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Foresight Analysis: Probabilistic Scenarios for the Electric Automotive Sector in Lima by 2030

Juan José Céspedes-Angeles
Facultad de Ingeniería, Universidad de Lima, Peru
20192593@aloe.ulima.edu.pe

Joseph Anthony Neyra-Salazar
Facultad de Ingeniería, Universidad de Lima, Peru
20191396@aloe.ulima.edu.pe

Gustavo Adolfo Luna-Victoria-León
Research Professor
Facultad de Ingeniería, Universidad de Lima, Peru
galuna@ulima.edu.pe

Abstract

This study conducts a prospective analysis of Lima's electric automotive sector by 2030, aiming to evaluate CO2 reduction scenarios through increased electric vehicle (EV) adoption. Addressing limited EV penetration and rising urban pollution, the research employs a mixed-methods approach, utilizing MICMAC, MACTOR, and SMIC Prob-Expert, complemented by the Delphi method. The study identified the General Sales Tax (IGV) and Public Knowledge on Climate Change (NivelCon) as "repeater" variables crucial to the system. Key actors, including the Ministry of Transport and Communications (MTC), the Government of Peru, and Importers, were also found to be "repeaters," highlighting their essential coordinated contribution. However, probabilistic scenarios project a high likelihood (38.9%) for an "inertial" future, where incentives are not implemented, nor is public awareness fostered. Conversely, the scenario where both hypotheses are achieved presents a lower probability (27.9%). These findings emphasize that political will, the resolution of conflicts of interest, and sustained public awareness efforts are critical for accelerating EV adoption and mitigating climate impact in Lima.

Keywords
Electric vehicles, MICMAC, Foresight analysis, Sustainable transport, Delphi method

1. Introduction
The issue of CO_2 emissions from the automotive sector is closely linked to serious threats to public health. These emissions not only exacerbate climate change but also negatively affect human health, particularly by contributing to respiratory diseases. Respiratory illnesses in Peru—such as pneumonia, asthma, and chronic obstructive diseases—are directly related to air pollution. According to the Ministry of Health, respiratory diseases caused by poor air quality cost the country more than US$ 800 million annually in healthcare expenses and productivity losses (MINAM, 2021).

Climate change has become a global concern since the mid-20th century, when significant increases in the concentration of greenhouse gases (GHG) in the atmosphere began to be detected, mainly attributable to human activities such as the burning of fossil fuels, deforestation, and intensive agriculture. These gases—including carbon dioxide (CO_2), methane (CH_4), and nitrogen oxides (NO_x)—trap heat in the atmosphere, thus contributing to the phenomenon of global warming (IPCC, 2021).

In the case of Peru, the main sources of greenhouse gas (GHG) emissions are found in the sectors of agriculture, land-use change, forestry, and energy. The Ministry of the Environment (MINAM) highlights that deforestation in the Amazon and emissions from the transportation sector are the principal sources of GHG in the country (MINAM, 2021).

According to the 2023 World Air Quality Report by IQAir, which evaluates the concentration of PM2.5 particles, Peru ranked 51st worldwide, with an average level of 18.8 $\mu g/m^3$. Although this figure represents an improvement compared to the 23.5 $\mu g/m^3$ reported in 2022, it remains significantly above the WHO-recommended range of 0 to 5 $\mu g/m^3$.

1.1 Objectives

1. Identify and analyze the key factors and variables that influence the adoption of electric vehicles in Lima, including economic, technological, regulatory, and social aspects, based on market data and previous studies.
2. Develop and evaluate different prospective scenarios for the adoption of electric vehicles in Lima, considering variables such as EV market growth, expansion of charging infrastructure, and incentive and regulatory policies.
3. Estimate the potential reduction of CO_2 emissions impact in Lima's transportation sector under each prospective scenario, using simulation models and quantitative analysis.
4. Propose strategies and public policies based on the results of the prospective analysis, including incentives for EV acquisition, development of charging infrastructure, and awareness campaigns.
5. Develop a roadmap to implement the proposed strategies, in alignment with the Sustainable Development Goals established for the city of Lima.

