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Influence of the introduction of electric vehicles on CO_2 emissions in Peru

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Abstract*– In Peru, as in many countries, road transport is dominated by vehicles with gasoline or diesel internal combustion engines, which represents a challenge for decarbonization in the world. In industrialized countries there is an interest in electric vehicles, with the aim of achieving emissions reduction objectives, to improve air quality and reduce greenhouse gas emissions. That is why the trend is to electrify the vehicle fleet, thereby reducing fossil fuel imports, thus progressively eliminating energy dependence. Lima has a serious pollution problem that is due to the transportation sector, both due to the emission of gases, as well as noise, traffic and the poor transportation system. For this reason, it is important to evaluate the environmental impact produced by electric vehicles at different penetration rates in the private sector transport fleet. The objective is to evaluate the importance of EVs in reducing GHG emissions. In this work, an econometric model is used and the use of neural networks ANN, the dependent variable is the CO_2 emissions in Peru. Different scenarios have been created, each with different penetration rates. As a result, in the reduction of CO_2 emissions, for light vehicles (cars), by 2030 in all scenarios, a reduction in emissions of 0.48% has been demonstrated for the global rate, 2.82% for an AAP scenario, 5.73% for a NGV scenario and a reduction of 20.99% for the very optimistic EV30@30 scenario. With the result, it is observed that the massification of EVs will be essential to reduce GHG emissions.

KEYWORDS-- ***EV penetration rate, Environmental impact, Electric vehicles, neural networks ANN, CO_2 emissions.***

I. INTRODUCTION

In 2009, both the European Union (EU) and G8 leaders agreed that CO_2 emissions must be reduced by 80% by 2050, if atmospheric CO_2 is to stabilize at 450 parts per million (CO_{2eq}) while maintaining warming. global below what is considered to be the safe level of 2ºC. The level of carbon dioxide concentration in the atmosphere has increased at an average rate of 2 ppm/year over the last decade [1]. The balance between energy use and the environment and the problems related to global warming and air pollution are the main requirements for the transport sector [2]. Since the transportation sector is the largest contributor to greenhouse gas emissions in the energy sector, policies must focus on this sector. But full 80% decarbonization by 2050 requires 95% decarbonization of the road transport sector [3]. In 2016, the transportation sector represented 24% of CO_2 emissions from human activity, of which road transportation represented 75% of the global emissions of said sector [4], according to the International Energy Agency (IEA) [5], in that sense, road transport will be very difficult to decarbonize. [6] The International Energy Agency (IEA) establishes policies to reduce CO_{2eq} emissions, which is why many countries adopted the introduction of electric vehicles into the market as an important objective, it is essential to achieve the objectives of the Paris Agreement [7], given that global energy consumption is expected to grow by 30% until 2040 [5]. The continuous increase in road transport demand has a significant effect on oil dependency and greenhouse gas emissions [8]. Driven by a rapidly growing global human population, a growing demand for the freedom to travel, and the affordability made possible by modern manufacturing, there has been an exponential increase in the number of automobiles: in 2013 there were more than one billion automobiles in the world [9].

In response to concerns about rapid climate change and air pollution, electric vehicles (EVs) have spread rapidly in some countries since the early 2010s [10], as electric-powered vehicles are emerging. as a less polluting alternative to vehicles with internal combustion engines. Therefore, it is important to evaluate its penetration in the vehicle market in the future [11]. While it is true that EVs are more expensive than conventional vehicles, it is forecast that price equilibrium with these vehicles can only be achieved by 2026 and 2032, when 50 and 80 million BEVs, respectively, would have been produced throughout the world. world [12]. The increase in the costs of petroleum derivatives, limitations in polluting emissions and the development of photovoltaic (PV) and electrical storage systems make it possible to extend the use of electric vehicles [13].

