What products does it buy? With which country are most transactions performed? These questions are aligned with the recommendations of the World Trade Organization in its publication "A Practical Guide to Trade Policy Analysis".

TABLE III. FORMULAS CALCULATION

Field name	Tableau Formulas
Average Price MT	[Millones de USD/FOB]/[TM]
Exported tariff headings	COUNTD([Par Codigo Nan])
Annual change	SUM([TM]) / TOTAL(SUM([TM]))
MT Variation	ZN(SUM([TM])) - LOOKUP(ZN(SUM([TM])), -1)) / ABS(LOOKUP(ZN(SUM([TM])), -1))
USD/FOB Variation	ZN(SUM([Millones de USD/FOB])) - LOOKUP(ZN(SUM([Millones de USD/FOB])), -1)) / ABS(LOOKUP(ZN(SUM([Millones de USD/FOB])), -1)

C. *Application of the visualization model*

In this stage, the visualization model was designed to represent the data in an understandable and compelling format based on Gestalt visualization principles, establishing an appropriate pipeline (route) [28]. Various visualization techniques, such as graphs, charts, and interactive dashboards, were used to communicate the patterns and trends identified in the data [29]. Thus, the available data were considered as viewable.

As we can observe, Table IV details the fields and elements represented in the visualization, detailing the purpose pursued by each view.

1) *Interactions*

The interactions added to the visualization aim to facilitate the users' journey through the designed environment. Table V specifies the interactions included in the representation and their usefulness for the user, considering the visualization principles.

D. *Model validation*

The expert on the subject verified the results shown by the applied model provided, and adequate answers to the questions generated in the business knowledge stage contributed to the users' knowledge. For that, Munzner [10] considers four levels of validation:

- Mastery of the situation
- Use of correct terminology
- Review understanding of the problem to be solved
- Try answering basic questions

The subsections detailed below are the types of validation necessary to apply during testing a visualization model, preferably during user interviews so that it contributes to the area of knowledge.

1) *Data abstraction*

In this context, the need to evaluate the listed approaches is emphasized, which helps to improve clarity and effectiveness in data management in analysis and presentation.

- Compare with existing reports.
- Have an alternative scenario.
- Evaluate other visualizations.
- Check simplicity.

TABLE IV. APPLICATION OF THE VISUALIZATION MODEL I

Field name	Data Type	Applied Visualization	Represented Element	Objective
Continent/Country	Geographical (GIS)	Map	Surface	Spatial Positioning
Millons od USB/FOB	Numeric	Circle size Bar size Rectangle area	Marks	Comparison
MT	Numeric	Bar size Rectangle area	Marks	Comparison
Year	Date	Line	Marks	Order
Continent	Geographical (GIS)	Map Region area	Surface Region	Spatial Positioning
Section	Numeric	Circle size	Marks	Comparison
Section name	Text	Data size	Structured list	Order Group
International Subheading codes	Numeric	Textual representation in 6 digits	Structured list	Comparison
Chapter description	Text	Data table	Structured list	Order Group
Regional Subheading codes	Numeric	Textual representation in 8 digits	Structured list	Comparison
Regional Subheading description	Text	Data table	Structured list	Order Group

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TABLE V. APPLICATION OF THE MODEL VIEW II PATTERN

Sheet name	Applied Visualization	Applied Interaction	Function
Overview	Annual evolution of exports by continent	Continent filter	Filtering of other views
	Export by section	Click on named circular area	Filtering of other views
	World map	Slider to select year for display, reproducible for the entire period	Display by country of exported values in Dollars
	Top trading partners	Click on rectangular area	Filtering of other views
By tariff items	Price comparison by continent and section	Click on Section, Discount Tariff item N1, Item description N2	Filtering of other views on the sheet
		Sliding bar to select the name of the section to display	Filtering of other views
	Top 10 trading partners by item, sub-item N1 and N2	Click on horizontal bar	Filtering of other views
Annual change	Year-over-Year Evolution of Main Trading Partners	Sliding chart to select the year for comparison	Filtering from other views
		Click on horizontal bar, Country code	Filtering from other views
	Volume of traded tariff lines	Click on the continent name	Filter from own view
	Exports by section	Click on the section name	Greater detail Level 1 and Level 2, Section Code, Value in sales dollars in pre-filtered period.

The subsections detailed below are the types of validation necessary to apply during testing a visualization model, preferably during user interviews so that it contributes to the area of knowledge.

2) Visual coding, functional interactions

These three elements combine to improve the user experience in exploring and understanding data through a visual interface.

- Validate manipulability
- Interaction validity
- Validity response to actions

3) Algorithmics Implementation

It ensures that operations and algorithms are efficient and fast in providing results in real time or with acceptable response times. They ensured that the software complies with usage licenses and that visualizations were available for seamless integration into the workflow. This is essential to maintain effectiveness in implementing data processing and visualization systems. Thus, these aspects are fundamental to guarantee efficient and legal operation in algorithm and data management.

- Validate response speed (Software or own code).
- Validate access to licenses and views.

IV. RESULTS

Following the research objectives, the results of the data analysis process are presented. The development was performed with Tableau software, which provides significant details in visual analysis.

A. Prepared dataset to be analyzed with tools display

Each variable was analyzed in case of missing data to prepare the dataset and reach a correct analysis. Depending on the data type, different methods were used to clean the data to reduce the noise and inconsistencies found in the dataset. The number of records prepared for the analysis in Tableau was 318,629.

B. Model visualization of the export evolution

Based on the data prepared for Tableau software, it includes the graphs corresponding to the inter-annual variation of export amounts of Ecuador in millions of dollars and tons between 2008 and 2018 in non-oil items. As we can observe in Fig. 2, the most representative years in positive variation from the point of view of the tons exported were 2011 and 2014, having their counterpart in the years 2010 and 2012 in terms of millions of dollars/FOB. The years with the most significant positive variation were 2010, 2011, and 2014. However, the years that represented negative percentages were 2009, 2015, and 2016.

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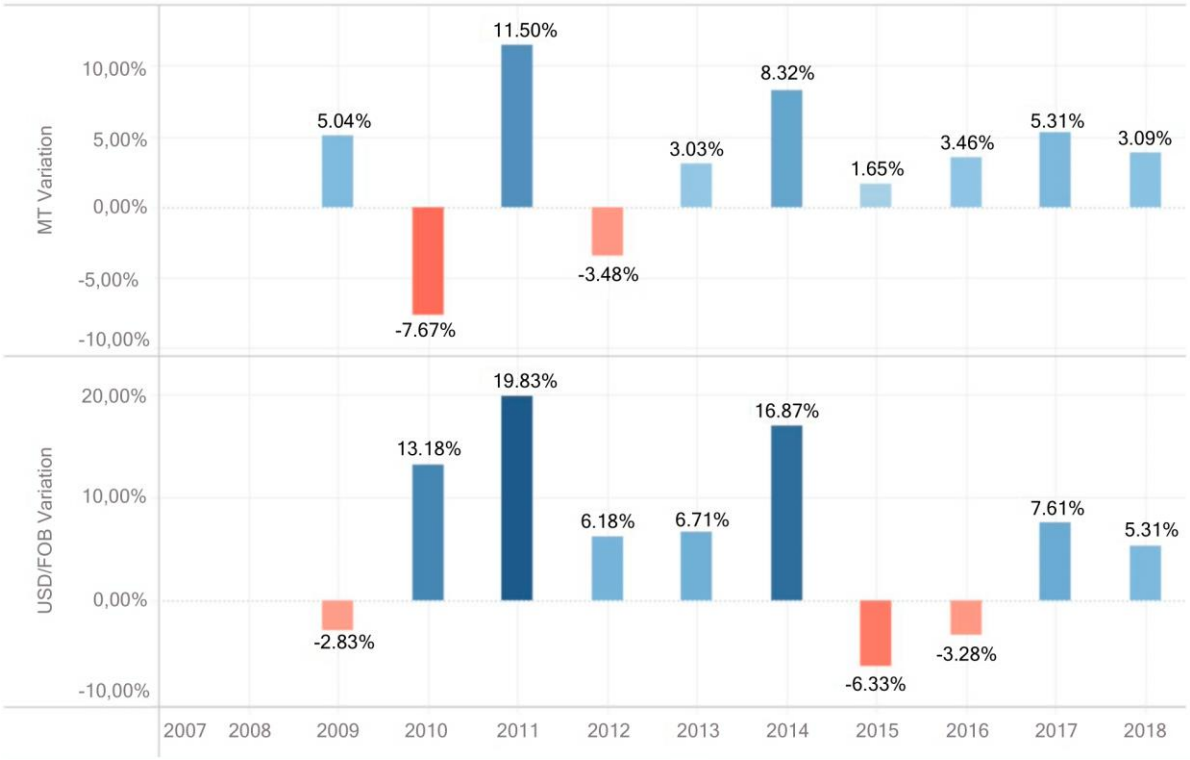

Fig. 2. Annual Variation of Exported Amounts (2008-2018)

Table VI contains information on the percentage of annual participation of each continent in total non-oil exports between 2008 and 2018. America has had the highest average percent participation throughout the years. Years show a decreasing trend from 50.52 % to 42.72%.

Over the same period, Europe has shown a significant level of participation, albeit with a decreasing trend. This is particularly noticeable as it transitions from 44.46% in 2008 to 38.08% in 2018. In other words, it has been a region of accelerated growth since 2012, increasing its share from 8.10 % to 18.90 % of the total amount exported in millions of dollars/FOB for 2018.

TABLE VI. ANNUAL EVOLUTION OF NOPN-OIL EXPORTS IN SHARE PERCENTAGE BY CONTINENT IN MILLIONS USD/FOB

Year/ Continent	Africa	America	Asia	Australia Oceania	Europe
2008	0.11	50.52	4.62	0.29	44.46
2009	0.10	49.18	4.17	0.35	46.20
2010	0.12	49.23	5.27	0.43	44.95
2011	0.27	49.89	6.97	0.36	42.51
2012	0.40	52.05	8.10	0.34	39.11
2013	0.30	50.37	9.20	0.40	39.74
2014	0.25	52.75	10.30	0.37	36.34
2015	0.63	49.67	13.62	0.48	35.61
2016	0.30	47.78	13.25	0.52	38.15
2017	0.15	45.65	13.35	0.54	40.31
2018	0.12	42.42	18.90	0.48	38.08
$\bar{X}$	0.25%	49.05%	9.81 %	0.39%	40.50%

We can see in Fig. 3 that from 2008 to 2018, in exports to the five continents, America appears as the largest trading partner in terms of USD/FOB; in second place is Europe. Then there is Asia, while polygons with a smaller area represent the trade exchange with Africa and Oceania.

Suppose the same analysis is performed in terms of tons. In that case, Europe is the commercial destination with the most significant participation, followed by America and Asia, which shows growth, based on the graph drawn as areas in this historical record. The cumulative development of exports to the different continents, particularly in America, Europe, and Asia, is a promising sign for the global market. Commercial transactions with Africa and Oceania, on the other hand, are negligible.

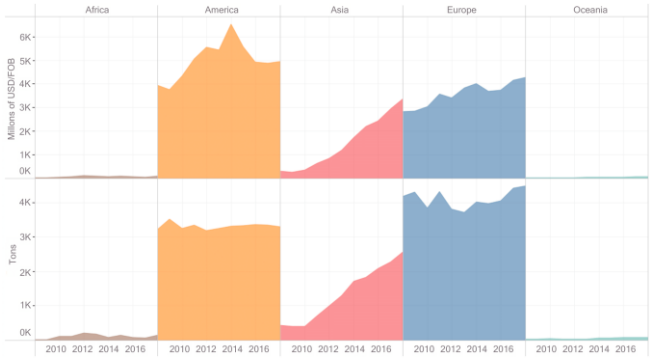

Fig. 3. Evaluation of Non-Oil Exports by Continent in USD/FOB and MT

America has a 49.21% participation in purchases in dollars, Europe occupies the second place with 35.23%, while with the reference Tons, Europe occupies the first place with 46.06 %, and America participates with 37.19 %. It can be understood that the countries located within these continents, including Ecuador, made the most outstanding exports in the

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period analyzed. Another critical analysis focused on the main trading partners, where the accumulated purchase amount of millions of USD/FOB and tons is analyzed between 2008 and 2018. The analysis highlights the participation in the purchases of the ten main trading partners of Ecuador, which in the Americas are the United States, Colombia, and Venezuela, while in Europe, Russia, Italy, Germany, the Netherlands, and Spain emerged, and finally in Asia, China, and Vietnam. As can be observed in Fig. 4, the geographical location of Ecuador's main trading partners is shown, where the size of the circle is the amount in millions of USD/FOB of exports made in 2018.

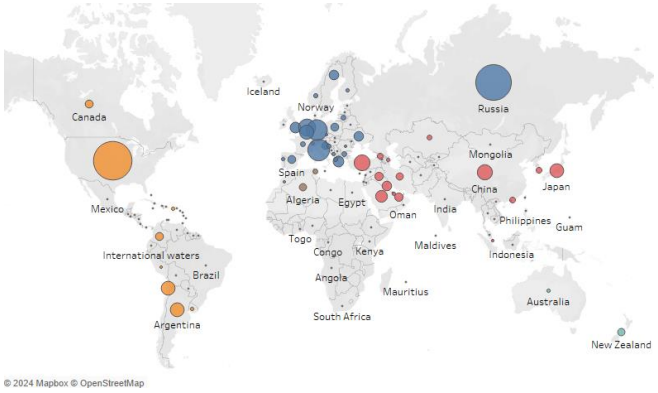

Fig. 4. Location and Identification of Main Commercial Partners in 2018

Fig. 5 indicates the percentage of participation in Ecuador's exports from 2008 and 2018 of the ten main trading partners, finding that the United States has a decrease both in millions of dollars since it changes from 31.23% to 29.38% and in tons, which ranges from 26.36% in 2008 to 22.87% in 2018. This decrease in percentage participation contrasts with what happens with countries on the Asian continent, where China and Vietnam have grown significantly. The first country goes from 0,87 % to 11.04 % and the second from 0.25 % to 13.99 % in millions of dollars; with this in the last year analyzed, they are already part of Ecuador's ten main commercial partners. Concerning Europe, the percentage variation in participation in total exports could be more notable, except for Italy and Spain, which shows a downward trend.

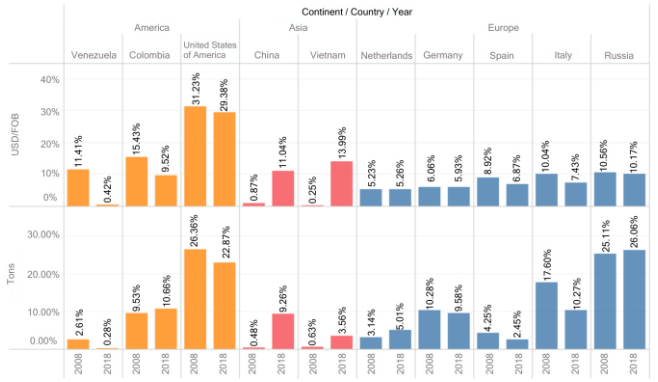

Fig. 5. Comparison of Importance in Total Exported 2008 vs 2018

The most exported products were detailed by ordering from the highest to the smallest sum of the accumulated purchase in terms of millions USD/FOB from 2008 to 2018, without applying country or item filters.

The most crucial section within exports is not Ecuadorian oil companies, but rather those products composed of the plant kingdom, followed by products from the food industries such as alcoholic liquids, vinegar, tobacco substitutes, beverages, tobacco, and tobacco manufacturers. In contrast, the smaller products are weapons, ammunition, and their parts and accessories.

Using a TreeMap in Fig. 6, the sections can be identified as most representative of the exports made by Ecuador. The amounts in millions of Dollars and tons are described in the same view, and a significant color code has been created for the rectangles, which can be associated with the data they represent.

Fig. 6. TreeMap by Exported Section

These are those tariff headings identified with a 6-digit coding, which come from the sections evidenced in the previous section and whose accumulated export amount in terms of Millions of USD/FOB between the years studied, placing them as the 15 most representative. In Fig. 7, we can note that code 080390 ("Edible fruits and nuts; citrus peels, melons or watermelons") comes to first place in the list, constituting 22% of the total, followed by 030617 ("Fish and crustaceans, mollusks, and other aquatic invertebrates") with 16% by weight, referring to the same amount.

The abstraction of the information is facilitated by using a bar graph in Fig. 7, which also provides a legend that includes color coding by years (recent blue, previous red). The existence of items that have not been traded in recent years can be noticed. Also, the total export amount is represented by the height of the bar.

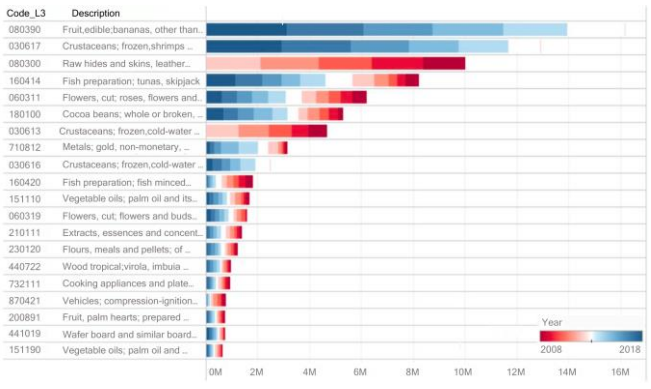

Fig. 7. Top 15 most essential tariff headings and contribution per accumulated year Millions of USD/FOB 2008-2018

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With the previously analyzed data, the need to develop a model of visualization of export data emerges, allowing the study of non-oil items marketed by Ecuador between 2008 and 2018. Figs. 8, 9, and 10 are included, where the analysis of one continent at a time is proposed to test the capacity of the model to provide the required information in consolidated views. Fig. 8 consolidates in quadrant I: the variation in importance in exports in Millions of USD/FOB and TM between 2008 and 2018 for the countries that belong to the American continent and are part of the top 10 partners. In quadrant II, the evolution of values exported throughout the period is evident in Ecuador's commercial sectors. Quadrant III shows the geographical location of each of the countries to which exports have been made, characterizing with the size of the circles the amount of their transactions in terms of Millions of USD/FOB. Finally, in quadrant IV, a tree graph identifies the sections and the number of exports in that year in Millions of USD/FOB and Tons.

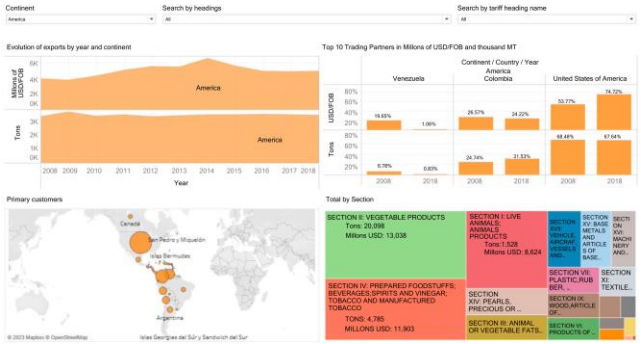

Fig. 8. Overview – America Case

Fig. 9 shows that when the name of the Vegetable Kingdom Products section is used as a filter and the continent filter, such as America, is kept active, the 6-digit codes of the most relevant items in quadrant I are displayed. Exports: The color legend allows us to identify the years they were exported. In quadrant II, the list of countries identified as the largest trading partners of that continent is shown; in quadrant III, the total amount exported both in Millions of USD/FOB and MT is provided, and finally, in quadrant IV, the variation in exports of the included items is illustrated and validated year after year.

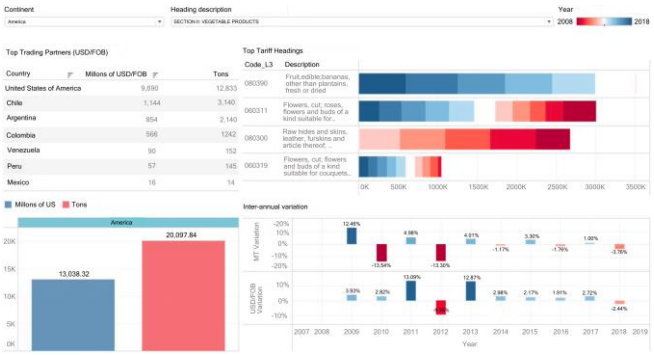

Fig. 9. Section-Level Match Level 3 Identification – America Case

Fig. 10 contains more significant details about the items corresponding to the Products of the Vegetable Kingdom section. 2015 to 2018 have been selected as a filter for this example. In quadrant I, we find a double-axis graph with an area diagram for the amount in Millions of USD/FOB and a line graph as the second axis, with the value of MT exported in the filtered period. Quadrants II and III contain the list of items that integrate the most representative item of exports in the section with a calculation of the average price per item, and in quadrant IV, a table with the number of items that were exported to each country on the chosen continent.

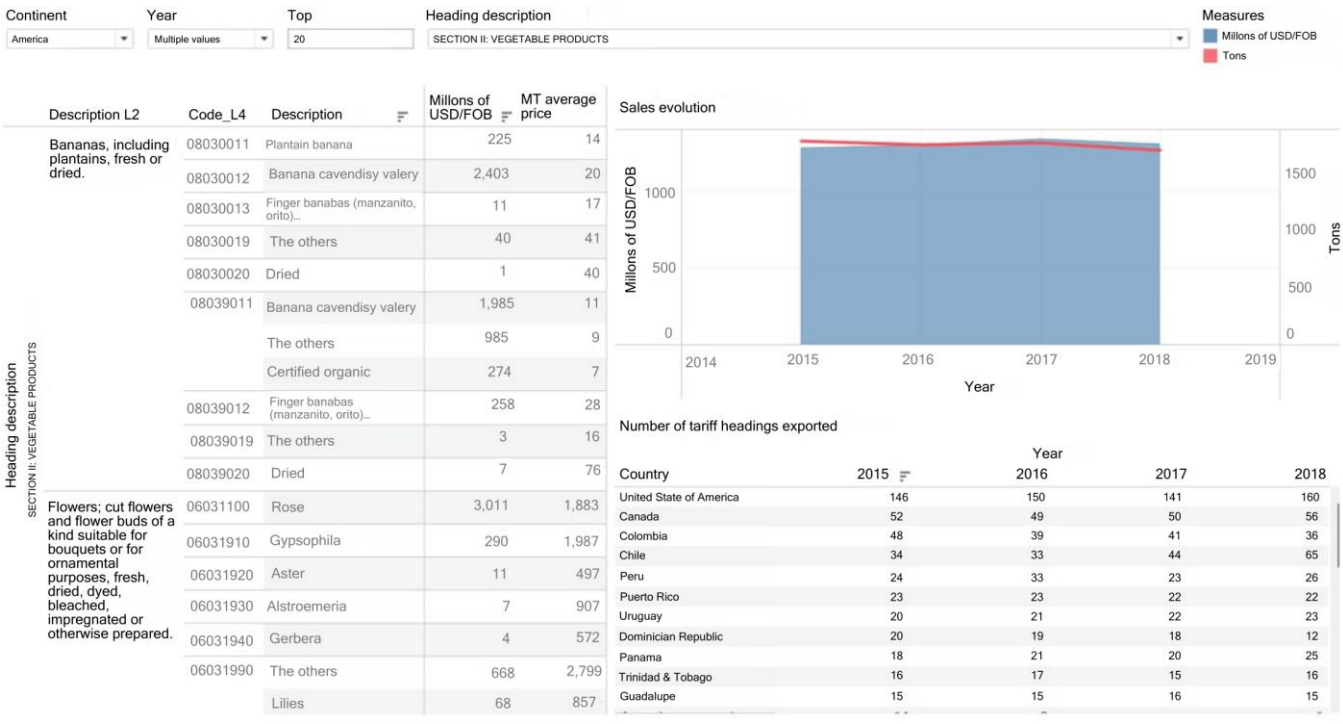

Fig. 10. Level 4 Tariff Items (8-digit tariff items) Cumulative Exports for the Year 2015 in Millions USD/FOB

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Through the visualizations shown above, it can be observed that the selection of appropriate graphic elements provides the user with a better assimilation of information. Also, it reduces the time and effort required to obtain conclusions. It gives the user a comprehensive vision of the topic by going from a macro level to reaching specific details, with fewer steps than conventional systems or programs, highlighting the prior data treatment with mining techniques. Choosing appropriate graphical representations can become a competitive advantage when making decisions—actions or decisions with data disposal.

V. Discussion

The research findings are aligned with the existing literature on main exports between 2016 and 2018 in Ecuador, as per the United Nations United Nations Department of Economic and Social Affairs [8] 4-digit tariff classification and main partner continents, offering a fresh perspective on the subject.

Through the results of this study, we approve the analysis of Durán, J. & Zaclicever, D. [18] on the commercial relationship with Colombia in textile materials and their manufacturers, further validating their findings.

Similarly, the publication of Casanova et al. [30] on the tariff items exported to China between 2008 and 2014 further supports our observations. Likewise, the most frequent destinations for Ecuadorian products mentioned in [31] and [5] concur with those determined by analyzing the export data from this research.

Hence, this study focuses solely on the values of Ecuadorian exports without calculating trade balance balances. Additionally, the analysis is limited to Ecuador and its trading partners and does not include the items in Section V of Ecuador's National Tariff corresponding to Mineral Products.

Therefore, the results of this research agree with the existing literature on Ecuador's main exports, such as the commercial relationship with Colombia in textile materials and the frequent destinations of Ecuadorian products. Data preparation, exploratory analysis, and visualization were performed using good practices recommended in the literature. The study is limited to Ecuadorian exports and does not include an analysis between countries or the Mineral Products categories.

VI. Conclusions

Records of Ecuador's export transactions constitute a competitive advantage for users who must make decisions. Therefore, a comprehensive review of the literature and available data sources on export data visualization was conducted. Additionally, academic studies and industry reports were identified that highlight the usefulness of this tool for exploring and understanding data.

The information provided by LIDI and the Central Bank of Ecuador was divided into a central "facts" table and peripheral "dimension" tables (star model) to improve efficiency and facilitate accurate queries. Thus, dashboards with graphs, tables, maps, and other visualizations were prepared to validate the results. These were socialized with interested parties, who evaluated the ability of the model to respond accurately and adjust to reality. The results were compared with existing studies, and satisfactory answers were obtained.

Due to the need for more data visualization in specific areas such as population, GDP, and distance between countries due to its low relevance, it can be included in future research, such as expanding the scope of the analysis and considering other relevant variables.

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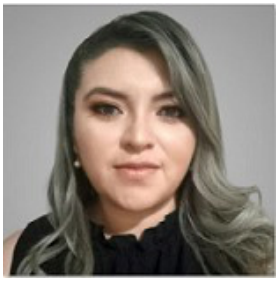

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Safeguarding Mobile Users from Violation by Third-party Apps

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Safeguarding Mobile Users from Violation by Third-party Apps

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***Abstract*—**Insecure third-party mobile applications (apps) can have a detrimental impact on mobile users in terms of information security and data privacy. Insufficient protection for third-party mobile apps platforms may result in harmful installations. The purpose of this paper was to make recommendations on guidelines for safeguarding mobile users from violations by third-party apps. In this regard, empirical data was collected through questionnaires developed to determine the necessary themes that led to the development of the recommendations. The findings showed that a large percentage of participants were not aware of basic security methods to safeguard themselves. Secondly, there is a need for increased confidence in data integrity protocols, and the necessity to ability for emphasizing strong availability controls and backup strategies for mobile users' continuous access to services. Since the findings align with the Confidentiality, Integrity, and Availability (CIA) triad framework, then the recommendations were made as an implementation strategy of the CIA triad for safeguarding mobile users against violation by third-party apps. Mobile users will benefit immensely from the recommendations as they empower them as the first defence against cybercrimes.

Keywords*—CIA cybersecurity, third-party apps security, third-party apps security*

I. Introduction

Nowadays, mobile devices are being used widely all over the world and the usage of mobile devices is growing significantly. The increase signifies the level of demand for good mobile services. Most of the latter services are provided by third-party apps. There is a vast range of sources regarding app stores from where users can easily install the apps. These would include the official app stores delivered from various platform providers, third-party stores, and a range of device manufacturers.

In a world where the mobile application market is constantly growing, new third-party applications (apps) and gadgets are being developed daily. It is critical to take great care while collecting and processing users' personal information. However, app designers rarely consider the suitable means for doing so, and as a result, unsafe applications are launched. In other words, app designers must always use secure-by-design principles.

On the other hand, most mobile users have social media app accounts which increases the lack of security in terms of the collection of personal user information. There are currently a lot of social media app subscribers in South Africa. For example, in 2023, there were 30,4 million Facebook users in South Africa which accounted for 49.6% of its entire population, of which 51.1% were women, the largest user group (9,4 million) were young people from 18 to 24 years of age [1]**.** Most of the app account subscribers tend to not know the type of data used willing or unwilling by such apps.