2. Literature Review

This research posed the following research questions as the central axis of the analysis: To what extent does CO_2 contribute or impact the carbon footprint? What is the current situation of the carbon footprint in the city of Lima? What successful international experiences in the implementation of electric vehicles could be applicable to Lima? What barriers would prevent the rapid adoption of an electric vehicle fleet in Peru/Latin America? For this systematic literature review, the research design relied on both qualitative and quantitative information, combined with an exploratory scope. The objective was to address the proposed goals and their corresponding research questions.

Search platforms such as Scopus, Web of Science, and Mendeley were used. The search carried out in Scopus was: "(TITLE-ABS-KEY (carbon AND footprint) AND TITLE-ABS-KEY (electric AND cars)) AND PUBYEAR > 2018 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE , 'ar') OR LIMIT-TO (DOCTYPE , 're')) AND (LIMIT-TO (OA , 'all')) AND (LIMIT-TO (SUBJAREA , 'ENER') OR LIMIT-TO (SUBJAREA , 'ENGI'))."

Additionally, filters were applied to refine the search and identify suitable articles that aligned with the research objectives. Only scientific articles and journals published in English between 2019 and 2023 were considered. Furthermore, only studies related to relevant fields, such as engineering, energy, and sustainability, were included.

3. Methods

The present study is framed within a prospective research design with a mixed-methods approach (qualitative and quantitative), aimed at analyzing possible scenarios for the adoption of electric vehicles in Lima by 2030 and their impact on reducing the carbon footprint. Recognized foresight analysis tools were used in accordance with the Foresight Guide for Policies and Plans of CEPLAN (2024), such as MICMAC, MACTOR, SMIC Prob-Expert, and the Delphi method. The main research variables included: CO_2 emissions, electric charging infrastructure, government incentives, technological costs, environmental awareness, energy supply, and regulatory frameworks.

4. Data Collection

The methodological process was developed in three sequential phases:

1. Structural Analysis (MICMAC): Thirty relevant system variables were identified, and their influence relationships were analyzed to determine the driving and dependent variables.
2. Actor Mapping (MACTOR): Strategic actors, their objectives, and power relations were identified, generating a matrix of convergences and divergences.
3. Probabilistic Scenarios (SMIC Prob-Expert): Twelve key hypotheses about the future of the sector were formulated, assigning probabilities of occurrence based on expert judgment. The software generated plausible combinations of scenarios.
4. Delphi Method: Two rounds of consultations were conducted to validate the hypotheses, key factors, and scenario results, reaching an 80% consensus level.

This procedure enabled the construction of alternative development scenarios for the electric automotive sector in Lima by 2030, along with their estimated impacts on the carbon footprint.

5. Results and Discussion

5.1 Numerical and Graphical Results

Add graphical results here. Make sure to describe all figures (Figure 1- Figure 4) and add inferences. If needed, add statistical analysis here.

The foresight tool is applied using the Cross-Impact Matrix method (MICMAC) to identify the key variables that determine changes and inertias within the study system and their influence on it. Additionally, based on the variables identified, the sector's actors and strategic objectives will be established. The influence and dependency among variables are identified through a quantitative assessment carried out in a two-entry matrix, with a total of n*(n–1) questions—156 in this case—where n corresponds to the thirteen variables considered for the analysis.