The environmental impact of electric vehicles (EV) depends largely on the energy source, for renewable sources the impact is positive [14]. Emissions from road transport and power generation would have a warming or cooling effect on the climate [3]. Many countries are trying to promote consumer adoption of BEVs in this regard by providing subsidies and expanding their related infrastructure [15]. To comply with increasingly strict emissions legislation, electric vehicles are expected to offer promising sustainable mobility in the future [16]. One of the main benefits of electric vehicles is the "shift" of harmful air pollutants from urban to rural areas, where population exposure is lower. Noise levels are also lower, especially in urban driving conditions [3]. EVs might not be green if EVs are charged from a dirty power grid

[17]. Studies suggest that HEVs, including plug-in HEVs, could become the dominant vehicle technology in the next two decades, while BEVs may require long-term policy support [12].

II. State of the art

In the literature, there are several relevant published works that focus on this topic of environmental impact for developed countries; in the Latin American region, research on the topic is scarce; therefore, this gap was a motivation for this study. Although Latin America does not demand much energy, its share in global consumption is expected to grow, especially in the transportation sector. This is essential for developing countries to adopt better policies to identify vehicle groups with the highest fuel demand [18].

In Europe, the use of electric vehicles instead of gasoline vehicles can save (around 60% of GHGs) in all or most EU Member States, depending on the estimated consumption of electric vehicles [19], as they would benefit from a future mix of decarbonized electricity and hydrogen in Europe [8]. A comparative study of the performance of an electric vehicle (Renault Zoe) in Scotland (Edinburgh) and Slovenia (Celje). Speed, energy use, driving tests were recorded, in both locations urban and suburban routes were covered for different times of the day. As a result, they showed that the energy, economic and environmental factor is varied and depends on the electricity generation in each city [9]. It has been shown that electric vehicles together with renewable electricity sources offer the potential to reduce negative impacts on the environment and that the level of impact depends on the type of electrical source, in addition to addressing the depletion of fossil fuels, in the Czech Republic and Poland [20], Finland [21], Romania [22], Italy [23] and Latvia [24]

In Asia, as is known China is the main emitter of CO_2 in the world, the effect of economic growth was the main factor to increase CO_2 emissions, the influencing factors that govern CO_2 emissions from the transportation sector were also identified. . During 1991-2015, CO_2 emissions from China's transportation sector exhibited an expansive coupling with economic development [25]. With the rapid growth of electric vehicles in China, its benefits must be scientifically identified to support the development of the industry, the economic and environmental benefits of recycling electric vehicles in China, as there is an economic saving of 473.9 dollars and energy saving of 25.6 GJ, as well as a GHG reduction of 4.1 tCO_{2equ}, per vehicle [26]. In 2011, Beijing launched a plan to replace electric vehicles (such as Midi taxis) with gasoline vehicles (such as Hyundai taxis). Whereas, electric vehicles also exhibited impacts from increases in the potential for acidification, eutrophication, human toxicity, and ecotoxicity. A Midi electric vehicle was lower than that of a Hyundai gasoline vehicle, but the emissions of $PM_{2.5}$, SO_x, CO, VOC, and NO_X of a Midi electric vehicle were higher than a Hyundai gasoline vehicle [27], in This energy and technological transition, the high price of vehicles limits their use to people with higher incomes, who already have private vehicles, in addition to being aware of the environmental benefits, will make people with a higher level of education willing to pay more [28].