With a growing number of users having accounts in social media apps, mobile app users need to understand and apply some safety protocols when engaging with third-party as well as online apps. For example, there are concerns regarding the misuse of data by third-party organizations [2]. Users do not require risky permissions from third-party apps to fully operate their mobile devices; however, 60% of third-party apps demand risky permissions [2]. The latter is against the users' privacy and increases the cyber-security threats that users might encounter, thereby creating complications for the user. On the other hand, app designers should think of secure-by-design principles for assisting mobile users not to make a pathway and doorway for cybercriminals.

Cybercriminals may employ smart mobile devices as an attack tactic. Unsurprisingly, smart mobile device users underestimated the value of their collective identities to thieves and how these can be sold [3]. Cybersecurity awareness is the first defence strategy against the violation of being bullied by third-party app providers. In this regard, it is important to find out what mobile users understand about privacy against third-party apps and how it could be violated by third-party apps. Based on their understanding, what recommendations could be made to safeguard users?

Against this background, this paper presents recommendations for safeguarding mobile users from third-party apps. It differs from a mere Google search as it uses empirical data from the users. This paper uses the Introduction, Methodology, Results and Discussion (IMRaD) format. In this regard, the following section will be a Methodology section, then Results and Discussion. The conclusion is presented after discussion.

II. METHODS

The research design is the plan or structure for carrying out research; it also specifies the strategies and methods utilized to collect and analyze data [15]. The research design utilized in this paper is depicted in Fig. 1. This research design comprises three phases: (i) literature scoping – collect themes and concepts relevant to safeguarding the mobile users, (ii) survey – data collection and analysis phase, and (iii)

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recommendations – data utilization phase. In this respect, mixed methods were adopted in this paper.

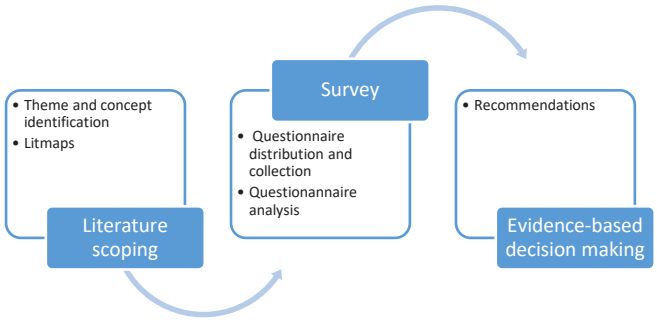

Fig. 1. The adopted research design (Source: Author)

A. Phase 1: Theme identification through literature scoping

To understand how mobile device users understand their devices, a literature scoping using Litmaps was conducted. A first seed literature article was selected and inserted in Litmaps. It generated a literature map that is illustrated in Fig. 2. The analyses of articles produced at least four themes that aim at safeguarding the mobile device against violation by third-party apps.

Fig. 2 produced cybersecurity themes that were relevant to this paper. The themes were within four broader areas: (i) governance – which looks at regulatory compliance requirements like the privacy of sharing the identification information; (ii) device management – which looks at how users operate their devices especially when they interact with third-party apps, (iii) authentication – looks at how the users access their apps; and (iv) data handling – looks at how users protect, keep and make data available always when they need it.

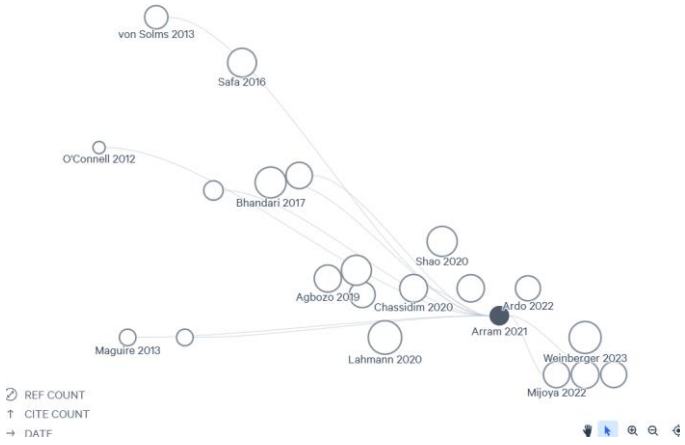

Fig. 2. A Litmap seed article for cybersecurity for safeguarding the user (Source: [5])

Using the CIA triad framework, questions of the questionnaire were designed from different reviewed literature [6–13]. Based on the latter broader themes, the CIA triad related questions were used to design the questionnaire as illustrated in Table 1 to Table 4.

TABLE I. GOVERNANCE QUESTIONNAIRE

Themes	CIA Triad	Questions
Governance	Confidentiality	Do you know what are security features of your mobile device through reading its user manual? Before downloading any app do you read its policies?
	Integrity	Do third-party apps force you to read the policy or memorandum of agreement before you use their app? Have you obtained any training regarding how you mobile device security features are?
	Availability	Do you use antivirus to protect your phone?
		Do you use update third-party apps after reading the guidelines?

TABLE II. DEVICE MANAGEMENT QUESTIONNAIRE

Themes	CIA Triad	Questions
Device Management	Confidentiality	Do you read and subscribe to the mobile device security guidelines before using the device? Do you read the mobile device security guidelines when you encounter security challenges?
	Integrity	Does the mobile device have different security settings available to the user? Can you locate the International Mobile Equipment Identity (IMEI) of your mobile device?
	Availability	When you download apps do you make sure that your device is always powered?
		Do you know more than one device that has the same apps?

TABLE III. PRIVACY THROUGH AUTHENTICATION QUESTIONNAIRE

Themes	**CIA Triad**	**Questions**
Authentication	Confidentiality	Do you unlock your screensaver with a PIN code or password? Do you keep your password and allow the system to recall it for you?
	Integrity	Do you use a Personal identification number (PIN) to

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		unlock your Subscriber Identity Module (SIM)? Do you use a PIN/password or biometric identification to gain access to your mobile device?
	Availability	Do you change your password when prompt to do so or at certain time interval?
		Do you save or write your passwords somewhere else to make sure if you lost, you could withdraw it.

TABLE IV. DATA HANDLING QUESTIONNAIRE

Themes	CIA Triad	Questions
Data Handling	Confidentiality	Do you create a password, then lock and save your information? Do you read the third-party app guidelines before downloading the app?
	Integrity	Do you know what a re website cookies? Do you know how your data is handled by cookies?
	Availability	How often create backups of your information?
		Do you create different protected copies of your documents?

B. Phase 2: Empirical data through Survey

A research survey is a means of collecting data and analyzing it into information to get insight into a specific group of people. In this context, this study surveyed a sample of 120 participants who were randomly drawn from a significant study population made up of students (40), professionals (40), and unemployed people (40). All sample characteristics closely matched the population. Due to the issue of the timeframe, the questionnaire was distributed in person, and the participants were clarified about the purpose of the questionnaire and their right of consent (i.e. participants were given a chance to agree or disagree).

C. Phase 3: Evidence-based decision making

Research recommendations are suggestions or advice provided to guide a study and are obtained through action-based research or questionnaire-oriented research. They allow decision makers or researchers to provide manageable guidelines for achieving or solving the phrased problem. Research implications are broader than research recommendations.

Fig. 3 illustrates research recommendations vs the implications. Since the article aims at using the empirical suggestions through the collected data; then the aim of this paper was to provide the research recommendations through evidence-based decision making.

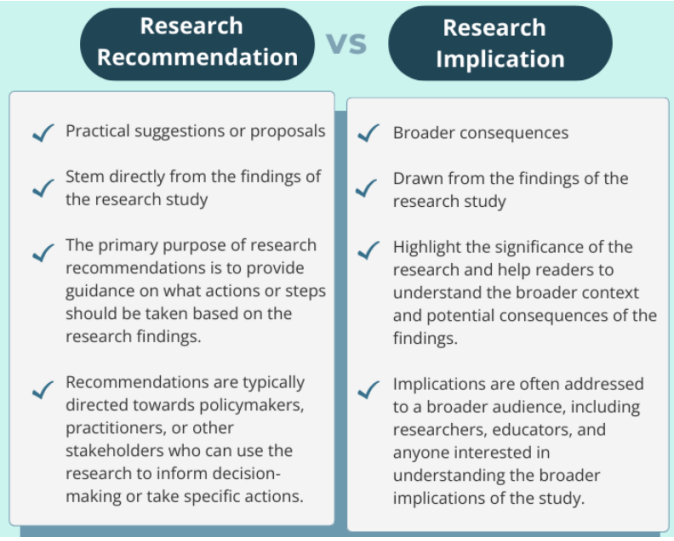

Fig. 3. Research recommendation vs research implications (Source: [17])

III. RESULTS AND DISCUSSION

A. Literature Scoping

Mobile apps are becoming an integral section of our daily lives [16]. With increasing dependence on apps, the major stakeholders for whom the data holds extensive value are the app providers, advertisers, and researchers. On this matter, through the analysis of the user data, the app providers could easily gain insights into the users' preferences and behavior [17].

Most studies that research mobile users' behavior, awareness, risk, ethics, and design use the Confidentiality, Integrity, and Availability (CIA) triad framework [6-11].

The CIA framework was adopted for this study because it elaborates on and strengthens mobile users' privacy through confidentiality, integrity, dependability and availability. In the context of CIA, confidentiality refers to privacy of Information and Communication Technologies (ICT), and the limitation of access to classified material and protecting private data or protection of sensible data about the users' livelihood [11].

While integrity refers to the knowledge that data or computing operations have not been corrupted or destroyed [11]. Furthermore, it describes the dependability of information and features offered by third-party apps [11]. Then, availability guarantees prompt and ongoing access to the system data for authorized app users [10].

Encryption is vital for information security but can also affect availability. If encryption is too strong or complex, it can slow down data access and processing, impacting system performance and availability.

The CIA framework will assist with a structure of recommendations that could be utilized for the protection of mobile users' Personal Identification Information (PII) data that could be accessed through mobile apps. In this context, the CIA triad was chosen as the theoretical baseline for examining the privacy and security risks that arise from third-party apps.

The CIA triad study conducted by [13] on mobile users regarding the PII showed that: (i) a large percentage of participants were confused about using a personal

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identification number (PIN) or a password to access their screen savers; (ii) participants expressed concerns about the dependability of their data, and (iii) participants cited instances where they questioned the correctness of their PII, (iv) while others mentioned they suspected an unauthorized changes.

On the other hand, some researchers felt like there should be a move from CIA to a new theory [14]. They argue that information security is commonly defined and modelled using the CIA triangle; however, it is unable to deal with the quickly evolving need for security. In this regard, they proposed that the CIA triad should include the four layers and be called Confidentiality, Availability, Controllability, and Authentication (CACA). Unfortunately, CACA does not include digital mass surveillance, and it was not clear how CACA is used to target end users.

Although, the work by [18] explored information security usage of but the privacy and security of users when using third-party apps were not mentioned nor described by authors. Furthermore, no recommendation to safeguard users was made by [18].

The legal aspects of safeguarding mobile users against violation of mobile apps are another important matter. The work by [19] looked at privacy harm as a legal action caused by negative impact to an individual due to unathorised access. The legal solution led to the use of Privacy Enhancing Technologies (PETs) and implementation of privacy enhancement mechanisms (such as Fair Information Practice Principles (FIPPs), and Code of Fair Information Practice (CFIP)) to protect PII [19].

Interestingly, with increasing dependence on apps even operating systems (OS) are now offering privacy and access controls. The latter is achieved by amalgamating authentication between users file access to give file permissions as well as system monitoring. The work by [20] reveals that the CIA triad fuels OS security; it is at the heart of access control mechanisms, authentication protocols, encryption techniques, and secure coding practices. On this point, the OS security deals with system vulnerabilities, malware, insider threats, software flaws, and social engineering attacks. A protection framework has been contributed by [21]. It uses static and dynamic analysis, in addition to a review of privacy policy statements to improve the mobile OS (i.e. Android) security. The analysis protects the sensitive information for being collected by either public or private apps.

This paper adopted the CIA Triad to develop a questionnaire, which was then used it to collect the data. Then analyzed the data to produce a recommendation. The latter is summarized through the sections below.

B. Survey

The CIA triad of mobile users showed that [13]: (i) a large percentage of participants were confused about using a personal identification number (PIN) or a password to access their screen savers; and (ii) participants expressed concerns about the dependability of their data, citing instances where they questioned the correctness or suspected unauthorized changes. The empirical results of this study are shown in Fig. 4 to Fig. 7.

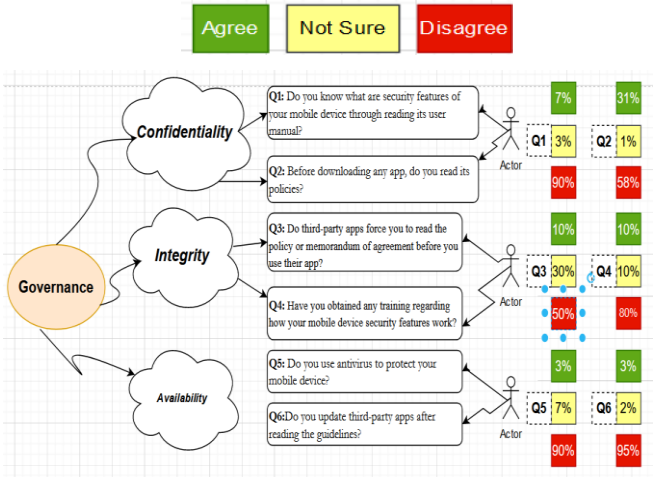

Fig. 4. Questionnaire response regarding cybersecurity governance as applied by mobile users

The issues regarding PII as acquired by third-party agencies beyond what is specified in the privacy and security policy have been gradually growing [15]. This means the growing user numbers lead to the growth, collection and capturing of PII data, stored in large amounts through mobile apps [18][22]. Consequently, mobile users are becoming concerned about how mobile apps acquire PII data [22]. However, the mobile users seem not adhere to the cybersecurity policies making them vulnerable to possible third-party app violation.

As illustrated in Fig. 4, the majority of mobile device users do not adhere to cybersecurity governance matters. In this regard, they become too exposed to the possibility of being attacked. For example, about 90% of the participants responded that they do not read any policies when coming them downloading third-party apps.

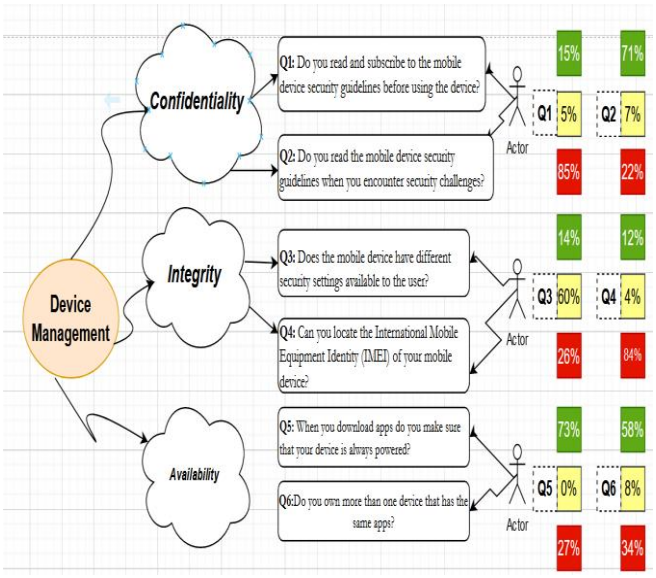

Fig. 5. Questionnaire responses regarding mobile device management

Fig. 5 illustrates the responses of mobile device owners in terms of their relationship or their understanding of device management. Most mobile devices could be used as a tool of

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attack for cybercriminals. Unsurprisingly, mobile device users in the survey underestimated the value of their understanding of their device. For example, 85% of the participants responded that they do not read their devices guiding documents or manuals to enhance their stand of protecting the device. Furthermore, 73% of participants responded that they own more than two mobile phones for other people not to have their numbers, instead of blocking unwanted users.

Fig. 6 indicates that the majority of participants understand the authentication management in protecting their mobile devices. The authentication to access the mobile device is a must through a password. In alignment to Fig.7, most participants use a password to protect their documents. Unfortunately, the majority of users save their passwords on the device and allow the system to recall the password for them. The latter is a privacy thread as anybody who could access their password might use their PII and other privacy information.

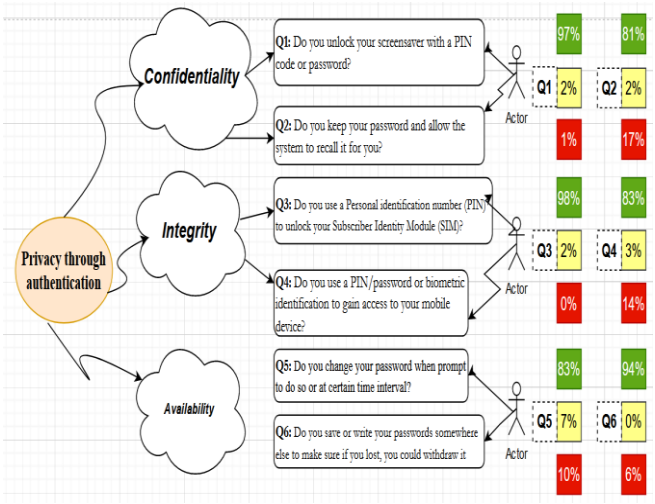

Fig. 6. Questionnaire responses regarding privacy through authentication

Fig. 7 illustrates how most mobile users handle issues relating to their data. Most participants have a redundancy plan to try and secure their data. In this regard, if one data set fails the original data could be available for re-used. Unfortunately, 51% users do not know what website cookies are; while 65% do not even know how cookies handle or use their data. Furthermore, most participants indicated that they do not read third-party app guidelines. The latter makes them vulnerable to third-party app organizations.

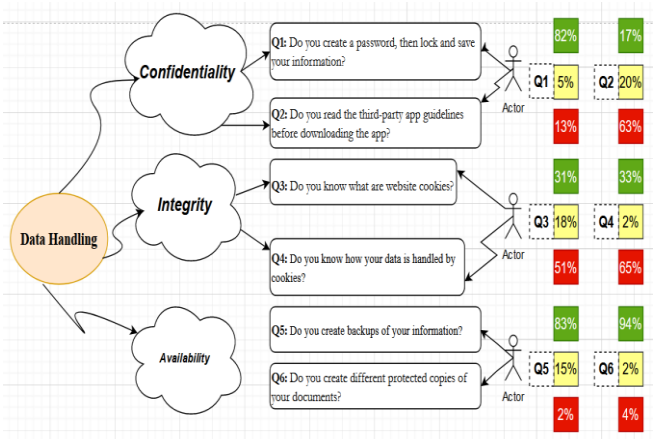

Fig. 7. Questionnaire responses regarding data handling

In general, most of the participants violated the CIA triad when coming to not using antivirus, backing their data and storing passwords in their same phones. The latter increases the chances of being vulnerable to violation by third party apps because their data is not secured. In this context, the following recommendations are contributed:

- Adhere to privacy policies and device management document – This can be done by providing the users with clear guidance on setting strong passwords, staying away from suspicious links and downloads, and using lock screen protection.
- Read about privacy and cybersecurity awareness and policies – awareness enhances a security-conscious culture among people. It helps minimize the human factor in security breaches and encourages people to be aware of their situation.
- Promote and practice privacy – user should promote, and practice promote privacy to avoid data leakage and superfluous permissions which could result in the release of personal information. While some of the flaws may be related to the system liberty, portability, and ease of use.
- Never rely of third-party apps for privacy and security guidance – Third-party tools should make sure that their data gathering policies are transparent to users. However, users should have more insight in reading the third-party application.
- Implement strong authentication and authorization – Implementation of strong authentication and authorization mechanisms is vital in hindering the unlawful access to the data in an app and its functionalities. The use of OAuth 2.0 and OpenID Connect is essential in ensuring secure authorization and therefore its implementation would ensure mobile security.
- Participate in user Education – although there was widespread knowledge of the importance of security measures with respect to password protection; however, users should be taught the best security practices and the possible risks related to mobile app usage.

IV. Conclusion

The rise of third-party apps raises concerns about privacy and security. This study employed the CIA triad theoretical framework to investigate and assess privacy issues related to third-party mobile applications that collect and share personal data from mobile users, with or without their agreement or understanding.

Mobile device users should be aware of how third-party apps acquire personal information. Furthermore, issues awareness regarding cybersecurity should not be ignored and it should always be emphasized when users purchase the devices.

The major goal of this paper was to collect empirical data from users and use it to assist in making the recommendation that could safeguard the mobile device users. Future studies will look at testing and validating these recommendations.

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A Systematic Literature Review on Defense Techniques Against Routing Attacks in Internet of Things

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***Abstract*—** The proliferation of the Internet of Things (IoT) has attracted different sectors such as agriculture, manufacturing, smart cities, transportation, etc. to adopt these technologies. Most IoT networks utilize Routing Protocol for Low Power and Lossy Networks (RPL) to exchange control and data packets across the network. However, RPL is susceptible to routing attacks such as rank attacks, DIS-flooding, etc. In recent years, different defense techniques have been proposed to act against these attacks i.e., Secure-Protocol, conventional Intrusion Detection Systems (IDS), and Machine Learning (ML)-based. This systematic literature review explores 39 published papers in the domain of defense techniques against routing attacks in RPL-based IoT. The findings of this study suggest that most Secure-Protocol can detect and mitigate routing attacks utilizing distributed placement, ML-based can detect most attacks but lack mitigation mechanisms, and conventional IDS technique utilizes a hybrid approach in detection and placement strategies. Additionally, this study reveals that India publishes more research papers in ML-based and Secure-Protocol. Furthermore, flooding attacks are the most discussed attacks in the selected studies. Finally, Cooja Contiki is the most used simulation tool.

Keywords*—Defense technique, RPL, Routing attacks, IoT*

I. INTRODUCTION

The Internet of Things (IoT) emerges with different innovations including smart agriculture, environmental monitoring, and smart grids, to name a few [1]. However, the broad adoption of IoT faces challenges in terms of security due to some of its characteristics, i.e., direct access to devices from the internet, the communication nature of wireless media, and potential unattended operations of relevant deployment. One of the significant enablers of IoT technology is the Low-power and Lossy Networks (LLNs) which comprise interconnected devices with low computational capabilities and less storage and are often operating on batteries such as sensor nodes and actuators [2]. Communication technologies in LLNs are subjected to limitations such as short communication range, high packet loss, low data rate, dynamically changing topology and frame size limitations. Such limitations render the development of efficient routing protocols for LLNs of significant importance. Routing is one of the fundamental driving forces of LLNs, it provides connectivity to various applications and enables seamless communication among IoT devices [3]. LLNs run on resource-constrained devices like radio transceivers and ultra-low powered micro-controllers as such, traditional routing protocols like Ad hoc On-Demand Distance Vector (AODV), Open Shortest Path First (OSPF), Dynamic Source Routing (DRS) are not suitable to facilitate data transmission between such devices due to network and device characteristics[4].

To overcome the limitations of traditional routing protocols in LLNS, the Internet Engineering Task Force (IETF) group for Routing Over Loss-power and Lossy Networks (ROLL) has introduced and standardized the IPv6 Routing Protocol for low-power and Lossy Networks (RPL) to meet various requirements of applications and obligations [5]. Moreover, it satisfies the routing necessities of LLNs [6]. It is worth noting that, the RPL as a prominent infusion to routing limitations in IoT is vulnerable to many network layer attacks, particularly routing attacks [7]. Some examples are DIS Flooding, Rank, Sinkhole, and Worst Parent attacks. These attacks exploit the vulnerabilities inherent in RPL-based IoT systems by consuming device power, causing topology inconsistencies, dropping data packets, and creating delays in packet delivery.

Recent review works demonstrate that RPL is susceptible to many routing attacks, additionally, several researchers have proposed defense techniques [8-10] to defend the IoT from those routing attacks. However, these studies do not discuss the three techniques this study covers i.e., Secure-Protocol,

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conventional Intrusion Detection Systems (IDS), and Machine Learning (ML)-based defense techniques in one paper. To the best of our knowledge this is the first review to discuss traditional and advanced defense techniques and to provide a link between publication country of origin, adopted defense technique, academic library, and year of publication. The contributions of our study are as follows 1) provide a comprehensive SLR method relevant to different RPL defense techniques, 2) formulate a set of research questions pertinent to various defense techniques, distributions of publications, statistics of network simulation tools, configurations setups, and discussed attacks. 3) provide a link between the publications of the origin country, defense techniques adopted, academic library, and year of publication.

The rest of the paper is organized as follows, section II provides related work of the study, Section III discusses the methodology used to conduct this SLR study, a discussion of results is presented in Section IV, and lastly, the conclusion in Section V.

II. Related works

The advent of IoT networks and their applicability in different sectors has ignited significant academic and industrial interest, especially in RPL security. This section provides a review of related work in the domain of security techniques in RPL-based IoT. We rigorously identify and evaluate four existing systematic review and traditional review papers that are pertinent to the critical aspects of our domain of interest.

Authors of [11] conducted a comprehensive traditional review comparing the Secure-Protocol and IDS security solutions. They, furthermore, gave an analysis of the RPL-specific attacks and their countermeasures highlighting essential attributes i.e., topology, resources, and traffic affected by these attacks. The study [8] provides an analysis of machine learning-based techniques to secure IoT following the SLR methods. The study presents a comprehensive review of different machine learning detection models and their pros and cons. However, the study is focused on application layer attacks.

The study [10] presents an extensive review of several routing attacks. In addition, it further provides an in-depth description of IDS and its different detection strategies that can be adopted for the detection of routing attacks. However, the study lacks an analysis of Secure-Protocol defense techniques. Authors of the study [9] demonstrated the significance of the Secure-Protocol as a defense technique against routing attacks. They further provide a distribution of publications; however, the study lacks a relationship between the publication year, country of origin, academic library, and defense techniques.

Table I below provides a summarized analysis of the related work.

TABLE I. SUMMARY OF RELATED STUDIES

Study	Scope of work	Strength	Similarity with our study	Limitation
[11]	A review of comparison of Secure-Protocol and IDS, RPL-specific attacks and their countermeasures, attack taxonomy, and cross-layer security solution for RPL	The study provides an in-depth analysis of RPL-specific attacks and their countermeasures.	Overview of security solutions for RPL	The study lacks a review of Machine learning as a potential security solution
[8]	SLR on machine learning and deep learning-based techniques to detect large-scale attacks	The paper presents a comprehensive review of machine learning and deep learning-based techniques	Overview of machine learning techniques	The paper lacks a review of traditional solutions i.e., Secure-Protocol and their attack focus is not routing attacks.
[10]	SLR on RPL and its existing threats, and classification of IDS techniques.	The study presents an extensive review of RPL threats and the classification of relevant IDS techniques.	Overview of IDS techniques	The research paper lacks a review of Secure-Protocol and machine-learning defense techniques
[9]	SLR on attacks defense mechanisms in RPL-based 6LoWPAN	The review provides a comprehensive in-depth analysis of various RPL security mechanisms, challenges, key issues, and recommends future research directions.	Overview of secure-protocol techniques	The study lacks a review of both IDS and machine learning-based defense techniques

III. Research methodology of SLR study

To gain an insight into which studies have been publishing in the sphere of defense techniques against routing attacks in LLN, the Systematic Literature Review (SLR) method was adopted in this article. This section of the article covers each step of SLR methodology in detail. In sections B, C, and D, the paper gives an explanation of key concepts of the SLR protocol, followed by Section E which explains the validation results of collected and synthesized publications

A. Research questions and SLR protocol

This paper aims to evaluate studies between 2018 and 2023 in the domain of defense techniques against routing attacks in RPL-based IoT have been conducted. To achieve this goal, it is required an understanding of RPL and different routing attacks that are threats to the RPL-based IoT. Secondly, we investigate different defense techniques which are proposed in the year range. This includes compiling findings, outlining weaknesses and strengths, and presenting empirical evidence in detecting and mitigating routing attacks.