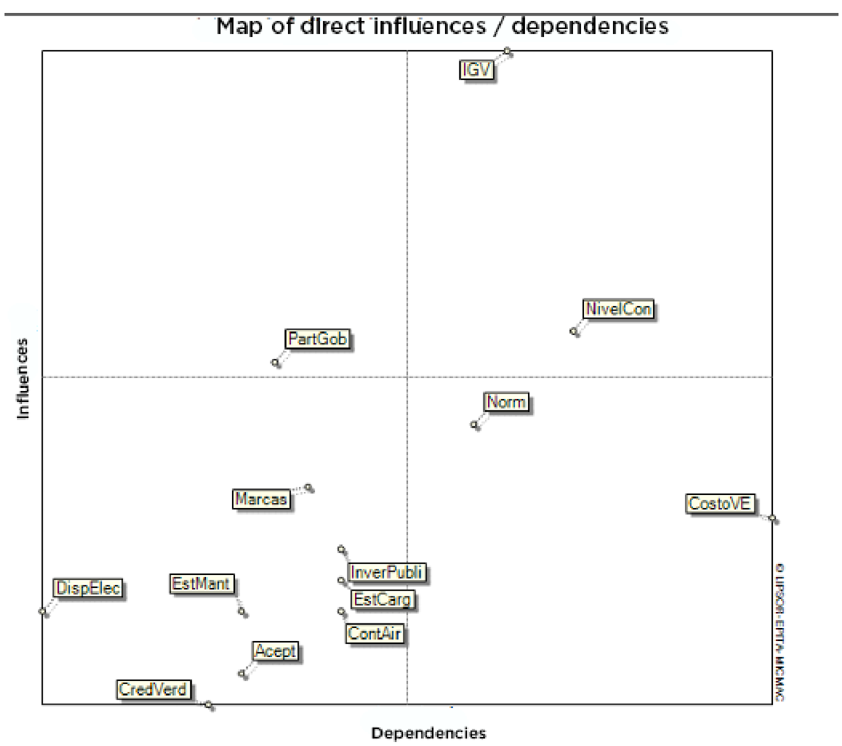

Figure 1. Map of direct influences / dependencies

The variables are classified according to their level of influence and dependence into: input, relay, output, excluded, and cluster variables. In this regard, the relay variables are those that exhibit both high dependence and high influence and are considered the key variables that determine the evolution of the system—namely, the General Sales Tax (IGV) and the Level of Knowledge on Climate Change (NivelCon).

Based on the key variables identified in the structural analysis, two strategic objectives are proposed:

1. Reduce the General Sales Tax (IGV) on electric vehicles by 10% within five years (IGV).
2. Increase the population's level of knowledge about climate change in Peru by 30% within five years (NivelCon).

In the electric vehicle automotive sector, seven actors were identified, each related to the study's objectives. The actors' driving power determines their position on the influence–dependence map, and they are therefore categorized into four quadrants: dominant, relay, autonomous, and dominated actors. The quantitative assessment is established according to the level of influence, where:

- 0 indicates that an actor has no means of action over another,
- 1 indicates influence over another actor's processes,
- 2 indicates influence over the actor's projects,
- 3 indicates influence over the actor's missions, and
- 4 indicates influence over the actor's very existence.