For this reason, the integration of photovoltaic systems is recommended, to have a 3E (energy, economic and environmental) viability on the night charging of an electric vehicle (EV) in a residential user, to take into account the sizing of the photovoltaic system, as well as their batteries, according to the average daily distances traveled [13]. Taiwan assessed the environmental impact with full penetration of electric vehicles (i.e. replacement of all light vehicles), CO, VOC, NO_X and $PM_{2.5}$ emissions in Taiwan from a fleet of 20.6 million vehicles would be reduced by 77 %, 15%, 13% and 10%, respectively [29], while NO_X and SO_2 emissions from the electricity sector would increase up to 8% and 11%, respectively, if the electricity to power electric vehicles were provided by thermal power plants [30]. In South Korea, we are told that the expected environmental impact of BEVs is an important factor in increasing consumer adoption of BEVs, and the environmental impact of BEVs is directly related to the electricity generation mix. BEV market share by up to 10% and reduce GHG emissions by up to 5% by 2026 [15], an economic benefit has also been identified, although charging risk is a barrier to its diffusion [10]. In Japan, the study carried out the introduction of light vehicles (EV) in the long term. CO_2 emissions are reduced by 51.9% [6] and 56.9% [11], between 2012 and 2050 in the Base scenario. The diffusion of small and lightweight battery electric vehicles has the largest reductions in CO_2 emissions, 87.3% compared to the 2050 baseline [11], it was also shown that purchase intention is different for each user according to vehicle, but it is also shown that environmental awareness has a direct effect on the purchase intention of a user who does not use it, while an indirect effect on the post-purchase satisfaction of a user of an electric vehicle [31]. By 2050, CO_2 emissions from land transport can be reduced by up to 55.8% with the spread of battery electric vehicles and hybrid electric vehicles. But despite the aggressive deployment of electric-powered vehicles, fossil fuels account for more than 52% of the energy consumed in all scenarios in 2050 [6].

In the US, according to Nienhueser et. al, 2016, it indicates that the North American population has a better acceptance of electric vehicles if the energy source comes from renewable energy, since they indicate a 433% increase in the use of charging stations. offer renewable energy. The preference of owners and renters is given with electricity prices of $0.61/hour for slow recharges and $1.82/hour for fast direct current chargers. The economic benefit will be positive as they directly translate into a 655% annual gross revenue increase from $1.45 million to $9.5 million, with an annual renewable energy credit acquisition cost of $13,700. The results also show a significant environmental benefit from emissions reduction [32]. Due to its electricity generation sources in Texas, (USA), there is no positive impact on the environment from the introduction of EVs in its vehicle fleet [33]. In Canada it was also shown that the effectiveness of electric vehicles depends on the sources of electricity. EV GHG intensity may vary over time (and regionally), with electricity emissions intensity declining by at least a third by 2050 and vehicle energy efficiency improving over time, simulation results show that, compared to 2015, 2050 average fleet EV emissions are 40-52% lower in British Columbia, 57-74% lower in Alberta, and 36-46% lower in Ontario [34]

In Africa, to be specific in Cameroon, the transport sector represents one of the economic sectors with high energy consumption and CO_2 emissions, the factors that influence the growth of energy consumption in the sector are mainly due to demographic change, followed by the energy matrix, energy intensity and economic activity, the country's vehicle fleet is old and is not at the forefront of technology [35].

In Latin America, some studies show that road transport in Ecuador released 14.3 $MtCO_2$ in 2012. When fuel consumption is compared by its costs, it can be confirmed that the Ecuadorian government covered, through subsidies, 68% of the costs. annual road transport fuel, demonstrating the importance of restructuring these expenses to achieve an efficient road transport system. [18]. As for the South American giant Brazil, the impacts of replacing the Brazilian light fleet are affected by the lack of advance planning, since thermal generation could reduce the benefits of BEVs or make them worse than ICEVs [14], The introduction of EVs into the fleet could reduce CO_2 emissions from 10 to 26 times lower than those of the motor vehicle fleet [36]. Gasoline vehicles have the greatest impacts for abiotic depletion, abiotic depletion potential of fossil fuels, and global warming potential. The battery electric vehicle has the lowest environmental impacts overall, followed by vehicles that use ethanol. Vehicles that use lithium-ion batteries have the highest human toxicity impacts. [37]. In the economic part, it indicates that EVs are for commercial use, making an analysis of the economic viability in terms of amortization and Net Present Value (NPV), with the recovery period for the EV investment being 13 years of operation [2].