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Lastly, give recommendations, challenges, and future research areas. To meet the objectives, we formulated several research questions as follows:

- RQ1: What is the distribution of studies into defense techniques in RPL-based IoT regarding country of origin, year of publication, type of defense technique, and academic library?
- RQ2: Which simulation tools are mostly used, and which configurations are mostly used particularly simulation area, simulation time, transmission range, and interference range?
- RQ3: Which attributes can be used to evaluate the robustness of defense techniques?
- RQ4: Which types of detection and placement strategies demonstrate the capability of addressing most attacks?
- RQ5: Which routing attacks are mostly addressed by the proposed defense techniques?
- RQ6: Which proposed techniques are capable of detecting and mitigating routing attacks?
- RQ7: Which performance metrics are commonly used to evaluate the performance of defense techniques?
- RQ8: What are the best defense techniques, detection and placement strategies, challenges, and future research areas?
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B. Identification of academic databases and Search keywords

In this step, we explored academic information sources, and four databases were exploited to extract and collect publications for inclusion in the subsequent extraction and synthesis procedure. In this article, a set of search keywords is declared by the union of specific and broad keywords to achieve a reasonable number of publications that are suitable to the research topic. From background section 2.1, RPL is a standardized routing protocol for IoT specifically LLN networks, However, the 'IoT' keyword is implicit in most publications, and 'RPL' is in the title abstract and keyword sections. So, we used two sets of keywords relevant to IoT and RPL subjects to collect publications. But, because we want an insight into defense techniques, we added two more sets of keywords 'mitigation technique', 'security model', 'defense strategy', 'detection scheme'; and 'routing attacks', and 'network layer attacks' to have two groups of keywords. It is worth mentioning that we eliminated keywords that were not relevant to the scope of this article.

C. Publications selection criterion

This step outlines the publication selection criteria used to retrieve publications aligned with the scope of this article. We used five factors to select and include publications that are aligned with our article, namely: publication year, language, duplications, type of publication, and availability of full text. First, we defined a publication year filter from 2018 to 2024 to include studies. Secondly, we only included publications that are published in the English language. This was done manually by screening the title and abstract of the studies. Thirdly, manually checking whether there are no duplicated publications from multiple databases. Fourthly, we determined the type of publication. In this procedure, we only considered studies that are conference proceedings, journal articles, and/or book chapters. And lastly, we only considered publications from which we could get their full-text reading. Table II below presents a summary of inclusion and exclusion elements considered in this study.

TABLE II. LIST OF PUBLICATIONS SELECTION CRITERIA

Inclusion	**Exclusion**
Published between 2018 & 2024	A study is a duplicate
Written in the English language	Published in a language other than English
A study remains within the borders of routing attacks in RPL	Not relevant to the scope of this article
A study is a journal article, a book chapter, and a conference proceeding	It is a grey literature
Full-text reading is available	Full-text reading is not available

D. Extraction of articles and synthesis

In this step, we explain how the final set of selected publications was produced from the initial set of retrieved publications. We explored the titles and abstracts of the selected publications to identify those that are relevant to RPL or LLN research and excluded those that are not. We further used the full-text read to include publications that focus on the prevention, mitigation, and detection of routing attacks in RPL.

E. Validation results

In the last step of our SLR study, we present three broad steps used to select studies. Refer to Fig. 1. The selected four databases of digital libraries produced 5,848 results with 1,513 from IEEE Xplore, 1,403 from ScienceDirect, 1,176 from MDPI, 962 from Springer, and 794 from IEEE Access. We then applied the publication year range and studies written in English exclusion criteria which reduces the results to 1,241. Excluding 685 duplicate studies the returned results were then reduced to 556.

To select relevant RPL-based studies within our scope, we screened their titles and abstracts, resulting in the exclusion of 319 and the inclusion of 237. The final set of studies which formed part of this SLR was a result of the conducted full-text reading and it was discovered that only 39 studies were relevant to the scope of this study.

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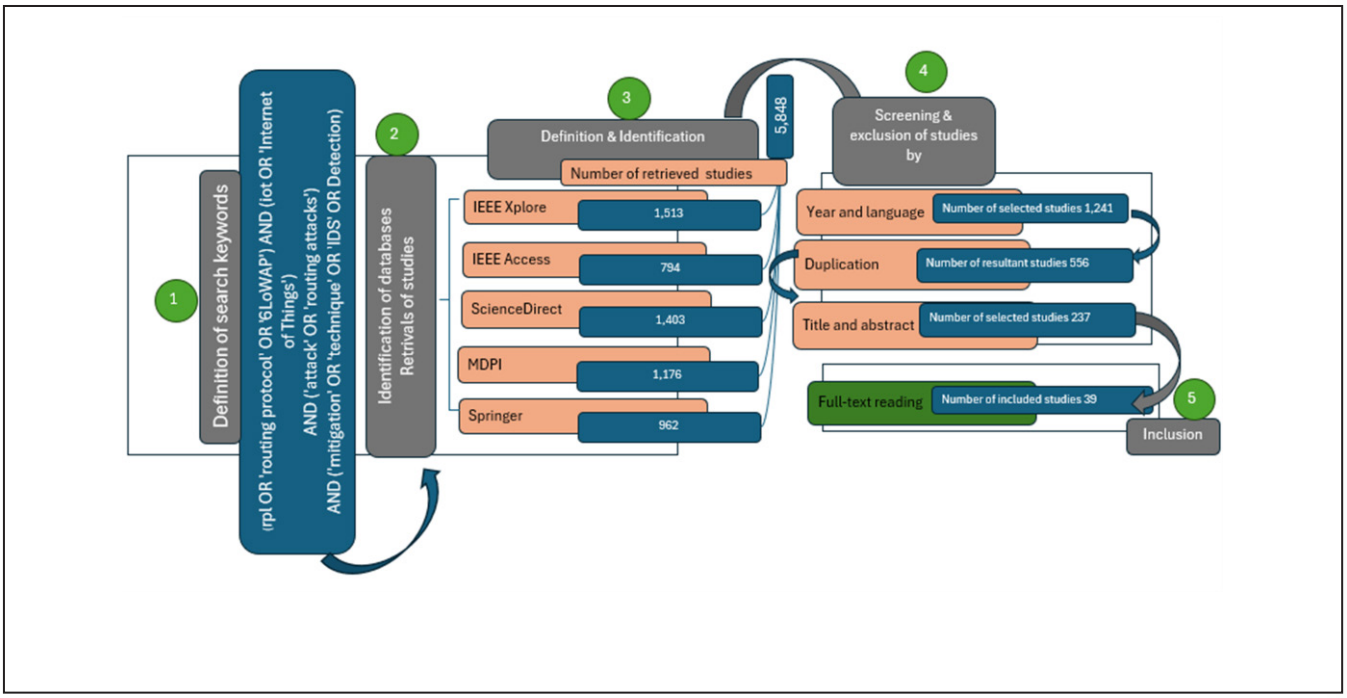

Fig. 1 Diagrammatic representation of SLR methodology steps

IV. Results and Discussion

This paper focuses on reviewing proposed defense techniques and determining the most suitable technique to defend RPL-based IoT against routing attacks. Thus, 39 publications proposing defense techniques are selected and critically evaluated to answer the research questions provided in the methodology section and achieve the objective of this paper.

1) RQ1: What is the distribution of studies into defense techniques in RPL-based IoT regarding country of origin, year of publication, academic library, and type of defense technique?

It is important to understand the distribution of publications, including academic sources, year of publication, defense technique, and country of origin. This information gives an insight into the spread of publications across countries, years, and academic libraries.

Fig. 2 presents the percentages of distribution of the selected studies across the four academic databases mentioned in section 4. Most of the studies were found in the IEEE Xplore and Science Direct constituting 44% and 23% respectively.

Furthermore, Fig. 3 depicts that most of the selected publications were published in 2022, 2021, and 2023 with 11, 9, and 8 publications, respectively.

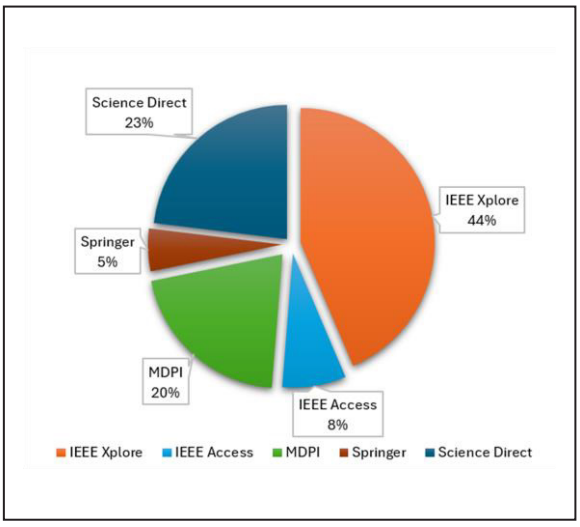

Fig 2 Contribution of Academic Libraries

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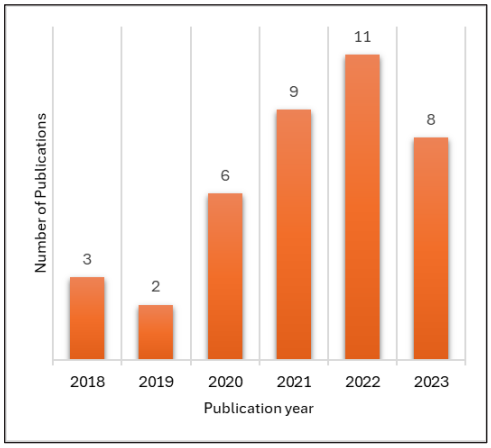

Fig. 3 Distribution of publications by year

It is also important to note that most of the selected publications proposed Machine Learning-based IDS as their defense techniques. As depicted in Fig. 4, ML-based IDS is the first largest proposed defense technique amounting to 17 publications; 11 are traditional Machine Learning, 4 are Deep Learning (DL), and 2 are Reinforcement Learning(RL). The second largest defense is Secure-Protocol with 14 publications in total and a threshold-based detection strategy is proposed in 5 studies followed by specification and trust-based detection strategies proposed in 3 studies each. Furthermore, Conventional Intrusion Detection Systems (IDS) constituted 8 publications. Four techniques were found in IDS studies i.e., anomaly, specification, signature, and hybrid. Anomaly and Hybrid detection strategies are each proposed in 3 studies.

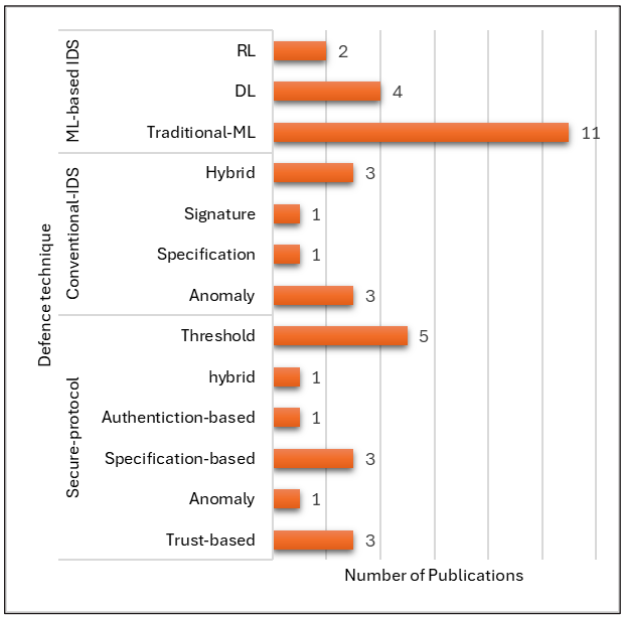

Figure 4 Distribution of different defense techniques and the adopted detection strategies

Fig. 5 presents the country of origin of the selected studies. Most of the selected publications are written by authors from India which are 12 in total followed by the UK with 6 publications. Furthermore, Saudi Arabia, Canada, Algeria, Malaysia, and Turkey, each has 2 papers from the selected studies.

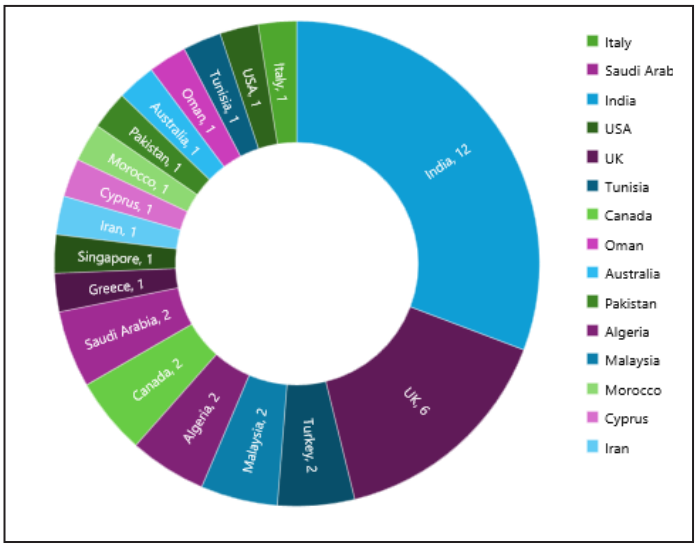

Fig. 5 Contribution by Country of origin

However, the information presented in Fig. 2,3,4 & 5 does not tell us the story as there is no link between them. Most of the SLR studies do present this information without including the link [9] we saw this as a loophole in most SLR and traditional literature review studies. We then developed a way to present the link between the distribution information of publications in Table III which presents the link between the distribution factor of publications.

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TABLE III. DISTRIBUTION OF DEFENSE TECHNIQUES IN ACADEMIC LIBRARY, COUNTRY OF ORIGIN AND YEAR OF PUBLICATIONS

		Defense Techniques		
		Secure-Protocol	**Conventional IDS**	**ML-based IDS**
Academic Libraries	**IEEE Xplore**	Canada[1 | 2022] India[1 | 2021] USA[1 | 2018] Singapore[1 | 2018]	Turkey [1 | 2021] India[1 | 2022; 1 | 2018] Italy[1 | 2021]	India[2 | 2021; 1 | 2022; 1 | 2019] Canada[1 | 2023] UK[1 | 2022; 1 | 2021] Cyprus[1 | 2020] Morocco[1 | 2020]
	IEEE Access	Saudi Arabia[1 | 2022] UK[1 | 2020]		Turkey[1 | 2020]
	MDPI	Saudi Arabia[1 | 2020] Algeria[1 | 2023]	UK[2 | 2022]	Oman[1 | 2023] Malaysia[2 | 2022] Australia[1 | 2023]
	Springer	India[1 | 2021]		Tunisia[1 | 2023]
	Science Direct	Algeria[1 | 2021] Iran[1 | 2022] Pakistan[1 | 2020] India[1 | 2022; 1 | 2023]	Greece[1 | 2021] India[1 | 2019]	UK[1 | 2023] India[1 | 2022]

The table gives an insight into the distribution of publications. It also demonstrates which defense techniques are most proposed in which countries and academic libraries e.g. ML-based IDS is mostly published in IEEE Xplore with 9 publications of which 5 are from India followed by the UK with 2 publications. Malaysia published 2 ML-based IDS studies with MDP. However, the second country to publish the most ML-based IDS is the UK with 3 followed by Malaysia across our academic libraries. It can also be seen that India, and the UK are the leading countries to propose Conventional IDS as a defense technique against routing attacks with 2 studies each. Between 2021 and 2023 it appears that Secure-Protocol has been proposed mostly in India, constituting 4 publications followed by Saudi Arabia with 2 in 2020 and 2022.

2) RQ2: Which simulation tools are mostly used, and which configurations are used particularly simulation area, simulation time, transmission range, and interference range?

It is observed that studies conduct their simulations using Cooja Contiki OS, MATLAB, NetSim, OMNET++, and NS3. From the selected studies 28 used Cooja Contiki OS, then 6 used MATLAB and NetSim equally, furthermore, 2 used OMNET++ and lastly, only one study was found to have used NS3 and Cooja Contiki OS. Fig. 6 presents a graphical presentation of the used simulation tools.

It is also identified that two studies did not disclose the simulation tools that they used in their experiments [12] & [13]. It is likewise noted that the selected studies choose simulation environments ranging from 100x100m to as large as 1000x1000m except for studies [14] & [15] that choose 70x70m and 5x5m, respectively. Furthermore, the transmission range of nodes in the network was also seen from the selected studies, and it was deduced that 9 of the selected studies used a transmission range configuration of 50m, whereas only one study [16] opted for a transmission range of 100m, however, the simulation area is not presented in that study.

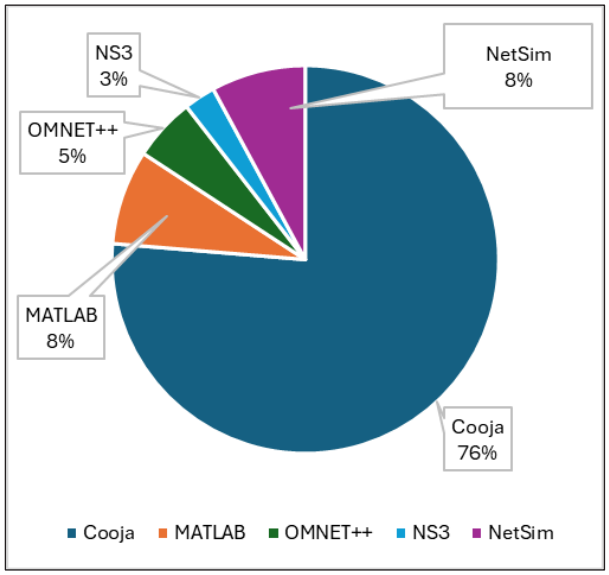

Fig. 6 Percentage of usage of simulation tools

Table IV below shows the technical configurations of the simulation area as well as adopted defense techniques, detection, and placement strategies. It is used to answer RQ2, RQ3, and RQ4.

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TABLE IV. TECHNICAL ANALYSIS OF PROPOSED DEFENCE TECHNIQUES

Study	Defense Technique	Detection strategy	Placement strategy	Network Size	malicious nodes	Mobility	Tools	No of Attacks	Simulation Area (m)	Trans Range (m)	Inter Range (m)
[2]	Secure-Protocol	Threshold-based	Distributed	50	2,5,10	Yes	Cooja	1	300x200	-	-
[5]	Secure-Protocol	Trust-based	Distributed	50, 100, 150	10%	Yes	MATLAB	1	100x100	-	-
[17]	Secure-Protocol	Threshold-based	-	20,40	-	-	Cooja	4	20x20	-	-
[1]	Secure-Protocol	Threshold-based	-	25	-	Yes	Cooja	1	100x100	30	25
[3]	Secure-Protocol	Trust-based	Decentralized	35	3	Yes	Cooja	1	-	50	-
[4]	Secure-Protocol	Authentication-based	Distributed	18, 28	3	Yes	Cooja	1	200x200	50	-
[18]	Secure-Protocol	Trust-based	Distribution	28	2	No	Cooja	3	210x150	-	-
[6]	Secure-Protocol	Hybrid (thresh-spec)	Distributed	30	5	No	Cooja	1	-	50	-
[19]	Secure-Protocol	Threshold-based	Distributed	100	30	No	OMNeT++	1	200x200	30	-
[20]	Secure-Protocol	Anomaly-based	Distributed	50	1	No	Cooja	1	280x150	50	70
[21]	Secure-Protocol	Specification-based	Distributed	50	10	No	Cooja	1	100x100	30	25
[22]	Secure-Protocol	Specification-based	Distributed	25,40,65	-	No	Cooja	1	300x300	25	50
[23]	Secure-Protocol	Specification-based	Distributed	13	1	No	Cooja	1	200x200	50	100
[24]	Secure-Protocol	Threshold-based	Distributed	20	4,1	No	Cooja	2	100x100	50	100
[25]	Conventional-IDS	Anomaly-based	Hybrid	8,16,24	12	No	Cooja	1	-	-	-
[26]	Conventional-IDS	Anomaly-based	Hybrid	10	1	No	Cooja	1	-	-	-
[27]	Conventional-IDS	Hybrid	Centralized	16	1	No	NetSim	14	-	-	-
[28]	Conventional-IDS	Specification-based	Distributed	10,20,30,40,50,60	-	-	MATLAB	2	1000x1000	-	-
[14]	Conventional-IDS	Anomaly-based	Distributed	36	6	No	Cooja, NS3	2	70x70	-	-
[29]	Conventional-IDS	Hybrid(Sig-Spe)	Hybrid	12	1	-	Cooja	6	-	-	-
[30]	Conventional-IDS	Signature-based	Central	30	20%	-	Cooja	4	-	-	-
[31]	ML-Based	Supervised-learning	Distributed	30	-	-	Cooja	3	100x100	-	-
[32]	ML-Based	Supervised-Learning	Centralized	10,20,40,100	2,4,8, 10	No	Cooja	5	-	-	-
[16]	ML-Based	Reinforcement-Learning	Centralized	30	1	No	Cooja	1	-	100	30
[12]	ML-Based	Deep-Learning	-	-	-	-	-	1	-	-	-
[33]	ML-Based	Supervised-learning	Decentralized	16,32,64,128	10%, 20%, 30%	Yes	NetSim	10	250x250	50	-
[34]	ML-Based	Supervised-Learning	Centralized	-	-	-	Cooja	4	-	-	-
[35]	ML-Based	Supervised-Learning	-	25	1	-	Cooja	3	200x200	-	-
[13]	ML-Based	Supervised-Learning	-	30	6		-	2	-	-	-
[36]	ML-Based	Deep-Learning	-	10	2	No	Cooja	1	-	-	-
[15]	ML-Based	Supervised-Learning	-	25	-	No	Cooja	1	5x5	-	-
[37]	ML-Based	Supervised-Learning	Centralized	-	-	No	MATLAB	7	-	-	-
[38]	ML-Based	Reinforcement-Learning	Decentralized	16,32,64,128	10%, 20%, 30%	Yes	NetSim	8	850x850	50	-
[39]	ML-Based	Deep-Learning	Centralized	6,11,16	1,1,3	No	Cooja	1	-	50	-
[40]	ML-Based	Deep-Learning	-	100	6	-	OMNeT++	3	500x500	60	-
[41]	ML-Based	Supervised-Learning	-	50	2	Yes	Cooja	2	-	-	-
[42]	ML-Based	Supervised-Learning	-	11	3	-	Cooja	7	200x200	-	-
[43]	ML-Based	Supervised-Learning	-	20,50	-	-	Cooja	2	-	50	100

3) RQ3: Which attributes can be used to evaluate the robustness of defense techniques?

In most IoT applications, devices are deployed in large numbers. Hence, network size and number of malicious nodes in a network, play a vital role in testing the robustness of security solutions in IoT environments.

The authors of the study [2] considered a network size of 50 nodes against 10 malicious nodes to test the robustness of their proposed scheme. Similarly, authors of the study [5] implemented three scenarios in their study, where they have 50, 100 & 150 network sizes with 10% of each network size as the malicious nodes. However, they only considered one type of attack in their study. In contrast, the study [18] despite

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having a smaller network size of 28 nodes and less number of malicious nodes of two nodes as compared to the studies [2] & [5], they tested the robustness of their proposed scheme by having multiple types of attacks in their study. It is relevant to consider multiple types of attacks when developing a defense scheme for networks such as IoT because these types of networks are susceptible to different types of attacks. In [30], the authors tested the robustness of their proposed scheme in a 30-node network size with 10% of them as malicious nodes where they implemented 4 different types of attacks in their scenarios. This ensures that the defense scheme can address multiple attacks. Furthermore, there are studies that considered a larger number of different types of attacks but only one malicious node was considered [7] & [27]. The former implemented two scenarios with 25 & 50 nodes in their network, while the latter only had 16 nodes in their simulation. However both studies considered a large number of attacks. Although, the robustness of their defense scheme might be jeopardized because of the number of malicious nodes considered and the network size. The study [33] demonstrated a desirable robustness test. By implementing scenarios of 16,32,64, & 128 network sizes and 10%,20%, & 30% as malicious nodes in each scenario. The study addressed eight different routing attacks. Though network size and the number of malicious nodes can be used to evaluate the robustness of the defense techniques, multiple attacks can also add a cherry on top.

4) RQ4: Which types of detection and placement strategies demonstrate the capability of addressing most attacks?

In this study, we demonstrated that three types of defense techniques can be employed to defend IoT networks against routing attacks, i.e., Secure-Protocol, conventional IDS, and ML-based IDS. However, the effectiveness of these techniques depends on the adopted detection strategy i.e., threshold, trust-based, signature-based, anomaly-based, hybrid, supervised-learning-based, etc., and placement strategy i.e., distributed, centralized, and hybrid. An adopted detection strategy that can address more than two attacks could be very effective in defense against routing attacks.

Authors of [17], adopted a threshold-based detection strategy to address four types of attacks. Althought they did not present their placement strategy it can be assumed to be distributed. Whereas authors in [18], adopted a trust-based strategy to detect three types of routing attacks. Studies by [7] & [29] adopted a hybrid strategy for both detection and placement in their proposed IDS techniques. The former can detect thirteen attacks, while the latter addresses six attacks. Moreover, they [27] adopted a hybrid detection strategy and utilized a centralized placement strategy to act against fourteen routing attacks. Authors of [30] adopted a signature-based detection strategy which is centralized to detect four attacks in their IDS. Studies that employ ML-based defense techniques appear to address more attacks than both IDS and Secure-protocol, where a centralized supervised learning-based detection strategy is realized [32], [34] & [37]. However, in [33], although they utilized supervised-learning-based detection the placement strategy used is decentralized, and their proposed technique addresses a total of eight attacks. Centralized placement of detection strategy appears to be effective, especially in a network of resource-constrained devices like LLNs. However, to consider mitigation of the attacks nodes in the network must participate; therefore, a hybrid placements strategy can be very effective in detecting and ensuring mitigation of routing attacks in RPL-based IoT networks, while both hybrid and supervised learning-based detection strategies demonstrate their effectiveness in addressing multiple attacks.

5) RQ5: Which routing attacks are mostly addressed by the proposed defense techniques?

Routing attacks can be divided into three categories according to their impact on the network i.e., traffic, network device resource, and topology impacting attacks. Traffic-impacting attacks such as Sinkholes, Wormhole, Blackhole, Grayhole, etc. are considered the most detrimental attacks in IoT [9, 27, 44]. However, flooding attacks seem to top the list of most investigated attacks in the selected studies. Flooding attacks exhaust the resources of network devices in the case of RPL-based IoT, particularly the energy of the devices, since most of the IoT devices are battery-powered. Furthermore, DIS-flooding attacks prevent nodes from participating in the transmission of both data and control messages. Fig. 7 below presents the distribution of investigated attacks in the selected studies.

It is found that 22 flooding attacks were investigated in the selected studies, followed by 16 rank attacks, which are resources and topology-impacting attacks, respectively.

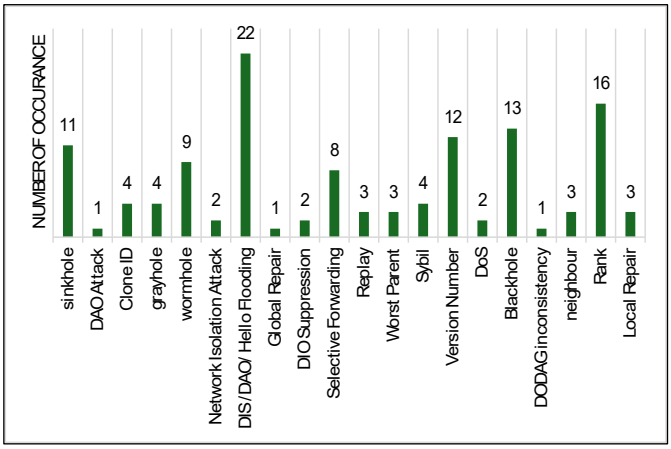

Fig.7 Distribution of discussed attacks in the selected studies

Moreover, the hole-family attacks i.e., Blackhole, Sinkhole, and Wormhole which are traffic-impacting attacks were found to be 13,11, & 9, respectively. Version Number attacks impact topology and, therefore, affect end-to-end delay and it appears 12 times in the selected studies as one of the most investigated attacks. To this end, it is evident that Flooding attacks, Rank attacks, Blackhole attacks, Version Number attacks, and Sinkhole attacks appear to be investigated most in the literature.

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6) RQ6: Which proposed techniques are capable of mitigating routing attacks?

Applications of IoT span multiple sectors including manufacturing, agriculture, health, smart homes and cities [45] as such their security is of great importance. However, in the case of attacks in the network, it is significant to detect and mitigate those attacks to allow normal functionality of the network. When developing defense techniques against attacks, more especially routing attacks mechanisms must be in place to then mitigate the attacks. Most of the Secure-Protocol techniques in the selected publications demonstrate the capability to mitigate the routing attacks that is 11 out of 13 proposed techniques mitigate the attacks. However, in studies that proposed IDS as their defense technique only 2 studies out of 8 can mitigate the attacks. Additionally, while ML-based defense techniques demonstrate a high detection rate, they lack mitigation mechanisms. Of the selected studies that employ ML as their defense only one study presented that their proposed technique could mitigate the attacks. The Secure-Protocol defense techniques demonstrate the results of attack mitigation.

7) RQ7: Which performance metrics are commonly used to evaluate the performance of defense techniques?

To evaluate the performance of RPL-based IoT networks several performance metrics can be used such as Packet Delivery Ratio (PDR), Control Message Overhead (CMO) which represents the number of control messages generated during an attack, throughput, End-to-End Delay (E2E), Energy Consumption (EC), Packet Loss Ratio (PLR) indicating the number of packets lost relative to the packets transmitted, etc. Fig. 8 depicts the distribution of evaluation performance metrics used in the selected studies.