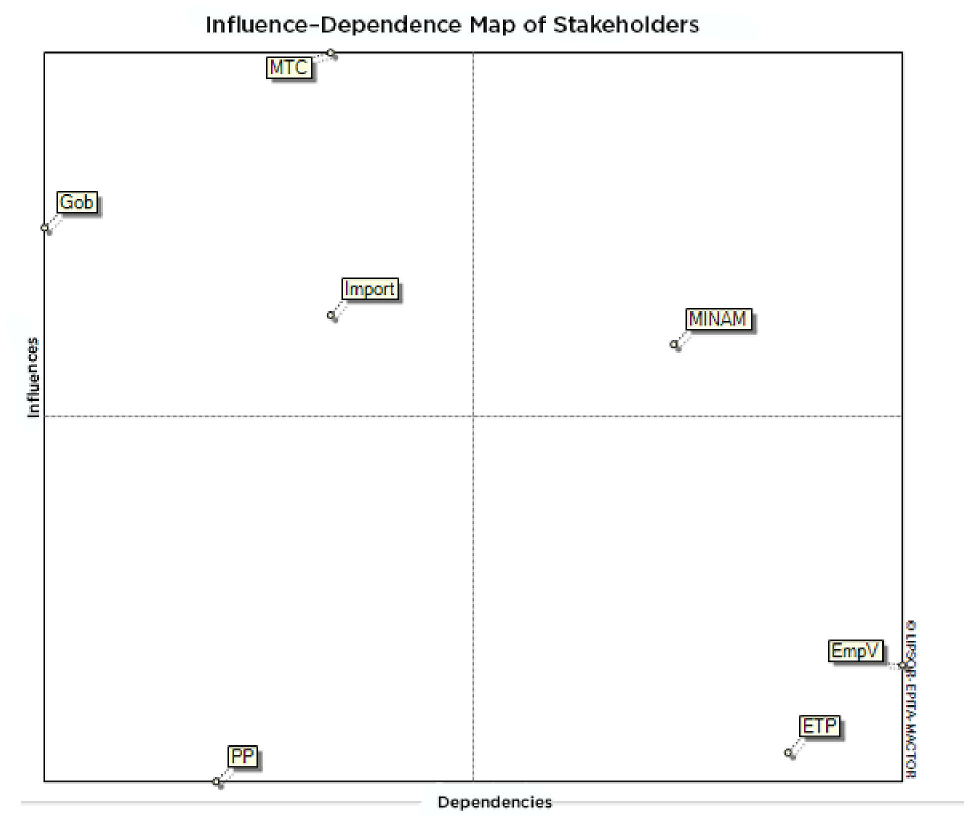

Figure 2. Influence–Dependence Map of Stakeholders

In this way, the stakeholders with the highest levels of influence and dependence—located in the quadrant of relay actors—are: the Ministry of Transport and Communications (MTC), the Government of Peru (Gob), and Importers (Impor).

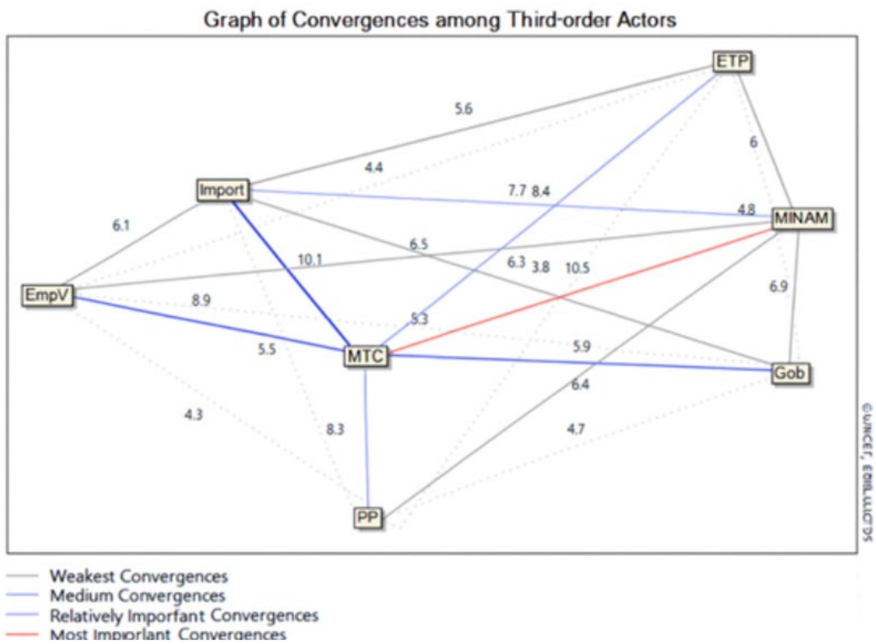

Figure 3. Graph of Convergences among Third Order Actors

Likewise, convergence determines the correlation of forces among the actors in relation to the sector's strategic objectives. A strong alliance is observed between the Ministry of Transport and Communications (MTC) and the Ministry of the Environment (MINAM), represented by the red line.