Some of the measures to be taken to this end are to reduce traditional energy consumption (including motor gasoline and diesel fuel) by adjusting prices and taxes, eliminating CO_2 intensive vehicles from traffic and promoting new energy sources and technologies, adapted to modern transportation. Cameroon should also boost the energy efficiency of its transport sector, through its enormous renewable energy potential that remains highly underutilized [35]. Policies should be formulated to raise awareness among citizens about environmental protection. Furthermore, the government should encourage public transportation instead of private transportation and promote favorable measures for walking and cycling for short-distance trips [35].

For more than 130 years after the invention of the automobile, a stable motoring culture highly dependent on fossil fuel developed, reflected in the operation of the VDE (Vehicle – Driver – Environment), it should be noted that the implementation of new technologies within this conservative system, is seen ambiguously by the automobile society, to give a boost to the technological transition many manage the prohibition of using hydrocarbon fuels in areas with greater air pollution [38]. Electric Vehicles have been declared as an effective alternative to internal combustion engines due to the reduction of CO_2 emissions and energy efficiency, especially if the electrical system is supported by renewable sources. [39] and will facilitate the achievement of the established environmental objectives [21].

Peru's energy consumption has always been seen as the main source of oil and the transport sector as the main consumer. Oil represents 40% of the share of sources, while the transport sector represents 37% of energy consumption [40], as shown in figure 1, that is, this makes the transportation sector the main emitter of greenhouse gases, which represents an important agent for studying, analyzing, optimizing or mitigating GHG emissions, even more so when there are deficiencies in the sector.

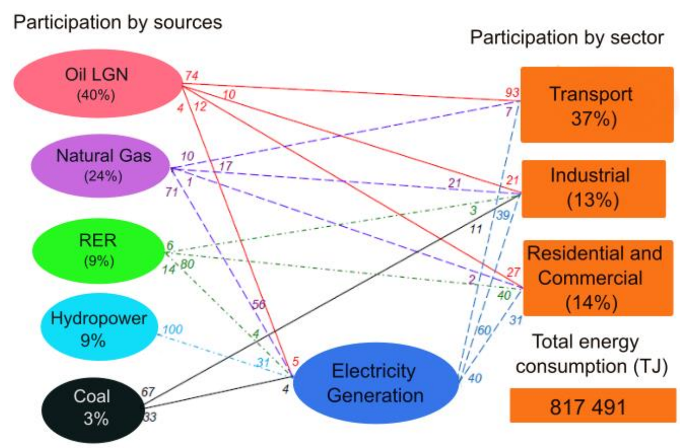

Fig. 1 Participation of sources and participation in energy consumption by sectors, in Peru in 2016 [40].

III. Neural Networks Methodology

This part of the study aims to develop a model to forecast the variation in the intensity of carbon emissions in Peru, due to the introduction of electric vehicles. Artificial neural networks (ANNs) are computational models that can represent complex relationships between input and output data in multidimensional spaces [41]. ANNs are a logic programming technique that simply imitates the functioning of the human brain, ANNs have several important characteristics, such as learning from data, generalizing, working with an infinite number of variables, etc. Artificial neural cells mainly consist of five elements; input variables, weights, sum functions, activation functions and output variables [42]. Inspired by biological neural networks, ANNs are massively parallel computing systems that consist of an extremely large number of simple processors with many interconnections [41]. The artificial neural network technique is used to model, optimize, simulate and forecast the performance of a system. It is becoming more popular in the last two decades due to its faster processing speed and high precision [43]. There are currently a wide variety of possible applications of ANN for those who are not computer science specialists. Therefore, with a very modest knowledge of the theory behind ANNs, it is possible to address complicated problems in the researcher's own area of specialty with the ANN technique [44]. Furthermore, unlike most statistical approaches, ANNs do not require predefined mathematical equations of the relationship between model inputs and corresponding outputs [45]. At the same time, ANNs are especially suitable for finding solutions to problems that have fuzzy information and are very complex where individuals often make decisions intuitively [43].

For our study, a reference to [46] was taken; this study had 4 neurons (GDP, GDP^2, energy, agricultural activity), but we will use 7 layers that we consider influence CO_2 emissions, emitted by the road transport sector. The input variables in the neural network are composed of the input layer, as detailed below.