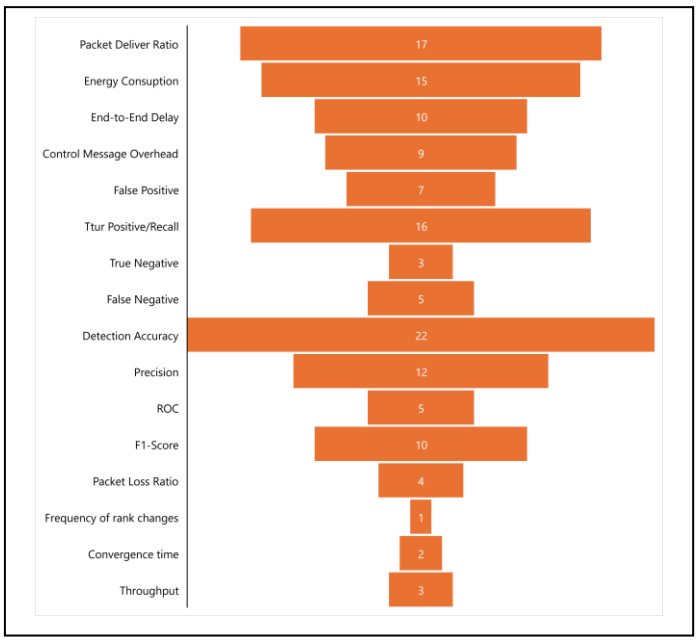

Fig. 8 Occurrence of evaluation metrics in selected studies

These metrics can also be used to measure the impact of routing attacks and the effectiveness of defense techniques on network performance. However, to evaluate the performance of the defense techniques, metrics such as Detection Rate (DR), Accuracy, True Negative (TN), False Positive (FP), False Negative (FN), True Positive (TP)/ Recall, etc., can be used. The most used evaluation metric for the defense techniques is detection / Accuracy which appeared 22 times in the selected studies. This metric is used to measure the number of detected malicious compared to the overall number of malicious nodes. To evaluate the effects of defense techniques we expect PDR to increase and PLR to decrease. However, most studies opted for PDR instead in which it appears 17 times and PLR only appeared 4 times in the selected studies.

The third most used metric is TP/Recall which measures the correct prediction of positive outcome by the defense technique. We mostly observe this metric in ML-based defense techniques. EC metric in RPL-based IoT is a crucial metric to consider because of the nature of the LLN devices we do not want to implement heavy techniques that harvest the energy of the nodes. The fifth most utilized metric is precision, especially for ML-based, which appears 12 times followed by E2E and F1-Score which both appear 10 times each. Functionality of RPL depends on Control messages exchanged between the nodes, hence CMO is an important metric to be considered in an RPL environment, it appears 9 times in the selected publications.

TABLE V presents the actual results obtained by the proposed defense techniques against routing attacks in RPL-based IoT. These are, however, the standard evaluation metrics commonly utilized to measure the performance of the network and the proposed defense techniques

It is recommended that the performance of a defense technique achieve at least 90%, more especially detection/accuracy, however, there are proposed techniques that obtained less than 90% detection/accuracy [27] in an IoT environment, this cannot be accepted because it implies that the technique can leave out more than 10% of the attacking nodes in the network which can still have a great impact on the performance of the network. Moreover, PDR is also an important metric to consider, and we must always strive for higher PRD, which evaluates the performance of the network under attacks and after attack i.e., upon mitigation of routing attacks. the proposed techniques in [39] obtained 69% of PDR, which means over 30% of packets are lost during network operation. Moreover, the technique in [31] achieved 76% of PDR which is still low same as [16] which produces 80% PDR indicating that 20% of packets are lost.

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TABLE V. STANDARD PERFORMANCE METRICS RESULTS OF SELECTED STUDIES

Study	Packet Delivery Ratio %	Energy Consumption	End-to-End delay	CMO	False Positive %	True Positive /Recall %	True Negative %	False Negative %	Detection \ Accuracy %	Precision %	ROC %	F1-Score %	PLR %	Frequency of rank changes %	Convergence time (s)	Throughput kbps
[2]	-	~2,4 mW		- 50%	-	-		-	--	-	-	91	-	-	-	-
[5]	-	-	-	-	-	-	-	-	-	-	-	-	-27,6	59.5	60	-
[17]	98.4					94.67		0.59	93.18	-	-	-	-	-	-	-
[1]	91	30%	0.883s	32	-	-		-	-	-	-	-	-	-	-	191
[3]	~93	2,3 mW	70s	+16 %	-	-		-	90	-	-	-	-	-	-	-
[4]	+66	2,31 mW	0,12 s	4439	0	100	100	0	100	100	-	-	25	-	-	-
[18]	98	6.75 mW	10s	-	-	-	-	-	--	-	-	-	-	-	-	-
[6]	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
[19]	~80	2,9mW	~2,2 s	-	-	-	-	-	~94	-	-	-	-	-	-	-
[20]	-	-	-	-	-	-	-	-	-	-	-	-	~10	-	-	-
[21]	95	2,4mW	0,9s	-	-	-	-	-	-	-	-	-	-	-	-	-
[22]	97,9	6,5mW	149.85	950	-	-	99.3	1.48	99.0	-	-	-	-	-	20	512.4
[23]	100	12.15mW	0.29 s	865	-	-	-	-	-	-	-	-	-	-	-	-
[24]	98.2	12.38mW	-	1043	-	-	-	-	95.64	-	-	-	-	-	-	-
[7]	-	+1.54%	-	94.7 %	-	-	-	-	-	-	-	-	-	-	-	-
[25]	-	-	-	-	-	87.9	-	-	-	-	-	-	-	-	-	-
[26]	96.3	>5%	0.03 ms	-	-	-	-	-	-	-	-	-	-	-	-	98.45
[27]	-	-	-	-	~14	-	-	-	85.71	-	-	-	-	-	-	-
[28]	-	-	-	-	-	50-96	-	-	-	-	-	-	-	-	-	-
[14]	92.8	-	-	-	-	-	-	-	-	-	-	-	8.2	-	-	-
[29]	High	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
[30]	-	5.3%	-	-	0.53	-	-	-	99	-	-	-	-	-	-	-
[31]	76	8.776mW	-	1474	-	96	-	-	92	98	-	96	-	-	-	-
[32]	-	-	-	-	-	99.3	-	-	99.3	99.2	-	99.3	-	-	-	-
[16]	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
[12]	-	-	-	-	-	-	-	-	97.76	-	-	-	-	-	-	-
[33]	-	3.50 mW	-	-	3.55	90.6	-	-	94.1	94.6	-	94.1	-	-	-	-
[34]	-	-	-	-	-	-	-	-	98	-	-	-	-	-	-	-
[35]	-	-	-	-	-	98.9	-	0.6	-	98.9	100	98.9	-	-	-	-
[13]	-	-	-	-	-	93.3	-	-	-	93.3	92	93.3	-	-	-	-
[36]	-	-	-	-	24	100	-	-	96	100	100	86	-	-	-	-
[15]	-	-	-	-	-	99.68	-	-	99.99	100	-	-	-	-	-	-
[37]	-	-	-	-	-	-	-	-	94.4	-	93.4	-	-	-	-	-
[38]	-	-	-	-	4.5	97.5	95.5	2.5	96.6	96.7	-	96.6	-	-	-	-
[39]	69	-	0.9s	-	-	-	-	-	99.95	-	-	-	-	-	-	-
[40]	-	-	-	-	-	92	-	-	98	92	100	92	-	-	-	-
[41]	-	-	-	-	-	99.8	-	-	99.8	99.7	-	-	-	-	-	-
[42]					0.78	97.1			97.1			97.1				
[43]	-	-	-	-	-	98.1	-	-	99.7	99	-	-	-	-	-	-

There are, furthermore, other uncommon evaluation metrics used to measure the performance of the proposed techniques. These metrics are presented in Table VI below. We used a table to track the frequency of occurrence of these

metrics. Other researchers can explore this table and use some of these metrics to evaluate their proposed techniques.

TABLE VI. UNCOMMON PERFORMANCE EVALUATION METRICS USED IN THE SELECTED PUBLICATIONS

Evaluation metric	occurrence	Evaluation metric	occurrence
No of Device detached	1	CPU	1
Single-hop Average Trip Time	1	Data Packet overhead	1
Isolation Latency	1	Average reward	1
Avg routing packets per min	1	Average Packet Delivery Time	1
No of DAO forwarded	1	Kappa	3
Attack Identification	1	MCC	4
Attack detection delay	1	Cross Entropy	2
Preferred parent change rate	2	Expected Transmission Count	1
Network overhead	1	RAM & ROM	1

8) RQ8: What are the best defense techniques, detection and placement strategies, challenges, and future research areas?

Three defense techniques were discovered i.e., Secure-Protocol, Conventional IDS, and ML-based technique. Amongst the three, Secure-Protocol appears to detect and mitigate routing attacks though it is limited to not more than 4 attacks. however, from the selected publications most of the ML-based techniques only detect attacks with high accuracy but lack mitigation mechanisms. This was discovered to be the limitation of most of the ML-based studies. One of the reasons for this lack of mitigation is the lack of pipeline development and deployment of the ML technique. Additionally, most of the Secure-Protocol techniques utilize a decentralized placement strategy to implement their defense techniques, while conventional IDS takes advantage of a hybrid placement approach utilizing both centralized and decentralized placement.

The future research direction the authors of this study will take is to investigate and set up a simulation environment for routing attacks in RPL-based IoT to measure their impact on the network. Furthermore, implement an ML-based defense technique that can detect and mitigate the investigated routing attacks. Taking into consideration the placement strategy; it was discovered that hybrid placement proves to be an efficient strategy that guarantees centralized detection and distributed mitigation implementation. Moreover, some secure-protocol detection strategies can be deployed to mitigate the attacks. In conclusion, integration of ML-based IDS and Secure-Protocol appears to be an effective approach to defend RPL-based IoT against routing attacks.

V. Conclusion

The Internet of Things (IoT) emerges with different innovations including smart agriculture, environmental monitoring, and smart grids, to name a few. One of the significant enablers of IoT technology is the Low-power and Lossy Networks (LLNs) which comprise interconnected devices with low computational capabilities and less storage and are often operating on batteries such as sensor nodes and actuators. However, the broad adoption of IoT faces challenges in terms of security due to some of its characteristics, i.e., direct access to devices from the internet, the communication nature of wireless media, and potential unattended operations of relevant deployment. This study has conducted a Systematic Literature Review on the defense techniques against routing attacks in RPL-based IoT; as such 9 research questions were formulated to assist the researcher in gaining an insight into the defense techniques that can be implemented to defend the RPL-based IoT against routing attacks that take advantage of vulnerabilities of RPL protocol to affect traffic, topology, and resources of the network. However, the defense techniques in the studies demonstrate the effectiveness in detecting the attacks. With proper implementation and strategic placement of the techniques and integration into a hybrid defense technique, the technique can be effective in detection and mitigation, efficient to the network resources consumption and robust to address and cope under a large number of attacks.

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A web-based tool for the sizing of grid-connected photovoltaic (PV) systems in Ecuador

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A web-based tool for the sizing of grid-connected photovoltaic (PV) systems in Ecuador

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***Abstract*—**The transition to cleaner and more sustainable energy sources involves the use of solar photovoltaic energy. This energy source has the potential to reduce greenhouse gas emissions and dependence on fossil fuels. The research project focused on the development of a web-based tool for sizing photovoltaic systems in Ecuador. This tool considers several factors, including technical, theoretical, economic and environmental aspects. The tool allows sizing based on electricity consumption and power requirements. Furthermore, the tool provides technical information, CO_2 reduction data and economic perspectives based on the operation of the electricity system in Ecuador. The comparative validation with installed systems and similar web tools demonstrated the reliability and robustness of the developed tool.

***Keywords*—** *photovoltaic systems, self-consumption, renewable energy, photovoltaic production*

I. Introduction

Solar photovoltaics is currently the fastest growing generation technology in terms of capacity expansion and has become one of the main sources of power generation [1]. In Latin America, the increase in electricity demand has highlighted the importance of solar PV as a crucial element to foster economic development and social welfare [2]. In Ecuador, despite the remarkable growth of renewable energies in recent years, a high dependence on fossil fuels persists, especially in sectors such as transport and industry [3]. The expansion of renewable energy sources, such as solar photovoltaics, has emerged as a pivotal strategy to mitigate the high costs and emissions associated with conventional energy sources, thereby facilitating the transition towards a more sustainable energy system [4].

Considering the aforementioned circumstances, there is a pressing need for the development of specialized analytical and dimensional tools for the analysis and assessment of photovoltaic systems, with particular emphasis on self-consumption modalities. In this context, we propose the development of a web tool to assess the technical and economic feasibility of implementing grid-connected photovoltaic systems in Ecuador. The objective is to provide significant support in decision-making in this area.

A. Conventional and renewable energies

Renewable energy is obtained from natural sources that are virtually inexhaustible and plays a crucial role in meeting global energy demand while preserving the environment [5]. Renewable energies, including solar, wind, water and biomass, do not generate greenhouse gas emissions during their operation, making them a sustainable and environmentally friendly alternative. These energies are essential for the transition towards a cleaner and more sustainable energy system. In this context, grid-connected photovoltaic systems (GRPS) for self-consumption represent an important innovation in the use of renewable sources. SFCRs generate electricity that can be fed into the grid. Their main components include photovoltaic modules, an inverter for grid connection, a grid exchange device and a bi-directional energy meter. The grid acts as an accumulator with indefinite capacity, and the user connected to this grid represents the load. The security of SFCRs is enhanced compared to standalone systems, as they can continue to operate in the event of a battery system failure, provided that a connection to the grid is available [6]. In the PV distribution mechanism, some countries have opted to give benefits to the system owner for the energy fed into the grid [7].

B. The impact of solar radiation on the performance of solar panels in Ecuador

Ecuador benefits from considerable solar radiation, reaching a Global Horizontal Irradiation of 2,264 kWh/m^2 (kilowatt hour per square meter) in the highland [8]. This makes it one of the countries with high solar energy potential. However, there are variations in radiation levels, with levels ranging between 30 % and 40 % across different regions due to atmospheric conditions [9]. The country has a solar energy potential that covers approximately 9.3 % of its national territory, with around 805 square kilometers suitable for photovoltaic systems. This translates to a gross theoretical potential of 35.7 GWp and an annual production of approximately 61.5 GWh [10].

In terms of energy policy, Ecuador is promoting the adoption of photovoltaic systems due to their advantages, in line with the Electrification Master Plan 2019-2027. In 2022, approximately 61.21 % of the total nominal capacity of electricity generation will come from renewable sources, with solar PV contributing a total of 27.76 MW, representing 0.53 % of the total energy supply generated by PV systems. These systems have been installed in several Ecuadorian provinces such as Cotopaxi, El Oro, Galapagos, Guayas, Imbabura, Loja, Manabí, Morona Santiago, Pastaza and Pichincha [11].

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C. *Standards and regulations*

In Ecuador, the implementation of photovoltaic systems is governed by various regulations that promote the sustainable use of solar energy and ensure technical safety. Regulation ARCONEL 003/18 allows for PV micro-generation of up to 100 kW in residential and commercial buildings, with the possibility of feeding excess power into the grid [12]. ARCONEL 057/18 extends these conditions to systems of up to 300 kW for residential buildings and up to 1,000 kW for commercial and industrial buildings, encouraging the uptake of PV [13]. The 2019 Organic Law on Energy Efficiency establishes a legal framework for the efficient and sustainable use of energy, contributing to the fight against climate change and improving the quality of life. Regulation ARCERNNR-001/2021 authorizes distributed generation systems with renewable energy sources up to 1 MW and introduces "net metering" to balance energy supplied and surplus. Regulation ARCERNNR-004/23 of 2023 establishes guidelines for the installation of photovoltaic micro-generation systems and mandates the implementation of metering and customer care systems, promoting sustainable projects to meet the growing demand for electricity [14].

D. *Electricity costs in Ecuador*

An analysis of the customer's electricity consumption was carried out, covering daily, monthly and annual consumption. This study is crucial to determine the average consumption in kWh on a bimonthly and annual basis and is essential to calculate the number of solar panels and inverters required for the PV system. To calculate a household's daily consumption, the consumption of each appliance is broken down according to its average hours of use [15].

The calculation of the average monthly electricity consumption typically involves the aggregation of the electricity consumption data recorded during a particular month. The calculation of the average monthly consumption is calculated using Equation 1 [15].

$$Cm_m = Cm_d * (KWh/día) * 30 \quad (1)$$

Where:
Cm_m : Average monthly consumption;
Cm_d : Average daily consumption.

Furthermore, total annual consumption refers to the total amount of a resource or service utilized over the course of a specific year. This can be calculated using Equation 2 [16].

$$\mathrm{Cm_t} = \mathrm{Cm}_m \left(\frac{\mathrm{KWh}}{\mathrm{day}}\right) * 12 \quad (2)$$

Where:
Cm_t: Total average annual consumption;
Cm_m: Monthly average consumption.

The cost of the public electricity service in Ecuador is regulated by the Electricity Regulation and Control Agency (ARCERNNR, by its Spanish acronym of Agencia de Regulación y Control de Energía y Recursos Naturales no Renovables), which establishes principles of solidarity and equity in the allocation of costs. Annual tariff parameters detail the costs of all stages of electricity supply, from generation to marketing [17]. In the residential category, billing costs focus on domestic use, considering consumption in kWh and a marketing charge. In the commercial category, the cost varies according to the amount of electricity used, with an additional marketing value. For medium voltage connections, the price is USD 0.095/kWh and USD 1.414 for marketing. In the industrial category, companies pay USD 0.083/kWh for energy and USD 1.414 for marketing [11].

II. METHODOLOGY

A methodology combining data collection based on the scientific method with deductive and analytical approaches was employed for the dimensioning (sizing) of solar photovoltaic systems. The analysis of the information enabled the definition of project objectives and the steps to be followed. Algorithms were developed to facilitate the visualization of dimensioning processes, which are illustrated in flow charts detailing the necessary calculations. Figure 1 shows the steps for programming the dimensioning page according to consumption, beginning with the selection of the connection type to obtain the corresponding tariffs. Additionally, an option is provided to calculate consumption based on appliances if consumption data is not available.

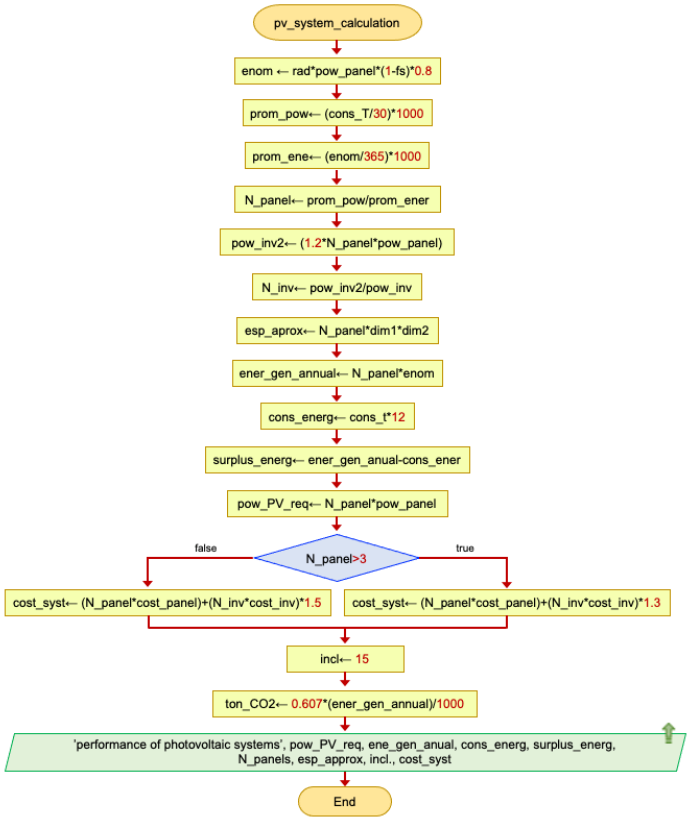

Fig. 1. Flow chart for the calculation of system performance

To calculate savings and returns, we used the diagram in Fig. 2, which shows how the system works. The sizing page is programmed according to the system power.

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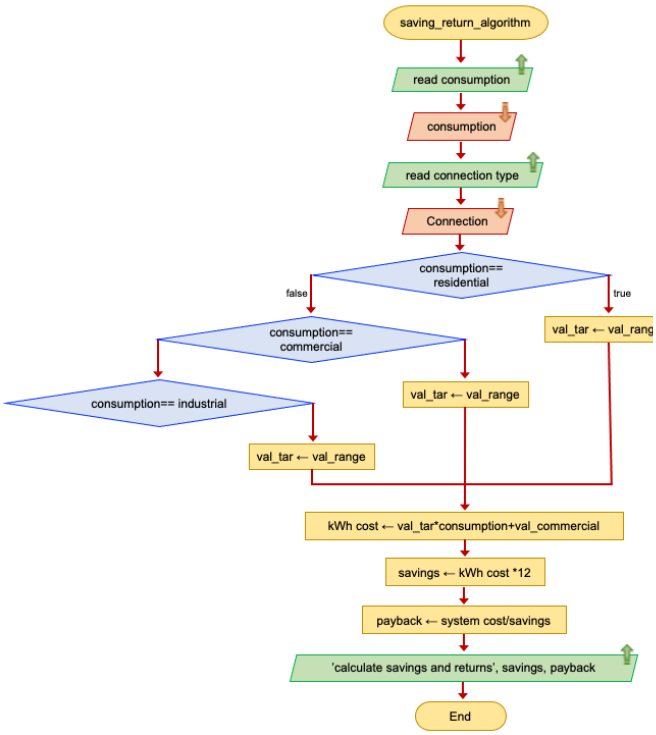

Fig. 2. Flow chart for the calculation of system savings and returns

The scientific method was used to ensure the validity and reliability of the data, allowing a thorough interpretation of the results. Relevant information was collected for the project, such as monthly averages of solar irradiation in Ecuador's 24 provinces, local electricity tariffs and the power ratings of household appliances. Solar radiation data was obtained from the Global Solar Atlas [18], which is essential for accurate analysis in project sizing.

Equally important, data on electricity tariffs and operating companies in Ecuador was obtained from the 2022 tariff schedule. Monthly irradiation data was collected for the 24 provinces of Ecuador for the sizing of the PV systems. This data was then used to determine the annual global radiation, enabling the calculation of the annual average Global Horizontal Irradiance (GHI) for each province. This process was conducted using Equation 3.

$$R_{GH} = \frac{\frac{G_{a0}}{G_{a\beta_{opt}}}}{G_{a,ef}(\alpha\beta)} * P_{RGH} \quad (3)$$

Where:
R_{GH}: Global Horizontal Irradiance (GHI);
$\frac{G_{a0}}{G_{a\beta_{opt}}}$: Monthly average irradiance;
$G_{a,ef}(\alpha\beta)$: Effective irradiance;
P_{RGH}: Average Global Horizontal Irradiance (GHI).

To calculate the Global Horizontal Irradiance, it is first necessary to determine the mean annual irradiance on a sloping surface. This is related to the optimum angle of slope and to the annual irradiance in the horizontal plane. The optimum angle of slope, denoted as β_{opt} in degrees, can be found using Equation 4 [7].

$$\frac{G_{a0}}{G_{a\beta opt}} = 1 - 4.46*10^{-4}*\beta_{opt} - 1.19*10^{-4}* \beta^2_{opt} \quad (4)$$

In the second step, the effective irradiance was calculated using regressions that consider angular losses and annual soiling losses for static systems. The following Equation 5 proposes this calculation [7].

$$G_{a,ef}(\alpha\beta) = G_{a,ef}(\beta_{opt}) * \left[g_1(\beta - \beta_{opt})^2 + g_2(\beta - \beta_{opt}) + g_3\right] \quad (5)$$

Where:

g1, g2, and g3 are values of the coefficients for the case of a module with average soiling.

In the third step, the optimal tilt angle of the solar panel, which varies according to the specific geographical location, was calculated. This value can be determined using Equation 6 [19].

$$\beta_{opt} = 3.7 + 0.69|\emptyset| \quad (6)$$

Where:
β_{opt}: Optimum tilt angle;
$|\emptyset|$: Latitude.

The average global horizontal radiation is obtained using Equation 7 [20]:

$$G_d = D_d + D_f * Cos\ \theta_z \quad (7)$$

Where:
G_d: Horizontal global radiation kWh/ m²;
D_d: Direct radiation kWh/ m²;
D_f: Diffuse radiation kWh/ m²;
θ_z: Zenith angle.

Direct radiation can be calculated by [21] and diffuse radiation by applying the formula used in [22].

The calculation of the zenith angle is of paramount importance for the accurate determination of global radiation, particularly in contexts pertaining to solar energy. This angle is defined by Equation 8 [23].

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \quad (8)$$

Where:

δ: Declination angle;

ω: Hour angle.

To calculate the solar declination, the equation relating it to the zenith angle is used. A specific day, in this case, day 183, corresponding to July 2 2022, is chosen to calculate this parameter using Equation 9.

$$\delta = 23.45° \text{ sen}\left[360\left(\frac{284 + n}{365}\right)\right] \quad (9)$$

The data obtained for each of the provinces are presented in Table I.

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TABLE I. RADIATION DATA FROM THE PROVINCES OF ECUADOR

Provinces	Annual Global Radiation kWh/m²	Provinces	Annual Global Radiation kWh/m²
Esmeraldas	1,386.45	Zamora	1,252.22
Manabí	1,727.76	Carchi	1,361.59
Santa Elena	1,817.08	Imbabura	1,506.27
Sto. Domingo de los Tsáchilas	1,251.50	Pichincha	2,212.78
Los Ríos	1,416.49	Cotopaxi	2,135.51
Guayas	1,616.51	Tungurahua	1,746.93
El Oro	1,251.68	Bolívar	1,549.69
Sucumbíos	1,647.94	Chimborazo	1.931.57
Napo	1,262.58	Cañar	1,754.43
Orellana	1,649.27	Azuay	1,752.21
Pastaza	1,653.36	Loja	1,974.33
Morona Santiago	1,294.65	Galápagos	2,065.73

Once all the requisite data has been gathered, the nominal photovoltaic (PV) power generated by a 405-watt panel is calculated. For the purposes of sizing, this panel is employed as a reference. The estimation of the energy production of the PV generator is conducted using Equation 10, which permits the estimation of the energy generated on a daily, monthly or yearly basis [7].

$$\mathbf{E_{PV} = P_{NOM,G} * Y_R * (1 - FS) * PR} \quad (10)$$

Where:
E_{PV}: Nominal energy produced per year (kWh);
$P_{NOM,G}$: Nominal power of the PV generator (1 kW/m²);
Y_R: Average annual incident radiation in the plane of the generator;
FS: Shadow factor (kWh/m²);
PR: Performant ratio which is 0.7 or 0.8.

The sizing of the photovoltaic (PV) modules is based on the monthly daily consumption, as defined in Equation 11.

$$\mathrm{Cm_{ta}} = \mathrm{Cm}_m \left(\frac{\mathrm{kWh}}{\mathrm{day}}\right) * 12 \quad (11)$$

Where:
$\mathrm{Cm_{ta}}$: Annual total consumption;
Cm_m: Monthly average consumption

The required number of PV modules is determined by the ratio of the monthly average daily consumption to the energy produced by a PV module, as shown in Equation 12 [15].

$$\mathrm{N} = \frac{\mathrm{Cm}_{dm}/30}{\mathrm{E_{FV}}/365} \quad (12)$$

Where:
Cm_{dm} : Monthly daily consumption.
E_{FV}: Nominal energy produced per year (kWh)

When sizing the inverter, the AC power requirement of the load must be considered, so that the rated power is 20% higher than the load requirement. The sum of the power of the devices to be operated simultaneously is considered. This sizing can be done using Equation (13) [16]. It is important to avoid oversizing the inverter so that it operates in optimum conditions.

$$\mathrm{P}_{INV} \approx \mathrm{SF} * \mathrm{P_{AC}} \quad (13)$$

Where:

P_{INV}: is the nominal capacity of the inverter (in kW or kVA),

E_{PV}: is the annual energy generated by the photovoltaic system (in kWh);

SF: is sizing factor, generally ranges between 0.8 and 1.25 depending on the system and climate conditions).

The following Equation 26 is used to calculate the CO_2 savings [24].

$$CO_{2\ savings} = E_{PV} \times F_{CO_2}$$

Where:

E_{PV}: is the annual energy generated by the photovoltaic system (in kWh);

F_{CO_2}: is the CO_2 emission factor of the grid electricity (in kg CO_2/kWh).