Through the application of the Delphi survey to five experts—including managers and specialists with political, economic, social, and technological knowledge, the information was collected and later processed using the Smic Prob Expert software. This resulted in the simple probabilities of achieving the strategic objectives, which were: 1 – IGV (0.489), and 2 – NivelCon (0.401).

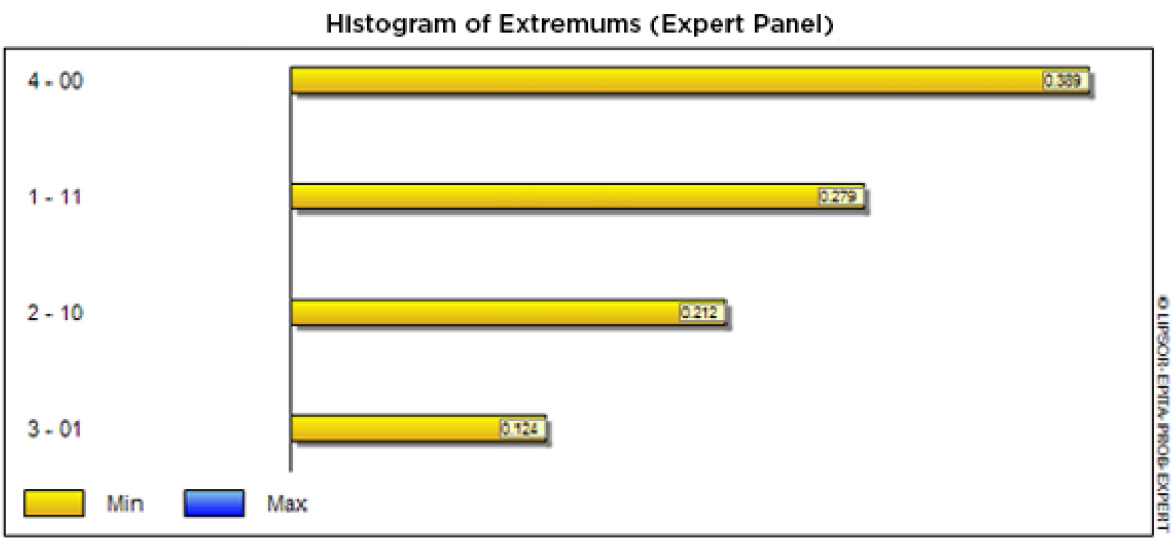

Figure 4. Histogram of extremums

In the histogram of extremums, it is evident that scenario (00), ranked in first place, has a relative probability of occurrence of 38.9%. This indicates that no incentive to reduce the VAT (IGV) on electric vehicles will be implemented by the year 2030, accompanied by a lack of commitment to promoting awareness of and the impact of climate change among the population of Lima.

In second place is the exploratory scenario (11), which ranks second in the histogram with a 27.9% probability of occurrence, in which both hypotheses do occur.

5.4 Validation

In Godet's 1994 methodology, key aspects are detailed, such as the initial variables, the importance of change factors and trends, as well as the sequence of use of the LIPSOR (Laboratory for Research in Strategic Foresight and Organization) software: MICMAC, MACTOR, and SMIC ProbExpert. All of these elements are used to develop the possible, probable, desirable, and "bet" scenarios.

Scenario Method:
Stage 1: Based on the literature review, variables will be identified and prioritized through the MICMAC structural analysis. Qualitative note: Incentive. If the objective can be achieved with qualitative information, the model should not be forced.

Stage 2: This stage will consist of grouping key variables and constructing preliminary hypotheses based on current projects, future projects, and threats for each variable or group. The status of each will be classified as excellent, good, fair, or poor, using quantitative indicators.

Stage 3: Simple probability analysis, as well as positive and negative conditional probability analysis, will be applied to obtain possible scenarios ranked from highest to lowest probability, using the Cross-Impact Matrix System-Probability Expert software — SMIC ProbExpert (LIPSOR, 2024).