- Input layer: 7 neurons representing (GDP, population, cars, trucks, buses, gasoline price, oil price)
  - GDP
  - Fuel Price for Light Vehicles
  - Fuel Price for Heavy Vehicles
  - Population.
  - Cars
  - Vans
  - Buses and trucks
- Hidden layer: variable number of neurons
- Output layer: 1 neuron representing (CO_2)

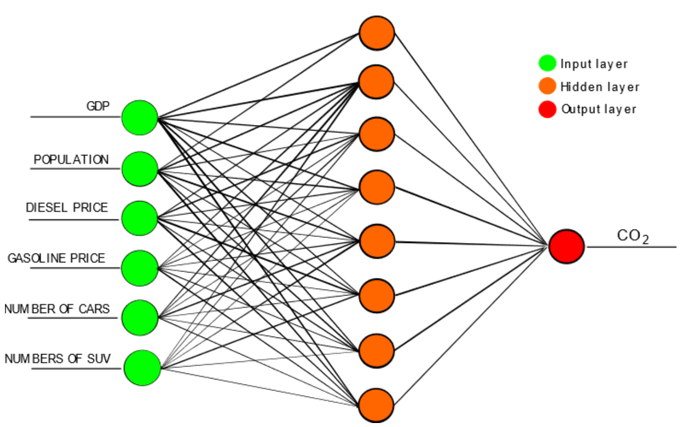

Fig. 2 Architectural structure of ANN

A. Case Study

1) Main Agents in GHG emissions for the Peruvian case

Daily human activities have caused severe environmental impacts, accelerating global warming. Such human activities, particularly the transport of passengers and goods, generate massive emissions of greenhouse gases (GHG), for example, carbon dioxide (CO_2). Therefore, the objective of this study was to predict the amount of CO_2 emissions derived from energy use in the transportation sector of Peru, as well as related factors, thus providing substantial benefit in determining policies to reduce CO_2 emissions. GHG and its impacts.

In this study, 6 independent variables were considered, namely, the

- Population size.
- The gross domestic product (GDP).
- The number of registered light vehicles.
- The number of medium and large registered vehicles.
- Fuel Price for Light Vehicles.
- Fuel Price for Heavy Vehicles.

1.1. Peruvian Population

The National Institute of Statistics and Informatics (INEI) announced that according to the First Results of the 2017 National Censuses: XII of Population, VII of Housing and III of Indigenous Communities, carried out on October 22 of last year, the population Peru's total reached 31 million 237 thousand 385 inhabitants, which includes the census population and the population omitted during registration. It should be noted that the population in the last intercensal period has had an average annual growth of 1.0%, INEI source.

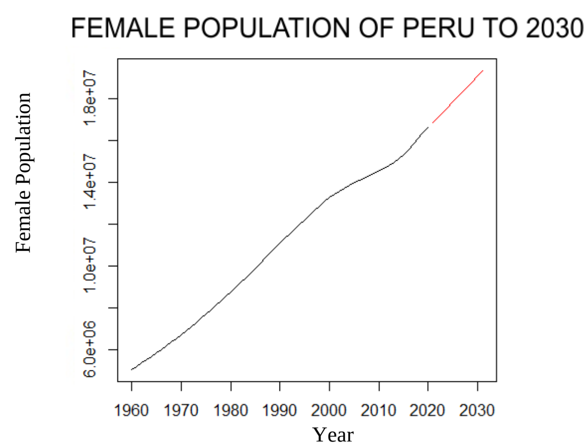

Fig. 3 Female population, own elaboration, source World Bank

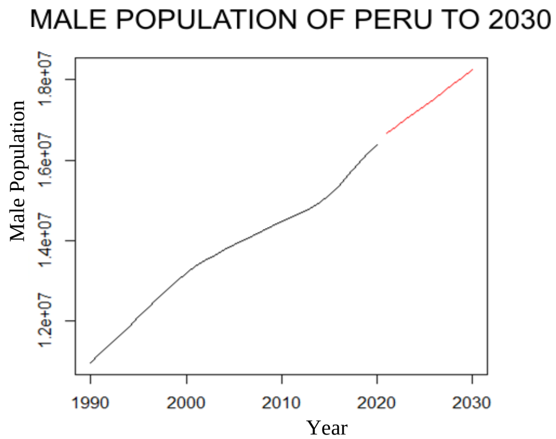

Fig 4. Male population, own elaboration, World Bank source.