III. WEB SYSTEM DEVELOPMENT

The website has been developed entirely in Spanish, as its purpose is to be used as a tool for residents of this country. The domain chosen was: "*www.solecuador.com*" and it is currently active (see Fig. 3.). The design and programming of the research web tool was based on the use of WordPress, a software widely recognized as a Content Management Platform (CMS) due to its ease of use and versatility, which made it the ideal choice for creating the tool for sizing photovoltaic systems. Below, there is a clear and concise presentation of the techniques and steps used to develop the project.

Fig. 3. Main website interface

A. Conventional and renewable energies

To design and implement a web tool to simulate SFV with connection to the electricity grid, which allows the technical and economic analysis of these systems, a MySQL database was created to store the different data to be used for the sizing of the system. The design of the database is shown in Fig. 4, where the organization and structure of the tables, as well as the relationships between them, can be appreciated.

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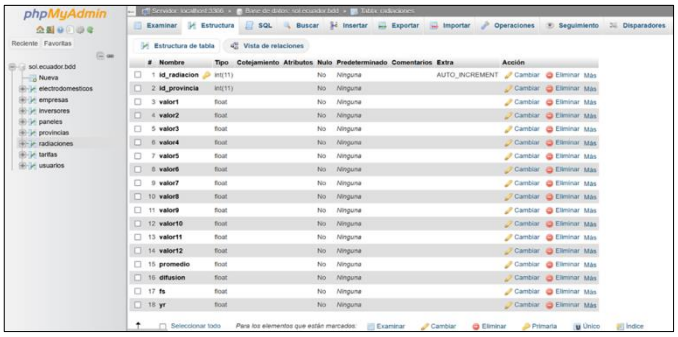


Fig. 4. Database configuration

One of the outstanding features of the database is its interactivity. An interface has been developed that allows the administrator to easily update key data. This includes information on provinces, solar radiation data, equipment specifications and the company's electricity tariff, as shown in Fig. 5. This real-time update capability gives the management team the flexibility to keep the data up to date and accurate. It also facilitates adaptation to changing environmental conditions, such as new regulations or equipment upgrades, ensuring the continued effectiveness and relevance of the site.

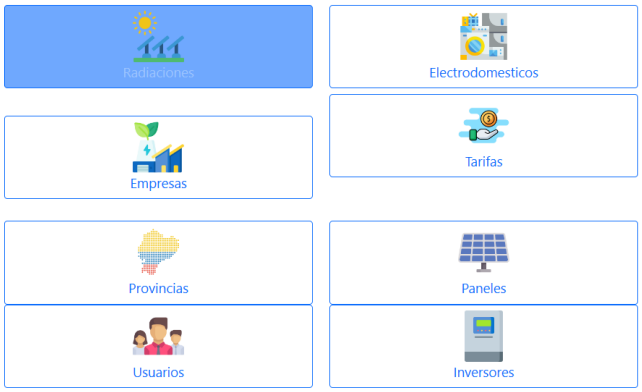
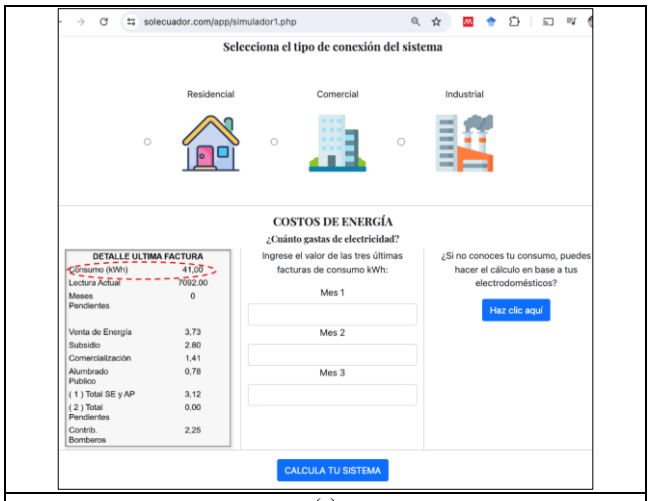


Fig. 5. Administrator interface for updating parameters

For the development of the web pages, the Twenty Twenty-Two Version: 1.4 theme was used, considering its relevance for the personalization and aesthetics of the site. The Akismet Anti-Spam Version 5.2 and Elementor Version 3.14.1 plugins were installed, for spam protection and efficient visual page creation, respectively. After installing Elementor, we proceed to edit the web page, addressing the structure, content and design, either through the visual editor or through HTML and CSS code. Once the main page is finished, the creation of the secondary pages begins, adapting the design to the structure and specific content of each page. Figure 6 shows the structure of the consumption-based simulator 1, designed according to equations 11, 12 and 13. This visual representation illustrates the organization and calculations required to simulate energy consumption and size the PV system based on the data provided.



(a)

(b)

Fig. 6. Design of the secondary side for the calculation of the sizing of photovoltaic systems based on their consumption. (a) Input screen, (b) Simulation result

On the other hand, Figure 7 shows the structure of simulator 2 based on its power output, using equations 10, 12 and 13. This figure shows how the necessary power of the photovoltaic system is organized and calculated to meet the defined energy demand.

(a)

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(b)

Fig. 7. Design of the secondary side for the calculation of the sizing of photovoltaic systems based on their power. (a) Input screen, (b) Simulation result

The data for the validation of the tool are taken from different web simulators, where the calculation was made for a consumption of 228 kWh, as shown in Table II, where the percentage difference that exists with each of the tools can be seen.

TABLE II. DATA TAKEN FROM THE DIFFERENT WEB TOOLS, FOR THE VALIDATION OF THE TOOL

Provinces	Web tools		Variation between systems
	Global Solar Atlas kWh/year	*Solecuador kWh/year*	
Pichincha	2,522.00	2,850.56	11.52 %
	PVGIS kWh/ year	Solecuador kWh/ year	
Pichincha	2,432.49	2,850.56	14.66 %
	Global Solar Atlas kWh/year	Solecuador kWh/ year	
Guayaquil	3,046.00	3,126.78	2.58 %
	PVGIS kWh/year	Solecuador kWh/ year	
Guayaquil	3,034.41	3,126.78	2.071 %
	Global Solar Atlas kWh/year	Solecuador kWh/ year	
Pastaza	3,062.00	3,194.85	4.15 %
	PVGIS kWh/year	Solecuador kWh/ year	
Pastaza	3,037.32	3,194.85	9.93 %

To validate the web tool, real data from three operational stations currently connected to the electricity grid was used. Station 1 is in the city of Manta, while stations 2 and 3 are in the city of Quito. All three stations are fully operational and monitored by the FRONIUS SolarWeb system. Table III shows the comparison between the data obtained from the real systems and the data generated by the tool. There is a significant difference in the results, since the radiation values used by the tool are for the period between 2019 and 2020. In addition, the tool not only provides information on the energy produced, but also calculates the tons of CO_2 that could be saved by installing the PV systems.

TABLE III. COMPARISON OF THE DATA OBTAINED FOR THE VALIDATION OF THE WEB TOOL

PV Station	Annual Comsuption (kWh/year)	PV Power (kWp)	PV Production (kWh/year)	Solecuador simulation (kWh/year)	Variation
Station 1	26,258	8.25	12,549.5	11,696.9	6.79 %
Station 2	22,439	5.23	7,766.6	9,254.6	16.07 %
Station 3	18,846	11.235	15,719.9	19,933.1	21.13 %

CONCLUSIONS

The sizing of the developed system is based on the consideration of several key parameters, such as the solar radiation at the specific system location, the orientation and tilt of the solar panels, and the efficiency of the components. The comprehensive assessment, which includes electricity consumption as a direct indicator of energy demand, is crucial in determining the right size of the system, requiring considered decisions on inverter capacity, panel power and storage capacity. This approach promotes efficient sizing.

The research highlights the potential of photovoltaic systems as a sustainable and renewable energy source. The literature review was not limited to theoretical, technical and economic aspects, but also addressed fundamental environmental considerations, such as calculating the amount of CO_2 that will be avoided by the operation of these systems, allowing for an effective and sustainable implementation.

Current regulations in Ecuador promote clean, renewable technologies and energy efficiency, as evidenced by the 2019 Organic Law on Energy Efficiency and specific regulations such as ARCONEL 057/18, ARCERNNR 001/2021, No. ARCERNNR-004/23 and No. ARCERNNR-008/23. These regulations define requirements for photovoltaic generation, the connection of distributed generation systems and energy storage, with the aim of effectively regulating the energy sector and moving towards a more modern, efficient and sustainable system.

When comparing the results of the Solecuador web tool with well-known tools such as PVGIS and SOLARGIS, minimal variation in the performance of PV systems was observed. However, when compared with data from operational PV systems, a greater difference in results was observed, possibly due to the increase in solar radiation in recent years. For this reason, an option has been implemented to allow the tool administrator to frequently update the solar radiation data by province, which will improve the reliability of the results.

The relevance of the economic factor has been crucial in the sizing of photovoltaic systems, highlighting key values such as the cost of energy, the cost of the photovoltaic system and the cost of installation. The tool has allowed a comprehensive economic analysis to be carried out, considering the specific parameters of the Ecuadorian environment, particularly through the application of cost per consumption bands. This attention not only optimized the

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technical efficiency of the system, but also provided a comprehensive assessment of the profitability and economic viability of implementing PV systems.

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Data Domain Servitization for Microservices Architecture

ARTICLE HISTORY

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***Abstract*—** Microservices have emerged as a software design paradigm where small, autonomous services interact to meet business requirements. However, transitioning from monolithic systems to microservices presents challenges, especially when multiple subdomains share transactional tables to maintain referential integrity across separate databases. Ensuring each microservice handles business data while adhering to ACID properties—namely, atomicity, consistency, isolation, and durability—is crucial. This requires unique, consistent, and low-dependency data from a business domain perspective.

Systematic Literature Review serves as a secondary research method aimed at evaluating the existing body of scientific literature. It helps identify existing work, highlight research gaps, and propose new research directions. In software engineering, SLRs offer a comprehensive overview of studied research areas.

This article reports an empirical study based on a systematic literature review aimed at identifying modeling techniques for segmenting data structures during microservice design. The review found limited methods to address the appropriate level of data granularity per microservice. These findings highlight a need for further research into processes and methodologies that can effectively handle data segmentation and consistency within microservice architectures.

***Keywords*—** *Servitization, Granularity, Data Segmentation, Microservices, Data Architecture, Microservices Architecture*

I. Introduction

Microservices architecture is a software architecture style focused on using small, lightweight services designed to adapt to dynamic business environments [1]. Each microservice results from decomposing monolithic systems or is modeled as an independent component from development to deployment. This approach enables the scalability and evolution of each service with autonomy over its data stores.

A microservices ecosystem manages its governance by delegating business responsibilities to each service, with boundaries defined by subdomains that handle specific parts of the business process. However, defining the subdomain for each microservice introduces several complexities when data entities that are closely related are shared. This approach necessitates maintaining independent data stores for each microservice, leading to various challenges such as ensuring the atomicity, consistency, isolation, and durability (ACID) of data, managing transactions and their dependencies, and defining mapping rules, among others [2].

Microservices are the result of breaking down an application services into smaller components to enhance composability, agility, deployment, and alignment with business objectives [1]. Shahir et al. state that decentralized data management is a crucial design characteristic of microservices. They propose that each microservice should manage its own database, as using a shared database violates the principles of microservices architecture. Therefore, a key element is to ensure that each microservice maintains its own data storage [2].

There is a growing demand for data-driven web applications, such as those used for recommendations, predictions, and segmentation. These applications are often transformed into complex conglomerates of services that operate with challenges in coherence and management within their architecture [3] Microservices can be a potential solution. Unlike traditional services, microservices represent an architectural style focused on decoupling and specialization. The guiding principle is that each microservice should perform a single task in the most efficient way and be easy to understand. This task should have the smallest possible function, but not necessarily the minimal one [1], [4], [5], [6], this leaves software architects with the responsibility of finding a middle ground and determining the appropriate level of function and data granularity based on their experience and judgment. According to authors like Nadareishvili et al., breaking a service into smaller parts requires a method that establishes the criteria for a minimum viable level of granularity to be managed by each microservice [7]. The existence of a minimum viable size is not proposed. Instead, they note that there is no definition in the literature regarding how small or independent microservices should be [8], ultimately leaving it to those designing microservices to establish their own guidelines.

Data modeling initially relies on the abstraction of business entities, evaluated as a unified set with attributes, relationships, and interactions [9]. In microservices design, this modeling must be segmented, with each microservice specializing in a specific section. This involves defining an individual storage strategy, consuming data from other microservices, and mapping to the original data source.

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The authors highlight the need for existing or new methods in the literature to guide the segmentation of data structures, ensuring viable microservices implementation. Without such methods, designers may rely on intuition and trial and error, potentially breaking design principles, consuming excessive resources, and blurring distinctions from traditional SOA services.

In a preliminary literature review, the authors did not find a proposed method for segmenting a business data model or determining the appropriate granularity for each microservice. Therefore, a more comprehensive study through a Systematic Literature Mapping is necessary to identify the presence or absence of such methods in the scientific literature. Identifying these methods would help highlight and disseminate them among software architects and researchers, promoting microservices architecture as a viable option. Conversely, if no such methods are found, it would open a new research area focused on this specific topic.

The study aims to conduct an exhaustive literature search to determine if methods exist for segmenting data structures in microservice design. The article explores the challenge of aligning microservice principles with a method to determine the appropriate data granularity (fine or coarse) for each service without physically dividing the business domain while ensuring better efficiency, performance, and balance of the microservice.

This article is structured as follows: Section II describes the Systematic Review procedure, including the method, research questions, inclusion and exclusion criteria, search strategy, selection process, and data extraction. Section III details the techniques found for data modeling in microservices. Section IV discusses the results obtained. Finally, Section V presents the conclusions of the study.

II. Systematic Review

A. Research Framework

According to Kitchenham [11] in several of his collaborations, has established the main approaches to carry out literature reviews rigorously in the field of software engineering such as Systematic Literature Review, SLR; Systematic Mapping Study, SMS [10] and Mapping Review Combined with a Systematic Review. A Systematic Mapping Study (SMS) is defined as "a broad review of primary studies in a specific topic to identify the available evidence in that area". In this context, primary and secondary studies are distinguished. A primary study is "an empirical study investigating a specific research question", while a secondary study is "a study that reviews all primary studies related to a specific research question with the aim of integrating/synthesizing the evidence related to that research question".

A Mapping Review Combined with a Systematic Review provides a structured reporting framework for research, often presenting results through categorization, which frequently offers a visual summary of its findings (the map). The analysis of results is conducted by extracting relevant information and categorizing it to determine the contributions of primary studies within the research area.

In addition to SMS, there are other types of secondary studies, such as Systematic Reviews. According to Kitchenham and Charters [10], a Systematic Literature Review is "a type of secondary study that uses a well-defined methodology to identify, analyze, and interpret all evidence related to a specific research question in an objective and repeatable manner (to some degree)".

Given the issues outlined in the introduction and the objectives set for this research work, an SMS was chosen as the proposed Research Framework.

B. Methodology

To minimize potential threats to the validity of the research and to provide appropriate answers to the research questions, the authors have chosen to use a Systematic Mapping Study (SMS) following the process below [10], [11]:

1) *Research Question*
   a) *Problem Statement*
   b) *Research Questions*

2) *Inclusion and Exclusion Criteria*
   a) *Selection Criteria*

3) *Search Strategy*
   a) *Control Group*
   b) *Search String*
   c) *Candidate Studies*

4) *Selection Process*
   a) *Candidate Studies*
   b) *Study Selection*
   c) *Primary Studies*

5) *Data Extraction*
   a) *Feature Extraction*
   b) *Model Extraction*

Figure 1 presents the sequence of steps performed as part of the Systematic Mapping Study applied to this research project.

C. Research Question

1) Problem Statement

Unlike traditional SOA services, a distinctive characteristic of microservices is that, by design, each one should have its own specialized and independent data model and storage. This approach avoids direct references between services, making them more decoupled and modular, enabling the composition of more complex deployments [2].

During business data modeling, analysts typically abstract all entities, attributes, relationships, and interactions to create a unified representation model [9]. However, in the design of microservices, it is necessary to segment the data to identify,

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for each microservice, the relevant entities, attributes, relationships, and interactions specific to its limited scope.

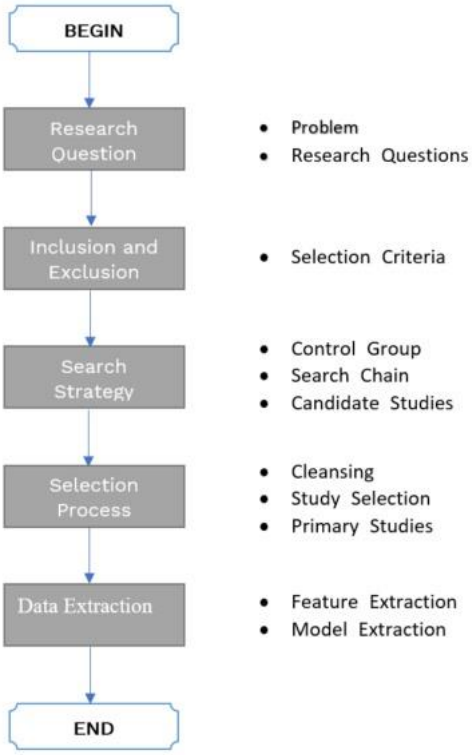

Fig. 1. Systematic Mapping Study Process

This segmentation process is often based on the intuition and judgment of the developer or software architect, lacking a guideline or method grounded in theory that defines the optimal level of granularity and the appropriate boundaries for subdivision.

Thus, there is a need to explore the scientific literature for proposed methods for data structure segmentation. If such methods are found, they could strengthen the theoretical and practical aspects that would encourage broader adoption of microservices architecture according to its theoretical conception. Without a defined method, each practitioner may select the desired level of granularity based on intuition and trial and error. This could lead to violations of certain design principles, excessive resource consumption, and neglect of the necessary differentiation from traditional SOA services, rendering microservices almost unnecessary.

2) Research Question

To ensure a comprehensive research approach to the proposed problem, the following research questions were defined by mutual agreement among the authors:

- **RQ1: What data modeling techniques can be used for business data segmentation in the construction of microservices?**
- **RQ2: How can the granularity of microservices be modeled or established?**

Table 1 presents the aspects that these research questions aim to address.

TABLE I. OBJECTIVES OF THE RESEARCH QUESTIONS

Question ID	Objective
QR1	Determine which data modeling techniques exist for data segmentation in the implementation of microservices. If any are found, detail the characteristics of the proposed data segmentation procedure and discuss its coverage in relation to the proposed problem.
QR2	Identify the approaches used to define and measure the levels of functional and data granularity in the implementation of microservices.

D. Inclusion and Exclusion Criteria

1) Inclusion Criteria:

- The article describes a method aimed at data segmentation in microservices design.
- The article describes a process or data modeling technique focused on data segmentation in microservices design.
- The article describes aspects or criteria used to define the granularity of microservices.
- The article presents examples or case studies demonstrating the application of data segmentation in microservices design.
- The article discusses the challenges of not having or being unable to define a data segmentation method in microservices design.

2) Exclusion Criteria:

- Articles that only define the concepts, benefits, criteria, or implementations of microservices architecture, without addressing the incorporation of a method for data segmentation in microservices design.
- Articles that focus solely on the design or applicability aspects of microservices without addressing data modeling.
- Articles that address data segmentation but do not focus on its applicability to microservices.

3) General Criteria:

- The search will be conducted in recognized scientific databases: Web of Science, IEEE Xplore, Scopus, and Science Direct.
- Only articles with full-text availability will be considered.
- Articles from the last three years will be considered, as this period encompasses the existence of microservices architecture.
- Additional articles will be considered through snowballing or opportunistic searches, as needed.

E. Search Strategy

1) Control Group

Based on the proposed topic, each author independently conducted preliminary searches in scientific databases using the terms identified in the research questions and their

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intuitive judgment to find related articles. The articles presented by each author are listed in Table II.

TABLE II. INITIALLY IDENTIFIED ARTICLES

Author	Articles
Author 1	[1], [12], [13], [14], [15], [16], [17]
Author 2	[1], [14], [17], [18], [19], [20], [21]

A review meeting was subsequently held to focus on selecting articles most closely aligned with the objective of the study by reviewing titles and abstracts.

The control group was formed with the articles presented in Table III.

TABLE III. ARTICLES FORMING THE CONTROL GROUP

Control Group Articles
[1], [14], [17], [18], [20], [21]

2) Search String

To construct an appropriate search string for this study, the definition of Population, Intervention, Outcomes, and Context (PICO) was used [22]. The terms were derived from the review of the Control Group articles and the Research Questions.

Additionally, synonyms or alternative words for key terms were identified. This broadens the scope of the search and helps to retrieve the maximum number of relevant primary studies on the topic.

The results of this activity are shown in Table IV.

TABLE IV. ELEMENTS IN THE RESEARCH QUESTIONS STRUCTURE

Population	Software architects and analysts, software researchers	Software analysts, software researchers
Intervention	Microservices (alternative: Microservitization)	microservice, microservitization
Outcomes	Data granularity (alternatives: database, data segmentation, data modeling)	granularity, database, data segmentation, data modeling
Context	Software development companies, software development teams, software consultants, software researchers, software product creators, software industry	software companies, software teams, software researchers, software product creators

The search strings were constructed by combining terms from the Intervention and Outcomes sections. The final expression was formed by conjunctions between sub-expressions in each group. A pilot test of preliminary search strings was conducted in the Scopus digital library. The results are presented in Table V.

TABLE V. PILOT RESULTS FOR SEARCH STRING IN SCOPUS

Search String	Count
("microservices" AND "granularity")	14
(("microservices" OR "microservitization") AND ("granularity" OR "database"))	95
(("microservices" OR "microservitization") AND ("granularity" OR "database" OR "data segmentation"))	95
(("microservices" OR "microservitization") AND ("granularity" OR "database" OR "data segmentation" OR "data modeling"))	96

The pilot results show that an adequate number of articles were retrieved using the last proposed search string. The search string includes all articles proposed for the control group. The authors agree that the chosen search string for this study is:

(("microservices" OR "microservitization") AND ("granularity" OR "database" OR "data segmentation" OR "data modeling"))

3) Candidate Studies

Searches were conducted in the following scientific databases: Web of Science, Scopus, IEEE Xplore, and Science Direct, using the search string selected in the previous step in the advanced search option. The results of the articles found are presented in Table VI.

TABLE VI. SEARCH RESULTS

Database	Count
Scopus	96
Web of Science	6
IEEE Xplore	11
Science Direct	86

F. Selection Process

1) Refinement

After querying the scientific databases, a total of 199 candidate articles were identified, establishing the baseline for analysis. However, some of these articles were duplicated across databases, necessitating a refinement process to remove duplicates or articles with identical content. Additionally, any references to entire conferences or workshops, rather than specific articles, were excluded. This resulted in 174 articles proceeding to the next stage.

2) Study Selection

Once the candidate studies were obtained, the selection process proceeds as follows:

- Apply the previously determined inclusion and exclusion criteria by reading the abstracts of the articles (31 articles).
- Obtain the full-text versions of the remaining articles, discarding those for which the full text could not be accessed (25 articles).
- Each author conducted an exploratory reading of each article to assess its relevance and

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contribution to the study and the research questions (25 articles reviewed).

- The authors performed a cross-validation through discussion, reaching a consensus on which articles should be selected (16 articles).

At the end of the selection process, 16 articles were chosen to proceed to the next stage.

3) Primary Studies

The selected articles were reviewed, considering the inclusion of additional articles through snowballing or opportunistic search techniques. The authors decided to use only the previously selected articles.

Finally, the authors reached a consensus and approved the list of articles for data extraction. A total of 16 primary articles were selected to proceed to the data extraction stage. The primary articles are as follows: [1], [3], [12], [15], [17], [20], [21], [23], [24], [25], [26], [27], [28], [29], [30], [31].

G. Data Extraction

1) Feature Extraction

The data extraction process involved reading the primary studies and highlighting elements that contribute to answering the research questions. The Atlas.ti tool was used for this purpose, allowing unified coding across all articles, providing traceability, and structuring semantic networks to support the writing of findings. Additionally, information on the publication type, year, and authors was collected and tabulated, enabling the organization of articles as needed. For example, Figure 2 shows the distribution of primary articles by year and publication type.

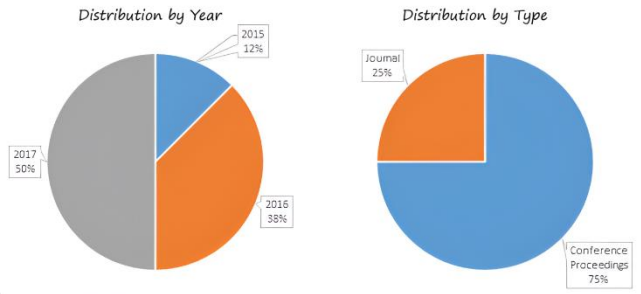

Fig. 2. Characteristics of Primary Studies

2) Model Extraction

Since one of the objectives of the study was to determine if a data modeling method exists for business data segmentation in the construction of microservices, the expectation was to find graphical representations in the primary articles outlining procedures for determining granularity in each case. This section aimed to collect visual schematics to complement the textual coding results. However, upon reviewing the primary articles, no representative graphical elements were found for this purpose. Therefore, the analysis will be based solely on the textual ideas presented in the primary studies.

III. Data Modeling Methods for Microservices

This research identifies architectural approaches for modeling the granularity of microservices to address key research challenges. The findings highlight the use of meta-modeling techniques that define microservice boundaries as adaptable entities, focusing on aspects such as business-driven design, tool heterogeneity, and decentralized governance [1]. These approaches support analysis, evolution, and localization, which are crucial for adapting microservice granularity based on quality attributes [32].

Migration to microservices, or microservitization, enhances autonomy, replaceability, and governance while improving the traceability of software architectures [33]. However, there is still a lack of consensus on the definition, properties, and modeling techniques of microservices. Effective migration involves determining optimal granularity, deployment strategies, and orchestration methods [34].

One of the main challenges is establishing the optimal granularity level, balancing microservice size and number to meet both individual and overall system requirements [1]. Microservitization involves identifying optimal service boundaries to enhance the Quality of Service (QoS) [35].

Recent trends, such as Service-Oriented-Architecture (SOA) and Microservice Architecture (MSA), have emerged as suitable approaches for cloud infrastructures [36]. MSA aims to create flexible, modular applications, but its practical implementation remains a significant research challenge. Modernization efforts involve understanding and transforming large applications into microservices, using model-driven methods to manage complexity and dependencies across business and data layers [37].

IV. Discussion

Currently, more organizations with complex business domains are moving away from monolithic software applications and adopting distributed architectures based on microservices. Microservices architecture aims for agile software development using small services that communicate via APIs, where each service implements complete business functionalities and can run independently. Microservices can be deployed across different machines, using diverse programming languages and data dependencies that the business requires, maximizing scalability and leveraging the strengths of each platform. They are designed as small, simple, and understandable executable units, which makes them easier to modify and maintain.

However, modeling the domain for each microservice with the necessary dependencies within the business context requires software architects to clearly define each service responsibilities and APIs to achieve good cohesion and low structural coupling. The architecture should facilitate parallel development with different teams working on separate microservices, allowing services to be rewritten with minimal effort if necessary. For microservices to be autonomous from development to deployment, architects need strategies for domain modeling, deployment, versioning, monitoring, security, maintenance, and managing business-driven changes.

The challenge posed by the research questions is to define the appropriate data domain modeling for visualizing the

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structural granularity that each microservice must implement. The research framework focuses on using software archetypes for modeling business data for each microservice, as archetypes are fundamental human mechanisms that organize, summarize, and generalize domain information. This is expected to have applications in software engineering. The framework is built upon a literature review that includes factors demonstrating the application of software archetype principles for business data modeling in software and service engineering. A case study will be conducted in Ecuadorian public and private institutions to model business data and evaluate the advantages and disadvantages of the proposed model.

For technology companies, understanding their business data is crucial, as it represents the backbone of their information systems. Therefore, software engineering employs various methodologies and techniques to address data modeling from different perspectives, from business domains to data storage. The proposed research framework will analyze systems that use data archetypes for microservices.

After conducting the study, the research questions are revisited:

- **RQ1:** What data modeling techniques can be used for business data segmentation in microservices construction?
  - It is proposed that services be stateless (do not manage a database) [24].
  - A centralized data model is proposed [25].
  - The use of decentralized NoSQL databases is proposed

    A method is proposed where only the most critical business elements are subdivided, based on the benefits of microservices [27].

- **RQ2:** How to model or establish microservice granularity?
  - Proposes a type of microservice diagram and microservice invocation diagram
  - Proposes SMART and Entice methods [23].