Delphi Method
Stage 1: Literature Review
A bibliographic review will be conducted to identify topics, innovations, technologies, and new companies, using the search equation TITLE-ABS-KEY (automotive sector and/or leather; electric vehicles and/or prospective scenarios; electric vehicles and/or Delphi method) in the Scopus database.

Stage 2: Development of Expert Profiles
Experts who will respond to the Delphi questionnaire will be profiled according to their academic level, experience, topics, and subtopics. It is important to note that the experts or key actors will belong to national and international institutions across various sectors, such as automotive companies, universities, governments, public and private sectors, among other organizations related to the automotive value chain.

Stage 3: First Delphi Round
The questionnaire will be developed based on the topics and subtopics obtained from the literature review. The first survey will be sent to experts to prioritize each topic up to the year 2030, using a Likert scale from 0 to 5. The Likert scale is a technique used to measure respondents' attitudes, opinions, or perceptions regarding a given statement, offering an ordered range of responses that typically varies from total agreement to total disagreement. Its purpose is to quantify qualitative responses to facilitate the statistical analysis of social data (Krosnick & Presser, 2010).

Stage 4: First Delphi Round and Preliminary Report
Based on the average percentage of consensus per subtopic, a subtopic will be considered a priority in the first Delphi round if it shows a consensus percentage above the group average and a modal value equal to or greater than 4 or 5 in the evaluation.

Stage 5: Second Delphi Round
The second Delphi round aimed to provide feedback to participants with the results of the first round, as experts were asked to review the list of priority and non-priority items.

Stage 6: Analysis of the Second Delphi Round and Final Report
Modal Frequency 2 (MF2), which allows the identification of priority topics, was calculated based on consensus across both Delphi rounds. In this regard, MF2 = MF1 + E2 – S2 (Eq. 1), where E2 represents the number of times a specific item proceeds to the second round, and S2 represents the number of times the item is removed in the second round.

6. Conclusion

The reduction of the General Sales Tax (IGV) is a key variable within the system. It was identified as a "relay" variable with high influence and dependency, indicating that changes to it can trigger significant systemic transformations. Moreover, there is substantial support from key actors. The MACTOR analysis revealed a majority of actors in favor of reducing the IGV (19 positions in favor vs. 3 against), reflecting political and social viability.

Social acceptance and environmental awareness are equally decisive. Alongside the IGV, the level of knowledge about climate change was identified as another key variable, highlighting the need for citizen education.

The scenario without an IGV reduction is currently the most probable (38.9%). According to the scenario simulation, the baseline scenario without incentives is the most likely, suggesting institutional inertia and a lack of concrete action.

The alliance among public actors is decisive. A strong convergence was detected between the Ministry of Transport and Communications (MTC) and the Ministry of the Environment (MINAM), representing a strategic opportunity to promote coordinated reforms in the transportation sector.

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Biographies

Juan José Cespedes-Angeles is a graduate in Industrial Engineering with a focus on environmental sustainability. He has experience in environmental compliance projects and sustainability initiatives across corporate operations. He currently holds the position of Environmental Sustainability Analyst at a leading financial services group in the region.

Joseph Anthony Neyra-Salazar is a Bachelor of Industrial Engineering from the University of Lima, with specializations in Business Engineering. He currently holds the position of After-Sales Intern at an automotive import company.

Gustavo Adolfo Luna-Victoria-León holds a doctoral degree in International Business from Universidad Ricardo Palma and a Master's in Business Administration from Universidad del Pacifico. He earned his Bachelor's in Industrial Engineering from Universidad de Lima and completed a postgraduate diploma in Project Management at ISIL. He is currently a professor at Universidad de Lima, teaching project formulation and evaluation, engineering problem analysis, and applied engineering project courses, as well as advising and evaluating undergraduate theses. He has more than 18 years of professional experience in the telecommunications industry, serving in roles such as Key Account Manager and Manager of Large Projects. His background includes leading multidisciplinary teams, managing high-value corporate accounts, and delivering nationwide technological and public safety projects. His expertise spans project planning, team leadership, commercial strategy, and large-scale project implementation.