V. Threats to Validity

Throughout the study, continuous discussions were held regarding the procedures to follow and the potential threats to validity. Efforts were made at every step to maintain the rigor and thoroughness required for the resulting document to contribute to scientific knowledge.

A. Threats in Search String Formation and Primary Study Selection

One challenge was determining the scope of our study since data modeling for microservices is a relatively new and less explored topic in the technological field (emerging over the last three years). Different communities often use varying terminologies for the same concepts. To cover the research questions comprehensively and avoid bias, we searched for terms related to microservices and data modeling across various contexts. While this approach reduces bias, it significantly increased the search effort, necessitating a manageable scope.

B. Threats to Study Selection and Data Extraction Consistency

The formulation of research questions helped in selecting relevant studies. However, two articles that appeared highly relevant based on their abstracts could not be accessed in full-text form and were therefore excluded. Due to time constraints for tabulation and coding, it was not possible to perform a detailed semantic analysis or comprehensive reading. The primary articles were reviewed based on coverage and a focus on relevant section.

VI. Conclusions

Microservices result from breaking down application services into smaller components, with a distinctive feature of having their own database separate from other microservices, enhancing composability and deployment capabilities. Organizations transitioning to a microservices-based-architecture often start with an existing system that already has a unified data model representing the entire business dynamic. Therefore, designing a migration strategy to microservices requires segmenting this model into smaller parts.

A preliminary literature review was conducted to find articles proposing a method for determining the appropriate level of granularity for model division. No references were found on this topic. Performing this task without a theoretical framework may lead to decisions based on intuition or trial and error, increasing resource consumption and questioning the need for microservices compared to the maturity of SOA-based web services.

An empirical study is proposed using the Systematic Mapping Study (SMS) method to conduct a thorough literature review to validate the existence of methods that define reasonable granularity in microservice design.

The literature review procedure followed these steps: Structuring the Research Question, Defining Inclusion and Exclusion Criteria, Formulating the Search Strategy, Executing the Selection Process to identify primary studies, and finally extracting the required data. This process enabled the coding of relevant elements in the primary articles, leading to the synthesis, analysis of results, and answering of the research questions.

Future work involves experimentation with existing model subdivision methods for microservices, so that, once validated across different scenarios, these methods can be considered best practices in implementing this architecture.

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Traffic Congestion in Ecuador: A Comprehensive Review, Key Factors, Impact, and Solutions of Smart Cities

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Traffic Congestion in Ecuador: A Comprehensive Review, Key Factors, Impact, and Solutions of Smart Cities

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***Abstract*—**This study explores the main sources of traffic congestion in Ecuadorian cities and proposes solutions to address this issue. The findings reveal that the main causes are natural disasters which disrupt the transportation infrastructure and leading to chaotic traffic flow, lack of infrastructure maintenance, inadequate education, cultural issues, improper traffic signal timing, or the absence of exclusive lanes for public transportation. Fast transit projects have also faced obstacles, including absence of political leadership, complications in the implementation, rushed planning processes, resistance from stakeholders like bus operators, and inaccurate cost estimations. Vehicle pollution is another consequence of lower-quality fuel and the topography of highland cities, which demand more engine power. The proposed solutions are categorized into three types: smart city technologies, implementing regulations, and enhancing public transportation systems. To address traffic accidents, it is recommended to identify high-risk areas, monitor fleet variables of buses, educate the population on responsible driving practices, and implement designated driver applications. By considering and implementing these solutions, Ecuadorian cities can alleviate traffic congestion, enhance transportation efficiency, reduce pollution, and improve road safety.

Keywords*—smart cities; urban planning; vehicular traffic; data mining; optimization*

I. INTRODUCTION

Traffic congestion in Ecuador has become a significant problem, increasing travel times, fuel consumption, and negative environmental impacts. However, analyzing traffic congestion can provide invaluable insights that can lead to the development of more efficient transportation systems.

Even though the use of smart solutions can improve traffic congestion, they are not always applicable in developing countries due to many factors. They include poor infrastructure, such as roads and traffic signs in bad conditions which are not useful for intelligent traffic lights, autonomous vehicles, or automated transportation systems. Urban planning is another challenge, as many Latin-American cities grow disproportionately. Additionally, culture and lenient laws contribute to this issue, with many drivers who do not follow the traffic rules. High-costs of technology are also a problem, as the implementation and operation of smart traffic solutions can be unaffordable in many countries; or the characteristics of territory: the topography of the land, the risks of natural disasters. However, it is important to identify those technological solutions that can be suitable for the characteristics of countries like Ecuador.

Researchers have also focused on studying this problem. Their valuable contributions have enriched our understanding of traffic congestion and have led to innovative solutions. We cite some of their effort to improve transportation systems in the aforementioned country.

In [1], they remark that in cities like Babahoyo, the inhabitants prioritize using private cars instead of the public transportation system. In [2], they proposed an increase in teleworking in Ecuador to tackle the traffic congestion problem, and he analyzes the economic and environmental costs of commuting from home to the workplace and its possible benefits and savings. In [3], they reported that urban planning is not considered on a practical basis in cities like Cuenca where its uncontrolled growth makes the city look disorganized and unsustainable. In [4], they used the Health Economic Assessment Tool (HEAT) to calculate the economic benefits of using the bicycle as a means of transportation. The study was conducted in the city of Cuenca and it obtained encouraging results even for small distances. [5] builds a mobile application for collecting traffic congestion data in the urban regeneration area in the city of Loja. In [6], they characterized the causes of accidents in Ecuador during the years 2015 to 2018, their findings suggest that lack of attention, drunkenness, excess speed, or changing lanes are the main causes of accidents in Ecuador. In contrast, the report by the Transit National Agency (ANT) for the first quarter of 2024 [58] indicates that the main causes of accidents include the driver's lack of skill and recklessness (39.30%), speeding (18.57%), failure to obey traffic signs (18.30%), and drunkenness (8.57%), among others. Solutions for reducing traffic accidents include conducting driver exams that assess both practical and theoretical knowledge, public strategic, tactic, and operational policies, and implementing technological solutions. These technologies may include vehicle-to-vehicle communications, the internet of vehicles model, smart lampposts with LED lights, wi-fi, and cameras, roadside units for helping near vehicles.

Ecuadorian cities have their necessities, challenges, and characteristics regarding traffic management. Our study performs a comprehensive analysis of traffic congestion in Ecuadorian cities, that identifies the specific causes of traffic congestion and, on the other hand, the technological and

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innovative solutions for traffic management that have been implemented in the country highlighting their impact and feasibility.

This paper continues with section 2 Materials and Methods in which we describe the methodology used for conducting this review and introduce the research questions. Section 3 Results describes the analyzed papers and provides answers to the research questions. Finally, the conclusions of the paper are presented.

II. Materials and Methods

To conduct the present research, we use the methodology proposed by [7], which suggests the following steps: a) formulate the research questions, b) conduct the search process, c) establish the inclusion and exclusion criteria, d) carry out the data extraction, and complete the data analysis and classification.

A. Research questions

RQ1: "What are the main sources of traffic congestion in Ecuadorian cities?"

RQ2: "What solutions have been proposed to reduce the traffic congestion in Ecuadorian cities?"

B. Conduct the research process

Next, we conducted a manual search in scientific databases with the search string "traffic congestion Ecuador" by means of the filter of retrieving papers from the year 2020, obtaining the following number of papers: Google Scholar 3150, Springer Link 694, ScienceDirect 157, IEEE Xplore 24, and Scopus 5.

C. Establish the inclusion and exclusion criteria

We consider the inclusion criteria: full papers written in English or Spanish that focus on studying the impact of traffic congestion or proposing solutions for traffic congestion in Ecuadorian localities.

We excluded papers published more than four years ago and those papers that fell below our quality evaluation criteria, obtaining a final selection of 50 papers.

D. Carry out the data extraction, and complete the data analysis and classification

For the data extraction part, we read the paper abstracts and conclusions, if the content was pertinent we continued reading the whole paper and retrieved the relevant information for the research questions.

The Fig. 1 shows the number of papers found in each scientific repository throughout the research process.

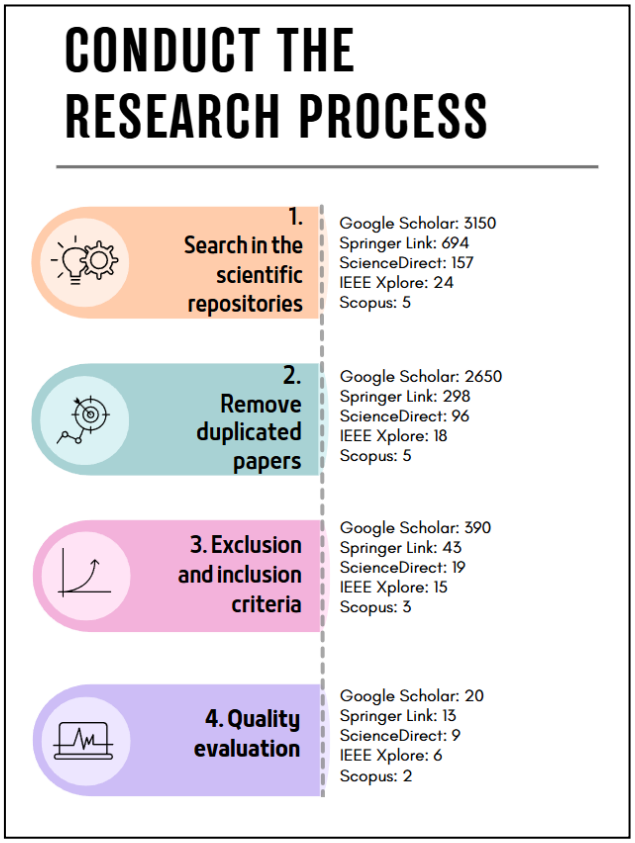

Fig. 1. Research process.

III. Results

A. Categorization of the analyzed papers

In Table I, we list the analyzed papers and the purpose of the study.

TABLE I. List of analyzed papers

Paper id	Purpose of the study
[8], [35], [36], [42], [55]	Proposing electric vehicle solutions
[9], [10], [15], [16], [17], [22], [25], [27], [28], [40], [43], [44], [46], [47]	Modeling traffic congestion
[11]	Traffic light timing, bus itinerary planning
[12], [19], [21], [23], [29], [30], [48], [33]	Implementing traffic prediction models
[13], [14], [18], [20], [24], [26], [31], [34], [39], [50], [51], [56]	Pollution estimation due to traffic
[37], [45]	Improving route infrastructure
[32], [37], [38], [41], [49], [52], [53], [54], [57]	Implementing smart city solutions

B. Description of the contribution of each analyzed paper

Next, we extracted the contribution of each paper for the present study.

In [8], they analyzed the cost of operation of electrical buses compared with traditional diesel buses. The experiment was conducted in the 3 best-performing bus lines in the city of

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Cuenca. A major challenge is the installation of fast charging stations for EVs in cities. The opportunity relates to the low cost of electricity in Ecuador.

In [9], they conducted a study of traffic congestion in the avenues America and Reales Tamarindos in Portoviejo city, finding a C level of service where the HCM (High Capacity Manual) standards indicate that A level of service corresponds to <10 delays per vehicle (s/veh), B corresponds to >10-20 s/veh, C corresponds to >20-35 s/veh, and D means >35-55.

In [10], they proposed a traffic congestion model that uses 6 density-flow equations and 6 speed-density equations to predict traffic conditions. The data is taken from Google traffic information where a green line means no traffic delays, an orange line represents medium traffic, a red line represents traffic congestion, and a darker red line represents a slow speed due to traffic congestion.

In [11], they conducted a study of traffic congestion on "Pedro Menendez Gilbert" avenue in Guayaquil city. The study suggests that instead of widening the avenue it should improve the traffic light cycle times and build an exit of the avenue which is less expensive and would give better results in the long term.

In [12], they proposed a traffic congestion prediction model that identifies interest origin and destination points in the city of Quito. The data is collected with the Google distance matrix tool. Interest points are grouped by clustering models, the taxi cars should be electrical and the rapid charging stations should be near interest points.

In [13], they introduced a visual recognition system that notifies via SMS when a driver transits in an restricted lane of the metrovia public transport network in Guayaquil city. The system issues a fine when the vehicle uses this lane and notifies the owner with an SMS message. The detection rate is 78.04%. The challenges faced are the calibration of the inclination angle of the camera, the resolution of the Raspberry Pi camera, and the need for a better algorithm to recognize the vehicle plates.

In [14], they presented an estimation of greenhouse gas emissions in the cities of Ibarra and Guayaquil. They use OpenStreetMap and the SUMO simulation software. The simulations predict the amount of carbon monoxide and dioxide, hydrocarbons, fine particles, and nitrogen oxides, estimating the contribution of gases from cars, trucks, motorcycles, and buses. The challenges include the complexity of extending the study to a larger area, the COVID-19 pandemic, and the use of manual counting of vehicles. They recommend the use of smart parking systems, and the use of simulation tools like SUMO before building city infrastructures like new roads.

In [15], they reported a study of vehicle congestion in the "Miguel Alcivar" and "Avenida del Ejercito", "Avenida Reales Tamarindos" and "P. E. Macías", and "Avenida Manabi" and "Tennis Club" in the city of Portoviejo. The findings reveal the use of private cars with 64.83%, motorcycles with 24.54%, bicycles with 6.40%, trucks with 3.76%, and buses with 0.47%. They recommend the use of sharing cars, increasing the frequency of buses, implementing new road spaces for bicycles, and educating the inhabitants of the city about the transit rules and the right use of the roads.

In [16], they presented a diagnosis of the urban mobility in the city of Bahía de Caráquez, it is found bad conditions on many streets due to natural disasters and lack of maintenance, lack of infrastructure for pedestrians and bicycles, the presence of unregulated parking lots, and inefficient public transportation. Private cars are preferred by 39% of the population while public transportation (buses, taxis, tricycles) are preferred by 32%. The solutions are the creation of "pedestrian islands" that are safe, comfortable, and exclusive areas for walking; encouraging the use of bicycles by designated spaces and bicycle renting locations; implementing the intermodal exchange of buses and bicycles, including information on routes and frequencies, improving accessibility for disabled people; and the regulation of activities in the public spaces.

In [17], the author studied the kinematic variables of the fleet of buses that travel from Ibarra city to Tulcán city and vice versa. The study includes the identification of danger zones where vehicles find curves in the route and also get high speeds. The buses during this trajectory stay 17.25% in idle state, 23.01% in cruise, 32.43% in accelerating mode, and 27.29% in deceleration. To compensate for the idle times, the buses get speeds higher than 100km/h, giving an unsafe driving of 61% on the route Ibarra - Tulcán, and 66% on the route Tulcán - Ibarra. It is explained that the pollution on this route is due to the lower quality of fuel, the topography of the city, and the traffic congestion.

In [18], they carried out a study of emissions of greenhouse gas in Guayaquil city. They use the International Vehicle Emissions Model (IVE) which is a computer model for estimating air pollutants. Small vehicles produce more carbon monoxide and volatile organic compounds, while buses produce more nitrogen oxide and particulate matter with a diameter of less than 10 μm (PM10). It is recommended a reduction of sulfur in the diesel fuel. Finally, higher pollution is not found on the highways but in very populated areas with an elevated number of roads.

In [19], they introduced a study of vehicle congestion around the metrovia public transport system in Guayaquil city. They get data through observation of vehicles and it is processed in ArcGIS to characterize intersections with their geometry, traffic flow, and traffic light cycles. The use of an exclusive lane for the metrovia system produces vehicle congestion and they suggest changing traffic light cycles accordingly.

In [20], they proposed a methodology for estimating the pollution made by vehicles. The data acquisition is obtained from the OBD II port [14] of the vehicle from different sensors such as intake manifold pressure (MAP), throttle position, or engine temperature. They use Freematics ONE data logger to obtain the engine and GPS information, the Portable Emission Measurement System (PEMS), and the Brain Bee AGS-688 that works through the non-dispersive infrared absorption method (NDIR) for the measurement of carbon dioxide, carbon monoxide, and hydrocarbons; and electrochemical cell for the measurement of nitrogen oxides. A neural network estimates the pollution emitted by the vehicles using the measured data. Finally, it suggests that the vehicles should comply with the Euro 6 vehicle emission standard.

In [21], they presented a cross-platform architecture for analyzing vehicle traffic. An Android application captures data and the Google distance matrix API estimates the distances and speed of vehicles. The area of study is in Quito, at the intersections of Shyris - United Nations and Amazonas

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- Gaspar de Villarroel avenues. They use the Sarimax model for prediction and the BigML tool for implementing the algorithms. The system is deployed with the Amazon web services with web and digital TV interfaces.

In [22], they conducted a study of traffic congestion in the cities of "La Troncal" and "El Triunfo". Betweenness centrality measures the importance of a node in a network as an intermediary in the communication with other nodes considering the shortest paths. Closeness centrality measures the importance of a node in a network based on the speed with which it can communicate with other nodes. These 2 metrics were used to estimate the congestion points of the cities. Using OpenStreetMap, Waze, and WazeRouteCalculator, the number of dead-end nodes and mesh nodes (streets with 4 exits) was determined. The WazeRoute Calculator was used to determine distances and traveling times from Ecuadorian cities on different business days.

In [23], they used linear regression, neural networks, and k-nearest neighbor algorithms to estimate traffic congestion around the University of Guayaquil. The temperature, distance, and times of the day predict the traffic flow around the surroundings of the building of the university, enabling the users to take alternative routes.

In [24], they presented a study of air quality based on the traffic flow in the city of Quito, they used Google Traffic and Waze to obtain data and the decision tree algorithm to estimate the amount of particulate matter (PM)—PM2.5 (aerodynamic diameter ≤2.5 μm). Monitoring stations in the central area of the city collect the validation data on pollution levels. The results suggest that before 9:00, the largest concentration of particulate matter is found, while the prediction model obtained an accuracy of 61% to 71%, which is acceptable for predictions using a low-cost method.

In [25], they conducted a simulation of cargo transportation in a mountainous city where difficult conditions are met like earthquakes, floods, landslides, or mudslides. It is also noted that many roads in Ecuador have presence of steepness, curvature, limited visibility, and high accident rates. The simulation took into account factors like speed flow of traffic, reduction of number of lanes, distance between points, and road conditions. On the other hand, they modified the ant colony algorithm used for optimization purposes and it is inspired by the behavior of real ants, which are known to find the shortest path between their nest and the food sources.

In [26], they carried out a study for estimating the amount of ozone pollution in the city of Cuenca using machine learning techniques like random forests, gradient boosting prediction, neural networks, and quantile regression methods. The data was obtained by the Air Quality Monitoring Network which has 20 stations across the city. The results show that the historic center, industrial land, high labor-population areas, and areas with high traffic light density have higher levels of ozone. As counter-measures, they suggested an early alarm system that identifies high levels of ozone, encourages scientific proof of the levels of pollution, improves and strict regulations of transport and industries, or alternatives in transportation.

In [27], they conducted a traffic study in the city of Portoviejo. The study zone is the intersection of the avenue Pedro Gual and Córdova street, which is a connection point to many places of interest. Among the mitigation solutions for traffic congestion, they suggested using radars to monitor traffic flow and to change the traffic light cycles according to the demands of cars, especially during the rush hour and in the zone of the bus station and the central market. Additionally, it was recomended the implementation of cameras in the public buses, and improving the information for the user of the public transportation system; educating the population and respecting the traffic regulations.

In [28], they reported a study of the sizing and routing of internet access points around the stations of the metro system in Quito. The study aimed to establish the areas where the implementation of access points will give uninterrupted internet access to the users of the metro system. It was also necessary to implement GPS and GPRS devices in each car of the metro system to update their location in real time. This study highlights that such effort can improve this transportation service and encourages the population to use it instead of driving particular cars.

In [29], they introduced a methodology for estimating traffic flow using clustering which is a technique that is used for trajectory analysis. The data of 218 trajectories and 30577 records was collected in October 2022 by university students using taxi cabs, motorcycles, and metrovia public system. The prediction model uses an adaptation of the DyClee algorithm obtaining different groups of instances with similar evolution patterns like common speeds at different time instants. Finally, an interactive map shows the grouping of traffic congestion events.

In [30], they presented a mathematical model based on the Sustainable Urban Mobility Plans (SUMPs), developed in 2014 in the city of Cuenca. The data consists of an origin-destination matrix between outer areas of the city and its central business district, cost functions, park-and-ride locations, and public transport parameters. The main contribution of the paper is that the public transport system can be planned considering the location of the park-and-ride locations. Finally, the model was able to identify the sources of demand that go to the central business district.

In [31], they introduced a study on using a plant species as a biomonitor. The Araucaria heterophylla needles have the capacity to accumulate metals. The results concluded that the concentration of Mn, Fe, Al, Ba, Zn, Cu, Cr, Pb, and Co increases with traffic intensity, while there is no relationship between the level of Ca, K, and Mg and the vehicular traffic intensity. However, the presence of green areas reduces the amount of pollution even in zones of high traffic density.

In [32], they presented a system for sending notifications of traffic congestion events to drivers in the city of Quito. The data included average vehicular speed, approximate delay times, and average traffic density. The real-time platform uses the message queue telemetry transport (MQTT) messaging service, which allows subscribers to obtain the relevant traffic information. The test results conclude that the application needs less battery, CPU, or GPU demand than applications like Google Maps or Waze.

In [33], they conducted a study on the causes of traffic accidents in Ecuador. The data was obtained from the National Transit Agency, which recorded 14410 accidents occurred in the years 2016-2018. A decision tree algorithm extracted rules

like a) the lack of attention is a main cause of traffic accidents that occur more frequently in the urban areas of the Chimborazo province, especially on Sunday nights with normal weather, and lateral collision is the most common event; b) drunkenness is another important cause of accidents, occurring in urban areas, on weekends, having normal weather, and the lateral and frontal collisions are the most common events. The use of the cell phone while driving is also an important cause of traffic accidents.

In [34], they presented a study on air quality in the capital of Ecuador, Quito. It is found that the period between February and April has the highest levels of nitrogen dioxide which coincides with the winter period. On the other hand, the lowest levels were found from June to August which coincides with student holidays when traffic flow decreases considerably. Despite the air quality being acceptable in terms of standards, vehicular traffic is identified as a main contributor of tropospheric ozone precursors (nitrogen oxides and volatile organic compounds). The metro system could be a solution to reduce both the contamination and traffic congestion levels.

In [35], they proposed a decarburization plan for Ecuador. It highlighted the efforts to electrify massive transportation systems like the metro in Quito, the tram in Cuenca, and the airway in Guayaquil. The challenges include poor infrastructure, high costs of electric vehicles, and high costs of batteries. The benefits include reducing subsidies for gasoline and diesel or decreasing greenhouse gas emissions.

In [36], they conducted a study on the optimal locations for building charging stations for electrical taxis. Quito has an altitude of 2800 meters and the internal combustion vehicles are very inefficient, moreover, taxi cabs are very noisy and are a major contributor to pollution. The study selected the BYD e5 model for the experimental calculations and considered the number of spots in each charging station based on the electrical vehicle penetration of 30%, 40%, and 50%. The results suggest that 393, 524, and 654 charging spots must be installed in total respectively for ET penetration levels of 30%, 40%, and 50%.

In [37], they carried out a study on the challenges and opportunities for the community of Montañita to become a smart city. It remarks that mobility is important for sustainability, efficiency of transportation infrastructure, as well as local, national, and international accessibility which is relevant since Montañita is a tourist community. Sustainable transportation is relevant for local and national governments to give the inhabitants quality access to study, work, or leisure. Intelligent mobility is not just the use of technology, but, giving the user access to relevant information such as schedules or traffic flow which reduces accidents, and enhances public transportation.

In [38], they conducted an experiment on position correction systems for autonomous vehicles. They used a low-cost Global Navigation Satellite System (GNSS) receiver with the RTKLIB software and the NTRIP protocol. They explained that autonomous vehicles can improve road safety, and reduce emissions and traffic congestion. The research is relevant because its goal is to use low-cost devices for autonomous vehicles which can help developing countries to adopt this technology. However, it will be difficult to implement autonomous vehicles in countries like Ecuador due to the road conditions. Finally, they reported that the use of the low-cost RTK (Real Time Kinematic) position correction system was affected by the coverage of the internet signal, the correction latency, and the interruption of the satellite signal. These barriers were compensated by the use of the inertial measurement unit with the odometry system of the car.

In [39], they performed a study on air pollution during the dry and rainy seasons in the city of Quito. Vehicle emissions are a main contributor of CO and PM and precursors of pollutants like NO2, and O3. For its part, NO is produced by combustion of vehicles. The meteorological variables that were used for detecting air pollutants are humidity, temperature, wind speed, and solar radiation. It was found that the presence of CO, NO2, and O3 has a negative correlation with relative humidity in the dry and wet seasons, and a negative correlation between PM2.5 and NO2 with wind speed during the dry season, indicating that atmospheric mixing contributes to the dilution of pollutants during the dry season.

In [40], they conducted a research on pedestrian counting in the city of Portoviejo to improve the mobility of citizens. They explained that according to the HCM 2000, the pedestrian service levels are A: >11.70 m2/pt, B: >3.6 m2/pt, C: >2.6 m2/pt, D: >1.35 m2/pt, E: >0.54 m2/pt, F: <0.54 m2/pt. The results suggested that pedestrian congestion occurs in América Avenue between Pedro Zambrano street and Manabí avenue, especially in the morning, having a D level of service. Mitigation measures include punishment for the incorrect use of the sidewalks like parking or placement of advertisement banners, building an exclusive path for bicycles, and training the inhabitants and the local authorities who make the policies of transportation.

In [41], they presented an analysis of the energy demand of the public passenger buses in the city of Cuenca. Speed, acceleration, slope of the road, and GPS location were collected using the OBD II port with an open-source data logger device. A machine learning algorithm obtained the energy demand and it is explained by the characteristics of the bus routes like average speeds from 16 to 19 km/h, road slopes of minimum 8.82%, high demand of passengers during the peak hours (the passenger per kilometer index (IPK) for the bus line #16 is 4.5), and continuous acceleration and decelerations due to traffic congestion (maximum accelerations of 0.1014 m/s2 were found in the bus line #28). Results showed that many bus routes have a consumption of 330.44 kW and slopes of 24.85%. Finally, they suggested new designs for bus routes.

In [42], they introduced a study on the energy autonomy of electrical vehicles in Cuenca which is a topologically irregular city in the highlands. The city has a motorization index higher than 200 vehicles per thousand inhabitants, the bad service of the public transportation system makes 66% of the population use particular vehicles in trajectories between 3km to 10km, the hybrid vehicle market represents 0.26% while the electric vehicles represent 0.01%. While only 19% of people in a survey are willing to buy an electric vehicle in the next years, the rest of them reject the maintenance costs, higher costs of electricity, and bad customer service for EVs. The topology of the city produces a modification of the torque curve of the electric engine which is considered a disadvantage for its implementation because it allows an autonomy of 124km which is 67% of the total capacity of the batteries. Finally, authorities should plan the energy

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consumption of industries and homes for the implementation of EVs.

In [43], they developed an extension for the traffic simulation tool called SUMO-based Traffic Mobility Generation Tool. Building simulation scenarios in the SUMO tool can be time-consuming for tasks like the road map, traffic elements such as traffic lights, the types of vehicles, or vehicle routes. The STGT extension allows an easy generation of the simulation scenario and provides performance statistics. The performance evaluation of the STGT extension was made using a real map of the financial district of the city of Quito obtained by the OpenStreetMap platform, while STGT generates the road network and the traffic demand configuration files.

In [44], he presented a study on a holistic decision-making process to improve public transportation in the city of Cuenca. Proposed measures include: increasing the population density in areas where the road infrastructure is sub-used; improving the routes of bus lines, redistributing the main interest points (attractors of trips); giving priority to the public transportation on the main corridors; implementing cameras, ticket validators, and emergency buttons in the units; reduce parking spots in the congested areas but increase them in the borders; change the perception that car ownership increases social status; and conduct training to bus drivers.

In [45], they conducted a study on the challenges in "rapid transit projects". They explained that in Ecuador 19 rapid transit projects were planned but only 9 were implemented. Among the barriers they found were a absence of political leadership or confrontation; difficulty of implementation; rushed planning process; resistance from stakeholders like bus operators; and bad estimation of the costs. Among the measures they have: connecting social, political, and technical perspectives; increasing private participation; encouraging community feedback and monitoring; and starting the implementation of projects before the end of the political cycle.

In [46], they tackled the unproportioned growth of cities, identifying the urban areas where people build houses near big cities forming integrated cities. They studied the patterns of mobility between nearby locations resulting in the identification of the Functional Urban Areas (FUA). Satellite images identify the urban cores, then they connect uncontiguous urban cores that belong to the same functional area and finally, they identify the remote areas for those urban cores. Results showed the presence of 34 urban cores in Ecuador and 28 FUA obtained by a minimum travel time, having Quito and Guayaquil cities as the largest attractors with 60% of the population. It is important to forecast future spots of high traffic congestion.

In [47], they conducted a study on the impact of the implementation of the metro system in the city of Quito. The higher density of the population is located in the south, northeast, and periphery. These areas are also the ones that have the lowest living conditions. The population with higher living conditions is located in the hypercenter, near the area of concentration of services like jobs, shops, and public transport stops. The areas of Cumbayá and Tumbaco, which are zones of high living conditions, are not well served with public transportation, so they use private cars to get to the hyper-center producing heavy congestion. The metro system will reduce the travel time of users but the impact will depend on the location of residence, where some zones will require better accessibility to the feeding units of the metro system.

In [48], they used a system to count passengers in public buses, with the implementation of a long short-term memory architecture of neural networks they could predict the future flow of passengers. This kind of project helps to optimize routes of the public transportation system, decreasing the amount of fuel (Ecuadorian public transportation systems utilize diesel) and the emission of CO2 gas. They also highlighted more benefits like passengers planning their routes, avoiding crowds, and getting to their destination on time. Moreover, they proposed the use of the Internet of Things and smart city technologies to implement smart nodes where passengers can register themselves and record their travels, those smart nodes would predict and improve their travel experience.

In [49], they used images from drones and weather images to detect vehicles and to classify the traffic conditions as heavy, medium, low, and empty, with that information they implemented a traffic prediction model for diverse areas and times. It is underlined that this project is pertinent since there is not much information on traffic congestion in large cities like Quito and the information obtained from traffic prediction models can improve the quality of life of their inhabitants. Finally, they also remarked that the use of drones can decrease the cost of traffic congestion studies, however, they are constrained by other factors like battery time, permission for flights, or experience with drones.

In [50], they conducted a study to determine the potential of the city of Cuenca to use a big data approach to become a smart and sustainable city driven by data. They emphasized that Cuenca is the third largest city in Ecuador with over 450,000 inhabitants and its growth has to be planned accordingly. In their research, they proposed using air quality and noise sensors, traffic monitoring devices, and smart lighting with a digital platform that can deliver information about the services in the city in real-time. They recommended the participation of public and private institutions to implement those initiatives.

In [51], they conducted a study on the implementation of a park-and-ride system in the city of Ibarra. Park-and-ride systems allow private car drivers to park their vehicles near public transportation stations, reducing the utilization of those private vehicles and decreasing fuel consumption and air pollution. In their study, they found that implementing park-and-ride systems in the city of Ibarra could reduce gas emissions per passenger by 13 times carbon dioxide, 8 times carbon monoxide, and 1.7 times nitrogen oxide.

In [52], they proposed a VANET (vehicular ad-hoc network) solution to optimize travel times in the city of Esmeraldas which has recently experienced a substantial growth in traffic congestion, especially in peak hours. VANETs are a special type of MANETs (mobile ad-hoc networks), in VANETs vehicles communicate with other vehicles or nearby infrastructure. They implemented a simulation with OMNET++ and SUMO simulators with results that show an improvement in selecting routes reducing travel time and distance.

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In [53], they conducted a study where they developed a classification model using a decision tree algorithm that identifies different transportation methods like walking, biking, taxi, tram, bus, and private vehicles utilizing data gathered with a mobile application. The experiment was carried out in the city of Cuenca and they used data related to date, time, latitude, longitude, altitude, and speed. This project is relevant as it can be used for detection of drivers that usually exceed speed limits, hot spots of traffic congestion, and more informed urban planning. For future work, they mentioned including weather data, public transportation schedules, and real-time traffic data to improve the precision of the algorithm.

In [54], they utilized artificial intelligence algorithms, computer vision, and blockchain technologies to build a simulated city model based on data gathered in the city of Quito. The results showed that the AI algorithms reduced traffic congestion by utilizing real-time traffic data from security cameras and traffic lights. Moreover, blockchain technology ensures the security and immutability of traffic data which is an innovative solution. This study is relevant to the results and could be implemented with traffic data from other cities.

In [55], they proposed the implementation of a light electric freight vehicle for the first/last mile in the historical center of Quito which is a busy and popular area. They explained that the high altitude of the city gives lower levels of oxygen and air pressure which decreases the performance of engines based on gasoline, this issue justifies the use of electric vehicles. They presented a detailed proposal for the execution which includes hardware and software designs, logistics, and legal aspects to consider. However, this initiative faces many challenges like the electrical supply crisis that frequently affects Ecuador. This also remarks that with the increasing adoption of electrical vehicles worldwide, the country will have to plan how to cover the shortage of electric power.

In [56], they studied the influence of travel times on carbon dioxide emissions in the city of Quito. The data was obtained by particular vehicles and the model utilized information like model, year of manufacture, vehicle manufacturer, and vehicle displacement. They estimated the amount of fuel that is consumed during heavy traffic conditions and implemented a regression model to forecast the CO2 gas emissions, finding that the model obtains a high significance and correlation. This study is pertinent as it presents an innovative approach that can be replicated in other cities, and their findings would tell the conditions of air pollution in those locations.

In [57], they developed a vehicle-to-vehicle communication model utilizing the ZigBee wireless protocol and the Arduino platform. The prototype triggers alerts when there is a possibility of a collision between the 2 vehicles, it also implements temperature and humidity sensors that report on a display. The experiments were conducted at different speeds and distances of the vehicles, obtaining good connection tests at speeds up to 300 meters. This project is significant because it uses low-cost technologies that offer advantages over more expensive commercial solutions, so further research should be considered.

C. Ansewring the research questions

To answer the research questions, we have the following analysis:

RQ1: "What are the main sources of traffic congestion in Ecuadorian cities?"

According to our findings, natural disasters like earthquakes, floods, landslides, or mudslides are a major challenge; lack of maintenance of infrastructure, lack of education, or cultural issues bring out chaotic traffic flow; bad public transportation service makes a high percentage of the population to use private cars even for short distances; Management of traffic like exclusive lanes for public transportation, or bad traffic lights timing lead to traffic congestion. Fast transit projects fail due to absence of political leadership or confrontation, difficulty of implementation, rushed planning process, resistance from stakeholders like bus operators, or bad estimation of costs.

Table II relates the analyzed papers to the categories of sources of traffic congestion and their outcome.

TABLE II. ANALYZED PAPERS RELATED TO THE CATEGORIES OF SOURCES OF TRAFFIC AND THEIR OUTCOME

Paper id	Category	Outcome
[16], [25]	Natural disasters	High cost of maintenance
[14], [35], [38]	Inadequate infrastructure	Cities with poor transit infrastructure may not attract businesses and residents, slowing urban growth and reducing investment opportunities
[13], [17], [40], [53]	Lack of education, cultural issues, not complying with traffic rules	Drivers may violate laws creating unsafe conditions
[8], [15], [42], [44], [47], [48], [51]	Bad public transportation service or planning	Poor service pushes more people to drive, leading to higher congestion
[11], [19], [27]	Bad traffic light timing	When traffic lights are not synchronized or have improper timing, they can cause bottlenecks leading to long queues and significant delays
[45], [49], [50], [55]	Lack of political leadership or confrontation, underestimation of implementation complexities	This can cause many infrastructure projects to fail
[10], [13], [16], [19], [22], [23], [27], [28], [32], [37], [54]	Lack of information on public transportation or traffic conditions	When schedules, routes, or traffic delays are not available, potential users may find it difficult to use public transportation
[9], [18], [20], [26], [30], [36], [40]	Lack of adoption of international transportation standards	Not adopting international transportation standards can significantly impact the efficiency, safety, and sustainability of a transportation system

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For its part, the pollution produced by vehicles is also a result of lower quality of fuel, and the topography of the highland cities that require more power from engines.

RQ2: "What solutions have been proposed to reduce the traffic congestion in Ecuadorian cities?"

Based on the results of our research, we can classify the solutions for traffic congestion into 3 types:

Smart cities technologies: Implement smart parking systems, visual recognition systems for pedestrians and vehicles, shared car applications, real-time traffic maps, or notification applications of traffic events. Big data and machine learning can help spot trends of high vehicle congestion in locations and periods. Use simulation and optimization in the most congested places.

Regulations: punishment for incorrect sidewalk use, such as parking or placement of advertisement banners; implementation of pedestrian islands; increase in bicycle spaces; improvement and strict regulations of transportation; and making transportation units accomplish international standards.

Improving public and private transportation systems: offering information on routes and frequencies, implementing GPS devices in buses to monitor travel speeds, or encouraging the adoption of electric vehicles.

Table III relates the analyzed papers to the three types of solutions of traffic congestion.

TABLE III. ANALYZED PAPERS RELATED TO THE TYPES OF SOLUTIONS OF TRAFFIC CONGESTION

Paper Id	Technology / tool	Regulations	Improvements
[9]	---	HCM standard	---
[10]	Google traffic API (real-time)	---	---
[11], [27]	---	---	Traffic light cycles
[12]	Google distance matrix tool (calculate commute time between origins and destinations)	---	---
[13]	Computer vision	---	---
[14]	OpenStreetMap, SUMO simulation software	---	---
[15]	---	Shared cars	---
[16]	---	Pedestrian islands	---
[17]	---	Identification of danger zones	---
[18]	---	IVE model (Computer model designed to estimate emissions from motor vehicles)	---
[19]	---	Exclusive lane for public transportation	Traffic light cycles
[20]	Freematics ONE data logger (Obtain the engine and GPS information of cars and buses)	---	---
[21]	Google distance matrix tool, BigML	---	---
[22]	OpenStreetMap, Waze, and WazeRouteCalculator	---	---
[23], [26], [29], [33], [48], [53]	Machine learning	---	---
[24]	Google traffic API, Waze	---	---
[25]	Artificial intelligence	---	---
[28]	---	---	GPS and GPRS devices in each car of the metro system
[30], [51]	---	Park-and-ride system	---
[32]	Google Maps, Waze	---	---
[35]	---	Electrification of massive transportation systems	---
[36]	---	---	Study of the optimal locations for electric charging stations
[37]	---	---	Information on bus schedules and traffic flow
[38]	Global Navigation Satellite System	---	---
[39]	---	Vehicle exhaust emissions	---
[40]	---	HCM standard	---
[41]	OBD II port	---	---
[42]	---	---	Electric public transportation
[43]	OpenStreetMap, SUMO simulation software	---	---
[44]	---	Priority to the public transportation	Conduct training to bus drivers
[45]	---	Connecting social, political, and technical perspectives; increasing private participation	---
[46]	Satellite images	Identification of the Functional Urban Areas	---
[47]	---	Extending public transportation system	---
[49]	Machine learning with dron images and weather images	---	---
[50]	Big data, noise sensors, smart lighting	---	---
[52]	VANETs, OMNET++ and SUMO simulators	---	---

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[54]	Artificial intelligence algorithms, computer vision, and blockchain (security and immutability of traffic data)	---	---
[55]	---	---	Light electric freight vehicle
[56]	Regression model	---	---
[57]	ZigBee wireless protocol	---	---

Moreover, to decrease pollution caused by vehicles, we found the use of electric vehicles, or design the routes of public transportation avoiding slopes.

Finally, having in mind the decrease in traffic accidents, we found the identification of danger zones on roads, monitoring kinematic variables of the fleet of buses, giving education to the population especially for avoiding drinking and driving, or implementing designated driver applications.

IV. Conclusions

Overall, this exhaustive study analyzes from an academic point of view, the main causes of traffic congestion in Ecuadorian cities, and the proposed solutions that have been implemented. The findings reveal that natural disasters are not only a threat for the lives of Ecuadorians but also represent a challenge for the maintenance of roads. The topography of cities, lack of education, or bad urban planning also explain the causes of high levels of traffic congestion. By focusing on infrastructure development, public transportation improvements, urban planning, traffic management strategies, data mining and big data technologies, and sustainable alternatives, Ecuador and other Latin-American countries can work towards reducing traffic congestion, enhancing mobility, and improving the overall quality of life for its citizens. However, the success of the implementation of those technologies depends of factors such as collaboration between the private and public organizations, good estimation of costs, acceptance of the citizens, or adequate management of privacy and security issues. We expect that this paper will be useful for researches, authorities and students to understand the current situation of traffic congestion in Ecuadorian cities and it would be a reference for its improvement.

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SIGMA: Wireless System with Geolocation for Environmental Monitoring

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***Abstract*—The increase in the number of automotive parks, the emissions generated by industries, and the forest fires, among others, deteriorate the air quality of the Metropolitan District of Quito. Low-cost devices (sensors) distributed throughout the city to collect and deliver information on concentrations of gaseous pollutants in real time are essential for preserving the health of the citizens. This kind of technology can contribute to improving air quality by controlling the emissions of harmful substances into the atmosphere. This paper shows a prototype system for environmental monitoring using open hardware and software technologies. The system comprises two subsystems: a transmitter (mobile) and a receiver (fixed). The transmitter unit has been installed in a public transport vehicle (a taxi or any public transportation), which allows the acquisition of environmental parameters such as carbon monoxide, ozone, nitrogen, temperature, humidity, geographic location, time, and date. The obtained measurements are sent in real-time to a receiver subsystem, mainly consisting of a server, where the received data is processed and published in a pollution map. This data informs citizens by geographical areas, about the different levels or concentration ranges of a particular gas, and general air pollution in the city.**

Index Terms*—Air pollution gas sensors, Pollution Map, Wireless Monitoring

I. Introduction

In the last ten years, the demographic and geographic growth of the city of Quito has generated a significant increase in public and private transportation, which in turn has led to a rise in emissions of air pollutants generated by vehicle combustion. This effect has deteriorated and is deteriorating the quality of life of the city's inhabitants.

Environmental monitoring systems related to air pollution are vital to preserving the ecosystem because they allow a better perception of the polluting emissions sent to the atmosphere and the air quality available at different points in the city. Currently, the city of Quito has an Environmental and Atmospheric Monitoring Network (REMMAQ), which is made up of static monitoring stations in charge of obtaining, processing, and presenting information on different environmental pollutants; however, the number of stations is minuscule compared to the size of the city (9 main stations) [1].

Accordingly, this work implements a wireless prototype for monitoring air pollutant gases, developed under free hardware and software platforms. The developed system allows real-time information on CO, O3, and NO2 gas concentrations in the environment. In addition, the collected data is processed and presented through a geographical map of pollution using a web interface.

The main advantage of the prototype is its mobile feature, which allows pollution information to be obtained anywhere, only through an Internet connection through the 3G cellular network. The prototype enables information to be received at locations far from static monitoring stations, providing additional data to the current network and providing inhabitants with easily interpreted information.

II. Related Work

Research related to the acquisition of pollutant gases in the environment uses different technologies in the development and implementation of the prototype. In [2], the MAQUMON system uses sensors for the acquisition of pollution information; the information is sent via Bluetooth technology to a transmitter node (Gateway) installed in a moving vehicle. When the transmitter node finds an available WiFi network, it transmits all the acquired information to a remote server to present the results in a web interface later. Its operation is based on data acquisition and accumulation (storage), using geolocation marks to reference the samples so that it does not send information in real-time.

On the other hand, in [3], a system based on a wireless sensor network (WSN) that acquires CO pollution data through the MiCS-552 sensor and the Octopus II platform is developed. The data collected by the WSN is transmitted to a central node (Gateway), which sends them to the remote database via text message (SMS) through the GSM cellular network. Access to the information is done through an Internet connection, although, the system does not have a user-friendly

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web interface that allows the interpretation of the information in a visual and didactic way.

According to the literature review, most researchers use technologies for the local transmission of information [4]. However, none focuses on transmitting data in real-time to a remote server through the cellular network via an Internet connection. Previous works also lack web interfaces for the presentation and straightforward interpretation of the information.

In the current research work, real-time monitoring of the pollution levels of *CO*, O_3, and NO_2 gases in Quito is carried out. The information is transmitted to a remote server through the cellular telephone network and 3G technology for Internet connection. The acquired data are presented through a user-friendly web interface, under the considerations established in the Quito Air Quality Index (IQCA) [1], in a geographic map of pollution and pollution vs. time graphs.

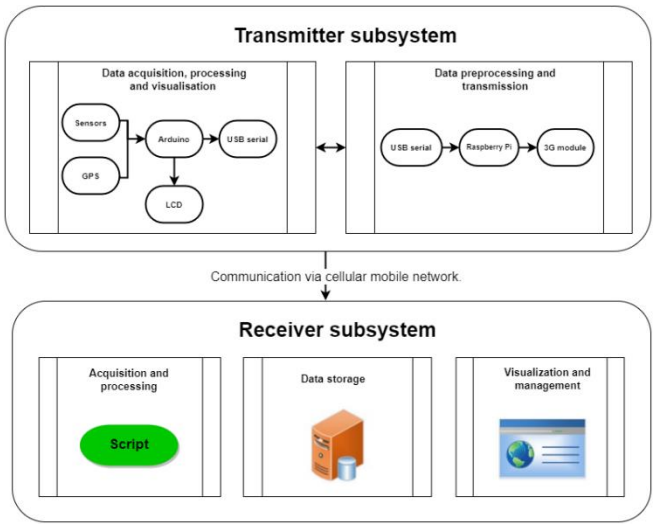

Figure 1. General scheme of the prototype system

III. Prototype System Architecture

The prototype system consists of a transmitter and a receiver subsystem, which interact with each other, monitoring and displaying the levels of *CO*, O_3, and NO_2 pollution in the air. The general scheme of the prototype and the sequence of information processing between the subsystems are presented in Fig. 1 and Fig. 2, respectively. The information processing in the transmitting subsystem is shown in Fig. 3. In contrast, the sequence of sending data to the receiving subsystem is presented in Fig. 4. The different hardware and software components that compose the prototype are shown in Table I.

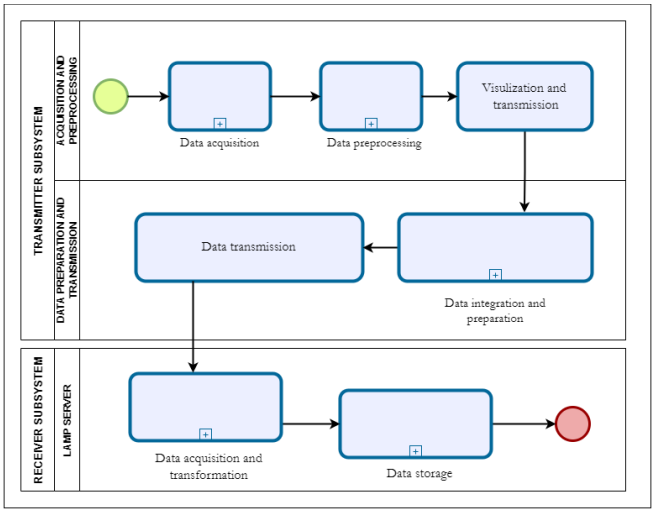

Figure 2. Sequence of information processing between the transmitting subsystem and the receiving subsystem.

A. *Transmitting subsystem*

The transmitter subsystem is responsible for performing the following functions:

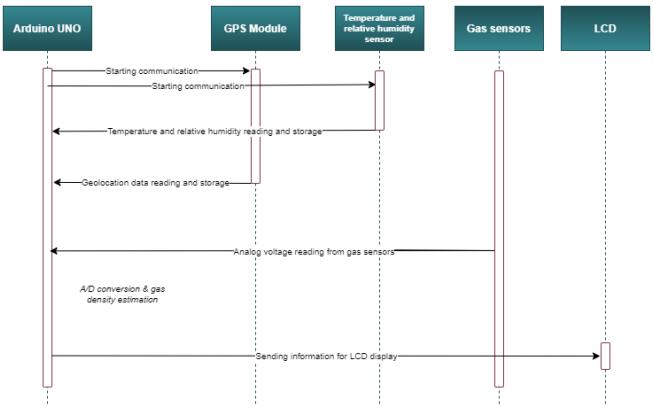

Figure 3. Sequence of information processing in the transmitting subsystem

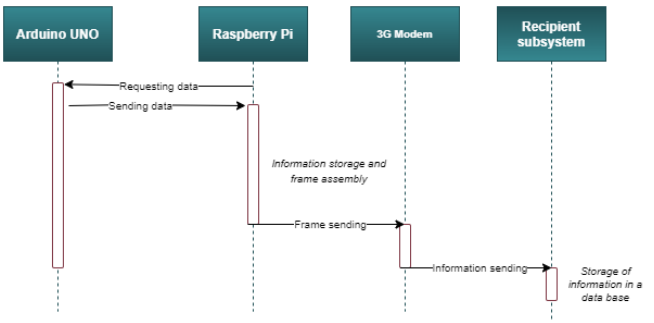

Figure 4. Sequence of sending data from transmitting subsystem to receiving subsystem

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Table I.
PROTOTYPE SYSTEM ELEMENTS [7][8][9][10][11][12][13]

Hardware	
Raspberry Pi 2	CPU: quad-core Cortex A7 at 900 MHz. GPU: video core IV, dual core. RAM: 1GB DDR2 Ports: 4 x USB 2.0, 1X 40 GPIO pin, 1 x HDMI 1.4, 1 x Ethernet, 1 x Combo audio/mic.
Arduino UNO	Microcontroller: ATmega328P Digital I/O Pins: 14 (6 outputs PWM) Analog input pins: 6
CO Sensor	Model: MQ-7 Technology: semiconductor Type of response: analog
O3 Sensor	Model: MQ-131 Technology: semiconductor Type of response: analog
NO2 Sensor	Model: NO2-AE Technology: electrochemical Type of response: analog
Temperature Sensor and Humidity	Model: DHT-22 Type of response: digital Detection range: -40 a 125 ℃ Accuracy: 0,2 ℃
GPS Module	Model: Adafruit Ultimate GPS Tracking sensitivity: -165 dBm Acquisition sensitivity: speed: 0,1 m/s
Modem cellular	Model: Huawei E173s-6 Type: USB stick Communication technologies: 3G
Display LCD	Model: LCD JHD162A Type: 16x2
Software	
O.S. Rasp.Pi	Raspbian Jessie release 8.0
Server	CentOS, Apache, MySQL, PHP

- Acquire gas concentration levels of *CO*, O_3 and NO_2, temperature and relative humidity.
- Acquire data on the GPS connection status, latitude, longitude, time, and date of the air sample.
- Process the acquired data, conditioning it for LCD preview and transmission to the receiver.
- Present the information through an LCD.
- Structure the data set and send the information to the receiver.

Initially, the subsystem receives all analog signals from the *CO*, O_3, and NO_2 gas sensors and digital signals sent by the temperature and relative humidity sensor and the GPS module. The Arduino UNO Single Board Microcontroller receives all this information through its input ports. The Arduino UNO board processes the received data to send it in a suitable format to the receiving subsystem and displays it on an LCD. Before sending information to the receiver, a set of data (Data) is formed by the Single Board Microcomputer Raspberry Pi, which is made up of the following fields:

- **Devide Id:** Identifier of the transmitter subsystem.
- **Latitude:** The transmitter's latitude (geographical location) at the moment of the air sample acquisition, expressed in decimal format.
- **Longitude:** The transmitter's longitude (geographic location) at the time of air sample acquisition, expressed in decimal format.
- **Time (Hour):** Time at which the air sample was acquired, expressed in the format hh:mm:ss.
- **Date:** The date the air sample was acquired, expressed in the format year-month-day.
- **CO:** Concentration of *CO* in the air sample, expressed in mg/m3.
- O_3: Concentration of O_3 in the air sample, expressed in mg/m3.
- NO_2: Concentration of NO_2 in the air sample, expressed in mg/m3.
- **Temperature:** Ambient temperature at the time of acquisition of the air sample, expressed in degrees Celsius.
- **Relative humidity:** Relative humidity at the time of air sample acquisition, expressed in percent.

The structured data sends the information to the receiving subsystem via the 3G interface connected to the Internet.

B. *Calibration of Gas Sensors*

To obtain the gas contamination data for *CO*, O_3, and NO_2, a multipoint calibration was performed, which consists of subjecting the sensor to different concentration levels of a specific gas (e.g., *CO* for the MQ-7 sensor) to obtain a straight line voltage response as a function of the gas concentration percentage. The multipoint calibration of these sensors was performed in [5], whose calibration equations are shown below:

$$y = 0.568x - 212.94 \quad (1)$$

$$y = \frac{0.6479x - 520.63}{1000} \quad (2)$$

$$y = 0.06105x - 50 \quad (3)$$

Where Eq. 1, Eq. 2, and Eq. 3 correspond to the MQ-7, MQ-131, and NO2-AE sensors, respectively.

The variable y corresponds to the gas concentration in ppm, and the variable x corresponds to the response voltage provided by the sensor, which is represented in bits. The voltage x results from the A/D conversion to 12 bits of the analog voltage provided by the sensor, so its values are between 0 and 4095 bits [5].

The concentrations of *CO*, O_3, and NO_2 gases acquired in the environment through the sensors are expressed in ppm, so Eq. 4 is applied to convert from ppm to mg/m3 and then to ug/m3, considering the atmospheric pressure of the place and the temperature at which the sample is obtained [6].

$$A = \frac{P \times M\omega \times B}{62.38 \times (273 + T)} \quad (4)$$

Where:

- A is the gas concentration in mg/m3.
- P is the atmospheric pressure in mmHg.
- $M\omega$ is the molecular weight of the gas.
- B is the concentration of the gas in ppm.
- *62,38* is the universal ideal gas constant.
- T is the temperature in ℃.

C. *Sampling Path*

A sampling area has been established for better visualization of the contamination data. It consists of a transfer route for the prototype, allowing evidence and limiting a

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geographical area in Quito. Additionally, contamination circles have been generated, which present graphically (different colors) the contamination values sent by the transmitter subsystem (for example, see Fig. 6).

D. Receiving subsystem

The receiving subsystem performs the following functions:

- Receive and process the information sent by the transmitter.
- Store the processed data.
- Display pollution levels on a geographical map.
- Present the pollution levels in a numerical report.
- Display pollution levels in a time graph.
- Manage specific database tables.

The server that hosts the receiving subsystem consists of a virtual machine installed in the server of the Informatics Laboratory of the Faculty of Electrical and Electronic Engineering of the Escuela Politécnica Nacional. The implementation of the receiving subsystem is based on LAMP software (Linux, Apache, MySQL, and PHP). The main task of the receiving subsystem is to receive and collect all the data sent by the transmitting subsystem. Additionally, it determines the belonging of an air sample to a specific area (pollution circle) within the established sampling route. The processing of the set of information is programmed in a script, which performs all the activities mentioned above through software processing. After receiving and processing the information, it is stored in an orderly manner in a database, allowing access to it and guaranteeing its availability and integrity. The database used is of the relational type, formed by different tables depending on the type of information to be stored. The designed database is shown in Fig. 5

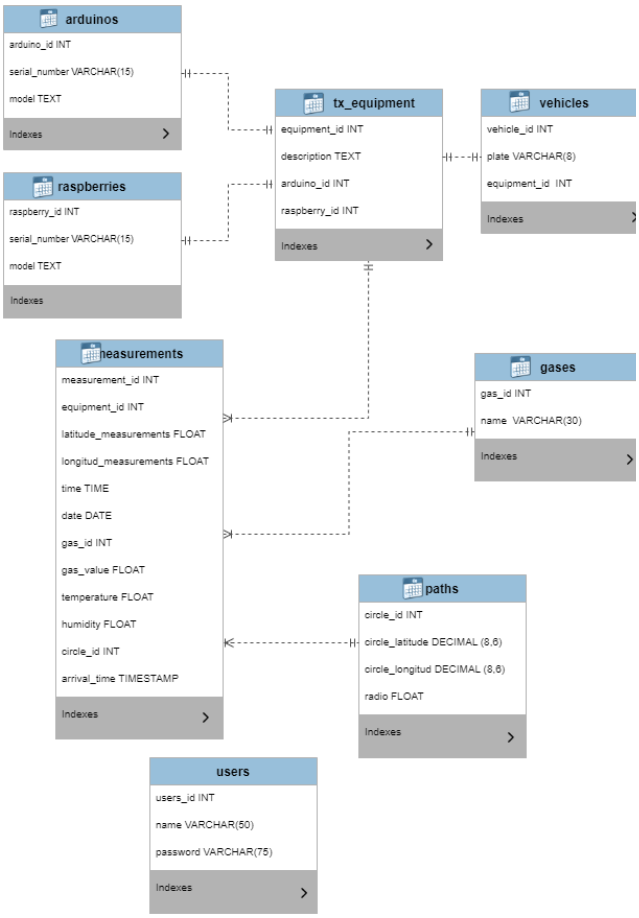

Figure 5. Database schematic

Finally, all the acquired information is presented to the user through a web application connected to the Internet, the web interface, and the means of interaction between the user and the receiving subsystem.

The elements contained in the web application are:

- **Home (home web interface):** Presents a brief introduction to the project.
- **Situation of Quito:** Provides information on national and local regulations regarding air pollution.
- **Gas map:** Presents a geographic map of air pollution.
- **Site administration:** Allows access to the administration of specific database tables, gas concentration reports, and pollution vs. time graphs.

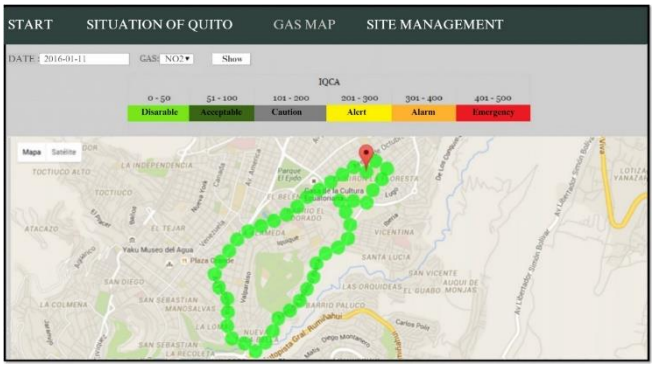

Figure 6. Results of *CO* test on monitoring path

Figure 7. Test results of O_3 on monitoring path

IV. Test and Results

A. Outdoor Scenario

Monitoring tests of *CO*, O_3, and NO_2 gases in outdoor environments. The results obtained from monitoring *CO*, O_3, and NO2 gases using the MQ-7, MQ-131, and NO2-AE sensors are presented in Fig. 6, Fig. 7, and Fig. 8, respectively.

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The results show that the SIGMA prototype presents greater concentrations of contamination in the environment by *CO*, O_3, and NO_2 gases within the monitoring route in the desirable range of the IQCA. Additionally, the acquired data was easier to interprete due to the implemented web interface.

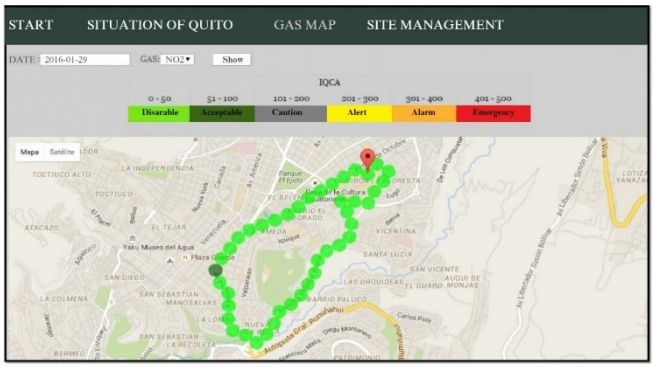

Figure 8. Test results of NO_2 on monitoring route

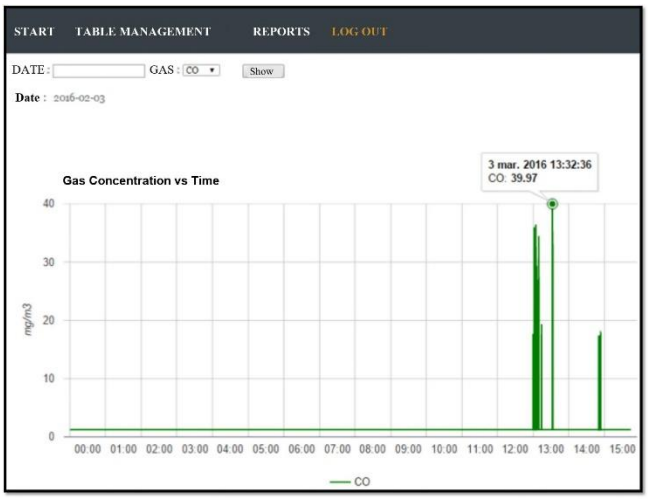

Figure 9. Resultados prueba de *CO* en indoor

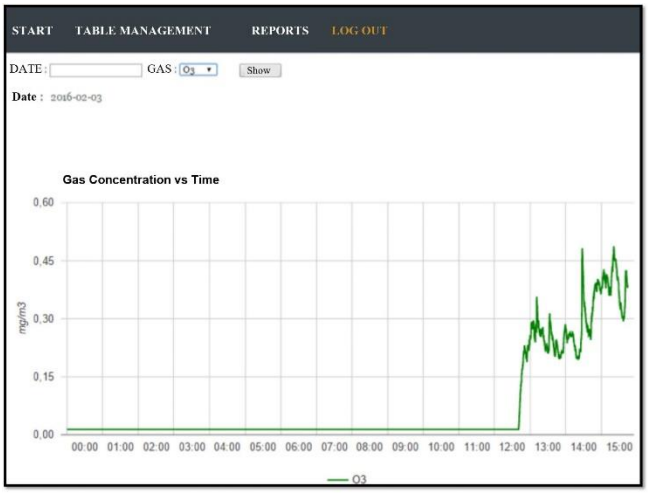

Figure 10. Resultados prueba de O_3 en indoor

B. *Indoor Scenario*

The monitoring tests of *CO*, O_3, and NO_2 gases in indoor environments were carried out in the kitchen area of the cafeteria of the Escuela Politécnica Nacional. This area was selected because it is a work environment where continuous combustion processes occur during the day (use of LPG for cooking food). The results obtained from monitoring *CO*, O_3, and NO2 gases using the MQ-7, MQ-131, and NO2-AE sensors in indoor environments are presented in Fig. 9, Fig. 10, and Fig. 11, respectively.

Analyzing the results, the SIGMA prototype found gas concentrations of *CO* and O_3 within the desirable level of IQCA. The graphical interface shows that the variations in the established area were sporadic, presenting peaks of contamination within a short period. Readers can access [6] for a detailed view of the implementation of the whole system and the specification of subsystems.

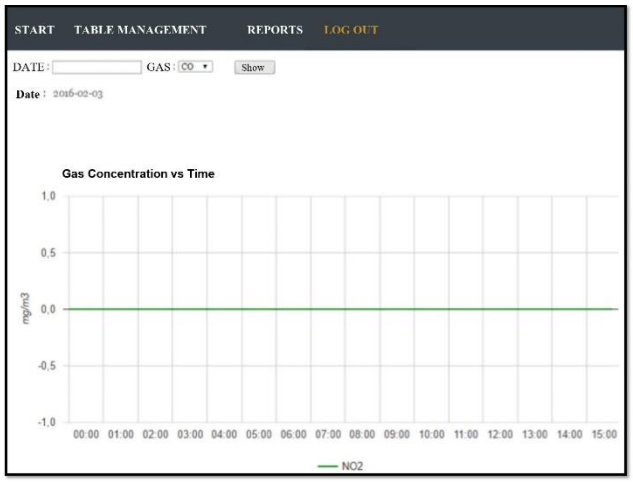

Figure 11. Resultados prueba de NO_2 en indoor

V. CONCLUSIONES

This article focuses on developing a low-cost prototype that is easy to implement with devices based on free and scalable hardware and software. However, it has also taken a step towards the Internet of Things in Smart Cities as it is a real-time data acquisition system with an interactive map that allows users to visualize updated information in a didactic way through color indicators according to the established in the IQCA.

The prototype system allows wireless monitoring of air pollutant gases (CO, O3, and NO2), thus contributing real-time information on the areas with the highest air pollution index. The web interface and the pollution circles established on the map allow for a more straightforward interpretation of the pollution data acquired within the sampling route. The design of the database is scalable and provides the possibility of obtaining information from several transmitters simultaneously, as well as future data. In addition, the contamination vs. time graph provides information on the variations of gas concentrations in indoor environments, allowing a better perception of the changes in short periods.

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According to the tests performed, the transmitter subsystem is suitable for monitoring CO, O3, and NO2 gases in outdoor and indoor environments with reduced temperature variations and contamination levels above the minimum detection range of the sensors used.

Future work is intended to use electrochemical sensors to acquire samples of pollutant gases, thus improving the accuracy of the data. Also, using 4G-LTE technology for its higher speed decreases the sampling time. A network of wireless sensors installed in several vehicles throughout the Metropolitan District of Quito could be implemented, allowing the monitoring of environmental parameters so that with the analysis of these, the regulatory entity can make decisions that contribute to achieving sustainable development in terms of improving the quality of the environment for citizens.

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A Visual Review and Bibliometric Analysis of Cloud Computing Traffic Flow Forecasting for a Digital Africa

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***Abstract*—**the use of cloud computing has grown globally in recent years. When allocating resources, cloud resources and traffic flow management need to be closely watched and controlled. This paper conducted a bibliographic study based on the Scopus database and the Institute of Electrical and Electronics Engineers (IEEE) to evaluate the adoption rate of resource management and traffic flow forecasting in cloud computing in Africa. There is still uncertainty about cloud computing adoption on the African continent. It is difficult to say that 54 African countries are fully prepared to adopt cloud computing. The growth of internet connectivity and potential economic development in Africa are contributing to the rapid growth of cloud computing. This technology enables individuals, private companies and the government to access computing resources and services remotely. It has the potential to significantly impact the education, healthcare and economic sectors; however, there are challenges such as limited infrastructure and data security concerns in Africa. This study demonstrates the limitations of the implementation of cloud computing in African countries such as South Africa, Nigeria, Namibia, Botswana, Zimbabwe, Uganda, Kenya, Cameron, Egypt and Ghana. Only 18.5% of the continent is researching the implementation of cloud computing, and the lack of cloud implementation remains a persistent issue because of scarce resources. However, Africa's adoption of cloud computing can be increased through alternative solutions suggested in the study.

Keywords*—Cloud Adoption, Traffic flow, and Africa*

I. INTRODUCTION

The African cloud computing market attracts foreign investors and has a penetration rate of 15% of cloud computing resources and traffic. This rate will grow significantly in the future. Cloud computing in African markets is still in its early stages with South Africa displaying the most activity. The private sector and businesses established in South Africa, such as Internet Solutions are the sources of demand. International suppliers compete with the increasing number of submarine cables connecting continents to high-speed internet. This growth is possible [1–3].

Cloud computing is becoming increasingly popular in Africa with governments and private entities alike recognizing the benefits and adopting cloud-based strategies [4]. As a result of limited and uneven cloud service delivery infrastructure development across the continent. African businesses want to adopt this technology; however, some of the African infrastructure challenges are signs of slowing down and cloud adoption remains low.

African organizations faced challenges in adopting cloud computing to reduce ICT costs, including user resistance, human factors, support and funding [5]. The use of cloud computing makes managing and maintaining ICT resources easier and more efficient. The African cloud computing market is gaining momentum due to the growing demand for digital transformation and a shift towards cloud applications across various industries and sectors [5–6].

In recent literature, African countries have been struggling to adopt this technology. They are facing challenges such as mimetic, coercive and normative. The implementation of cloud computing is hampered by doubts about the dependability of cloud service providers and a deficiency of cloud computing expertise [7]. Together with government regulations pertaining to cloud computing, cloud service providers have also come under fire for providing insufficient assistance and training [8]. A strong higher education system boosts a nation's worldwide competitiveness, economic power, social well-being and global leadership position. In this regard, African countries to increase their adoption of cloud computing a strong foundation of education in universities must be laid on the African continent about cloud computing [9-10].

The primary contribution of this paper is to identify publishing trends in 54 African countries and propose a strategy to encourage other countries to adopt cloud computing technology. The rest of this article is divided into related work, methods, results, discussion and recommendation and conclusions.

II. RELATED WORK

There is still uncertainty about cloud computing adoption on the African continent [11]. Africa is falling behind in cloud technology adoption owing to poor broadband access and expensive infrastructure. Better bandwidth must be made available by service providers and the government in order to overcome these obstacles, which could have a significant positive impact on cloud computing in Africa [12]. Africa's health industry is rapidly becoming digital, especially in the area of medical data. By providing safe, on-site access to patient information, medical data and health apps globally. Cloud computing enables "accessibility without borders" fostering interoperability and well-informed decision-making [13].

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Most countries in Africa are ignoring this benefit due to poor infrastructure and unaffordability. On the other hand, political interference is also a major blockade to the development of Africa [14]. To advance technology in Africa, cloud adoption must be encouraged and authorized by African regulators [14-15]. As African regimes become more authoritarian, residents will become increasingly disenfranchised from their leaders, resulting in political instability and bloodshed[15].This will cause internal displacement, increase external migration and impede social and economic growth. In order to resolve these problems, long-standing complaints and the cruel governance that permeates Africa must be addressed.

In contrast, African states are trying to adopt the technology. The usage of the internet in Africa has increased significantly [16]. Table 1 shows the top twelve African countries that are adopting the use of the internet. Morocco is leading the internet usage with 91.7%, followed by Libya with 89.4%, the Seychelles with 87%, followed by Tunisia with 79.6%, Botswana with 77.3%, Mauritius with 75.5%, and the internet usage in South Africa is 74.7%, followed by Gabon with 73.7 %, Algeria with 72.9%, Egypt with 72.2 %, Cabo Verde with 72.1 %, and Ghana with 69.8%, as shown in Table I. Top twelve countries internet usage% in Africa.

TABLE I. TOP TWELVE COUNTRIES OF INTERNET USAGE IN AFRICA

Numbering	Top twelve countries internet usage% in Africa	
	Country Name	Usage (%)
1	Morocco	91.7
2	Libya	89.4
3	Seychelles	87.7
4	Tunisia	79.6
5	Botswana	77.3
6	Maurituis	75.5
7	South africa	74.7
8	Gabon	73.7
9	Algeria	72.9
10	Egypt	72.2
11	Cabo verde	72.1
12	Ghana	69.8

It is difficult to say that 54 African countries are fully prepared to adopt cloud computing.

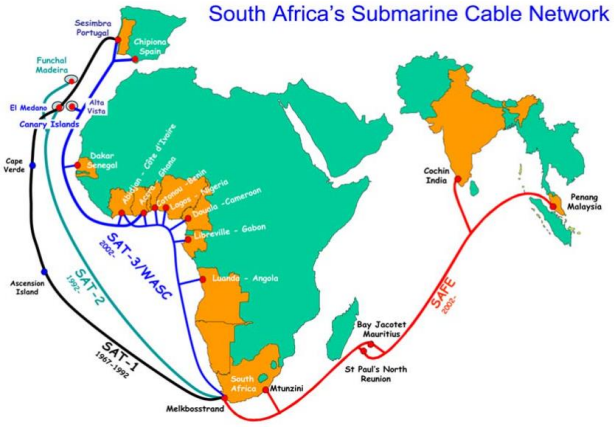

Fig. 1. Submarine cable network[17]

However, the arrival of several international submarine cables on the African continent (see Figure 1), has significantly increased international bandwidth capacity, which indicates an opportunity for investors to invest in cloud computing on the continent [17].

Cloud computing will make large scale genomic data analysis and storage more scalable and affordable on the African continent as cloud computing becomes more prevalent. The privacy and security concerns regarding human data must be addressed in accordance with African regulations [18]. Kenya is creating data security and privacy regulations, including a bill that allows cloud firms to handle personal data [19].

It is also critical to address a server placement, foster cloud computing confidence, and make investments in terrestrial broadband backbone networks. Additionally, the government has declared cable damage to be an economic crime punishable by severe fines [19-20].

Improved infrastructure and pricing are driving South Africa's cloud computing service expansion, innovation may be increased by addressing regulatory issues and encouraging cloud services in e-government and education [21]. Closing legislative gaps in cybersecurity, data privacy and data can boost offshore markets, increase consumer confidence in cloud services and spur economic development [22]. It is equally significant to pass laws pertaining to data security and privacy and to develop local expertise in advanced technologies, such as cloud computing.

There is no doubt that cloud computing can reduce costs and improve services exactly what Africans need right now [23]. By lowering capital costs, enhancing service delivery, boosting transparency and assisting small and midsize enterprises (SMEs) in IT procurement. The Nigerian government's implementation of a cloud computing strategy would boost the country's economy and create employment [24].

Technology Acceptance Model (TAM): During the pandemic, educational institutions logically adopted cloud computing to enhance academic performance, despite the secondary focus was not on secure services[25]. Cloud computing adoption in Ghana was proposed using partial least

squares structural equation modelling, the study reveals that institutional pressures, including mimetic, coercive and normative, account for 27% of cloud computing adoption variance, highlighting its adoption in low-adoption environments [25] .Other studies found that trust perception did not significantly impact the onboarding of cloud computing in North-Eastern Nigerian academic libraries [26].

Ghana's internet connection puts the country in a good position to progress in cloud computing, but adoption and knowledge remain poor [27]. Unlike other industries like banking, telecommunication, media and education, the industry is still in its infancy and lacks a single front and clear guidance from a unified entity. While educational societies in Sub-Saharan Africa have built their own private cloud computing infrastructure, universities are working with public cloud service providers such as Microsoft, Cisco and Amazon Web Services [27]. These universities play a critical role in the development of countries and to increase cloud computing adoption, it should be the subject in all areas of courses, no matter what career students are pursuing.

Web-based services were given a two-model modification to determine cloud computing adoption, the model increased adoption with 73% of the variance and determinants related to this adoption [28]. In Africa, Cloud service providers face reliability concerns, a lack of skills, inadequate support and government policies hindering adoption due to concerns about reliability, skills, and training [29].

Digital legacy in trade-dependent countries results in export-oriented firms investing in traditional digital assets. Large service sectors have high Cloud Computing adoption but low growth rates [30]. Implementing cloud computing in higher education faces significant challenges due to data risk, privacy, government regulation, peer pressure, data security and management factors [31]. Cloud Computing in Resource-Constrained Environments to facilitate e-Government Services in Ethiopia recommends the enhanced Framework for Cloud Computing adoption in Ethiopia's WoredaNet context [32]. There are more benefits to adopting cloud computing in Ethiopia's public sector than in private institutions [32]. Ethiopian companies find it difficult to use cloud computing because they do not trust international suppliers, mostly because they are worried about privacy and data security [33].

Ethiopia must embrace cloud computing if it wants to succeed in a digitalized, knowledge-based economy. The Ethiopian government should implement new regulations that support cloud computing and its effects on security, secrecy and protection of personal data in order to facilitate its growth. Programs for training businesses to implement cloud computing might also assist in addressing issues.

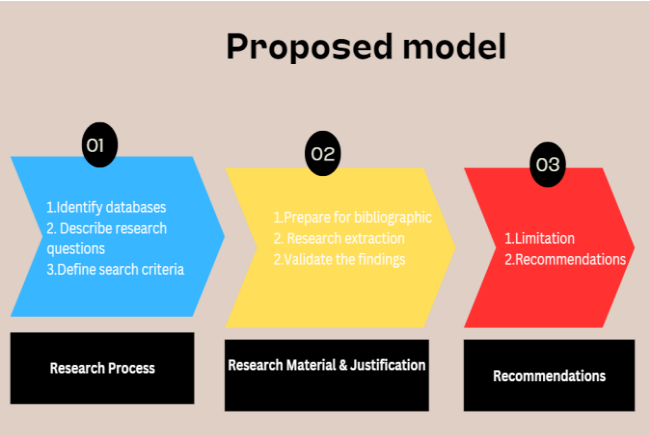

Fig. 2. Proposed model

III. METHODS

Figure 2 shows the research process and steps, which are grouped into three categories: research process, research material, justification, and recommendations.

A. Research Process

Identify databases – A literature search was conducted in two databases: the Institute of Electrical and Electronics Engineering (IEEE) and Scopus for literature related to cloud computing adoption in Africa.

Describe research questions – The research focuses on the challenges faced in Africa in implementing cloud computing, using specific research questions to guide the study.

What are cloud computing adoption challenges in Africa?

Search criteria: The search criteria explore English-written articles published between 2019 and 2023.

B. Research Material & justification

Research extraction- articles were filtered according to research question and search criteria. The data extracted was analyzed thematically.

Validate the findings-The research output was validated using two databases.

C. Dataset

This study included only English-language original articles and reviews published between January 1, 2019 and December 26, 2023, by 6213 authors and 278 sources.

IV. RESULTS

A. Bibliometric analysis review

Using a bibliometric analysis review of the cloud computing traffic flow forecasting for Africa, the results showed that South Africa and developing countries were most cited and are contributing to the implementation of cloud computing in Africa.

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Fig. 3. Analysis review

Remote sensing, distributed computer systems and information management are some of the tools and techniques highlighted in these results (see Figure 3).

B. Adoption strategy

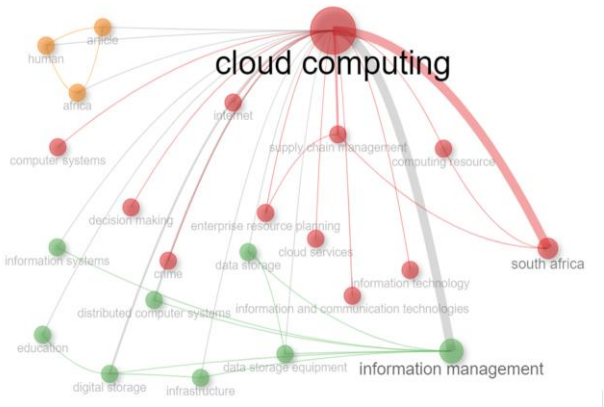

Fig. 4. Adoption strategy

To accelerate the implementation of cloud computing in Africa, it is very critical that the continent have a stable internet connection. The resources to adopt the internet in Africa are slowly covering the African region, for example. Several international submarine cables landed on the African continent (see Figure 1).To support Africa, however Africa needs supply chain management, cloud computing resources (such as skills, etc.), enterprise resource planning and distributed computer systems also local infrastructure to support the adoption of cloud computing (see Figure 4).

C. African Corresponding author's countries

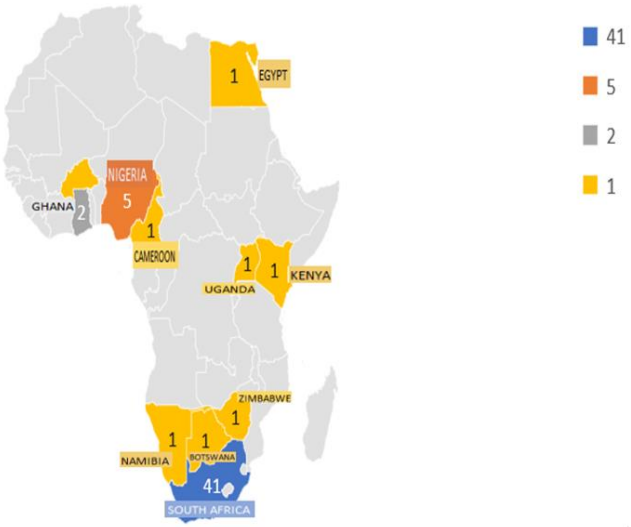

Fig. 5. African Corresponding author's countries

Using a bibliometric analysis review, the results indicate that there is research about the adoption of cloud computing in African countries such as South Africa, Nigeria, Namibia, Botswana, Zimbabwe, Uganda, Kenya, Cameron, Egypt, and Ghana. Only 10 countries are significantly contributing to the continent's research on the adoption of cloud computing (see figure 5).
As it can be seen in Figure 5, the most publication affiliations are from South Africa (41%), followed by Nigeria (5%), and Chana (2%). The following section investigates the top five affiliations that are publishing the most articles from three countries, which are South Africa, Nigeria, and Chana.

Table 1 shows the top five affiliations in South Africa. The University of Cape Town is leading with 20% of published documents, followed by the University of the Western Cape with 14%, the University of Pretoria with 11%, the University of Johannesburg with 10%, and the University of South Africa with 9% of cloud computing published documents.

TABLE II. TOP FIVE AFFILIATION IN SOUTH AFRICA

Numbering	**Top Five Affiliation in South Africa**	
	Affiliation Name	***Number of Documents (%)***
1	University of Cape Town	20
2	University of the Western Cape	14
3	University of Pretoria	11
4	University of Johannesburg	10
5	University of South Africa	9

The top five affiliations in Nigeria are displayed in Table II. With 4% of cloud computing-published documents, Covenant University leads the field, followed by the Federal Ministry of Health (1%), the University of Ibadan (2%), the University of Nigeria (3%), and the University of Ilorin (3%).

TABLE III. TOP FIVE AFFILIATION IN NEGERIA

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Numbering	Top Five Affiliation in Nigeria	
	Affiliation Name	*Number of Documents (%)*
1	Covenant University	4
2	University of Ilorin	3
3	University of Nigeria	3
4	University of Ibadan	2
5	Federal Ministry of Health	1

Table III shows the top five affiliations in Ghana. The Kwame Nkrumah University of Science & Technology is leading with 3% of published documents, followed by the University of the Cape Coast Ghana with 2%, the University of Ghana with 2%, the Ashesi University with 1%, and the Ghana Institute of Management and Public Administration with 1% of cloud computing published documents.

TABLE IV. TOP FIVE AFFILIATION IN GHANA

Numbering	Top Five Affiliation in Ghana	
	Affiliation Name	*Number of Documents (%)*
1	Kwame Nkrumah University of Science & Technology	3
2	University of Cape Coast Ghana	2
3	University of Ghana	2
4	Ashesi University	1
5	Ghana Institute of Management and Public Administration	1

D. World collaboration with Africa

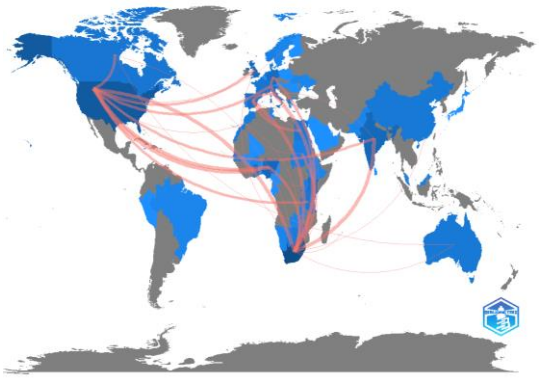

Fig. 6. World collaboration with Africa

Cloud computing is being adopted by a few African countries. In this regard, there is a slow cooperation with the developing countries (see Figure 6).

V. DISCUSSION AND RECOMMENDATION

Developing countries are supporting Africa by bringing technology to the continent, for example, international submarine cables on the African continent, according to this paper. It is hard to state that 54 African countries are fully prepared to adopt cloud computing. Only 10 countries on the continent are researching the implementation of cloud computing. The first recommendation is awareness of cloud computing adoption; it would be easy to implement and carry out awareness and discussion inside higher education institutions. The African government and private sector must invest in teaching and learning about cloud computing to create the required expertise to implement cloud computing. The second recommendation is collaboration; 18.5 percent of countries must inspire and support other African countries to adopt the change and implement cloud computing. There is also a need for Africa to adopt supply chain management, cloud computing resources (such as skills, etc.), enterprise resource planning, distributed computer systems, and local infrastructure to support the onboarding of cloud computing.

VI. CONCLUSION

The growth of internet connectivity and potential economic development in Africa are contributing to the rapid growth of cloud computing. Cloud computing enables individuals, private companies and the government to access computing resources and services remotely. It has the potential to significantly impact the education, healthcare, and economic sectors; however, there are challenges such as limited infrastructure and data security concerns.

This paper uses a bibliometric analysis of cloud computing traffic flow forecasting for a digital Africa. There is still uncertainty about cloud computing on the African continent. It is challenging to assert that all 54 African countries are fully prepared to implement cloud computing. The results indicate that there is research about the adoption of cloud computing in African countries such as South Africa, Nigeria, Namibia, Botswana, Zimbabwe, Uganda, Kenya, Cameron, Egypt, and Ghana. Only 18.5% of the continent is researching the adoption of cloud computing.

African nations encourage and help other African countries in adopting and implementing cloud computing. They may also begin at the educational institution, where they can teach our future leaders. This will make it simpler for the emerging nations to approach other non-participating African nations later on. In order to facilitate the implementation of cloud computing, Africa must also implement supply chain management, distributed computer systems, corporate resource planning, cloud computing resources (such as talents, etc.), and local infrastructure.

Since only the IEEE Xplore and Scopus databases were used in this report, other research databases will be included in the future to broaden the scope of this investigation. Researchers in the future will be able to analyze the data using bibliometric programs such as VOSviewer and Bibexcel. The findings might not be representative of all research on a visual review and bibliometric analysis of cloud computing traffic flow forecasting for a digital Africa. To examine additional studies, future research will require a more thorough search that encompasses all papers.

AUTHOR CONTRIBUTIONS

The authors acknowledge that this article was written as part of the outcomes produced while studying for a Ph.D. in computer science and information systems. After consulting with their supervisors, Ph.D. students elaborated the original draft of this work. In this study, they conceptualized the methodology, collected the data, set up the experimental platform, conducted bibliometric analysis of cloud computing traffic flow forecasting for a digital Africa, and analyzed the

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findings. Besides this, there are no conflicts of interest reported by any of the authors.

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