1.2. Economic Growth of Peru.

The GDP growth rate projections advance 2.2% in 2019, -11,145% in 2020 and 10.5% in 2021. "The government is committed to the objective of achieving a higher and more sustainable growth rate in the coming years" , according to the Ministry of Economy and Finance of Peru, with one of the most solid economies in Latin America, grew 2.5% in 2017 compared to 3.9% in 2016.

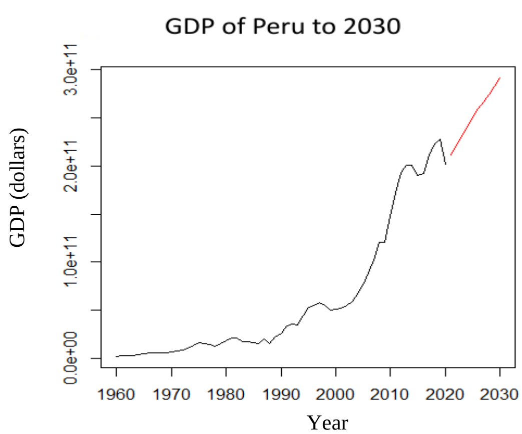

Fig 5. GDP of Peru, from the year 1960-2030, own elaboration, Source WB.

1.3. Fuel Prices

The price of fuel can have some influence on the demand for oil; many authors indicate that its consumption can be regulated through prices.

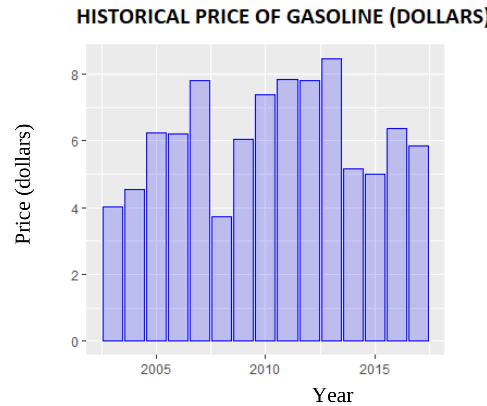

Figure 6. Gasoline prices from 2000 to 2017

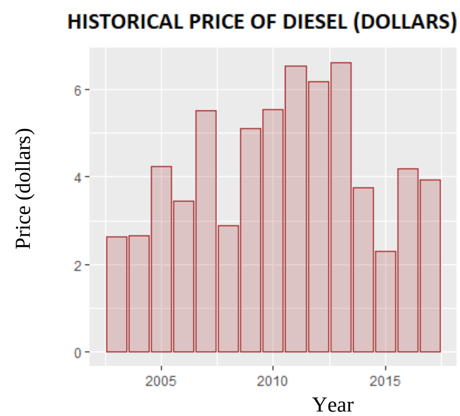

Figure 7. Diesel price from 2003 to 2017

1.4. Automotive Fleet of Peru

As already seen, the main consumer of the sector is passenger transportation, the vehicle fleet is growing at a higher rate since this new century, related to economic growth, this growth has been evidenced by the collapse of the roads, greater traffic on the main avenues of Lima. The rapid growth of energy demand and GHG emissions in the transportation sector in the last decade was affected by the importation of vehicles starting in 1992 and the greater purchasing power of the Peruvian population starting in 2002, (as shown in Figure 8), in turn, government policies identified the conversion of cars with engines powered by less polluting fuels with, in the case of LPG and CNG, scrap metal bonus.

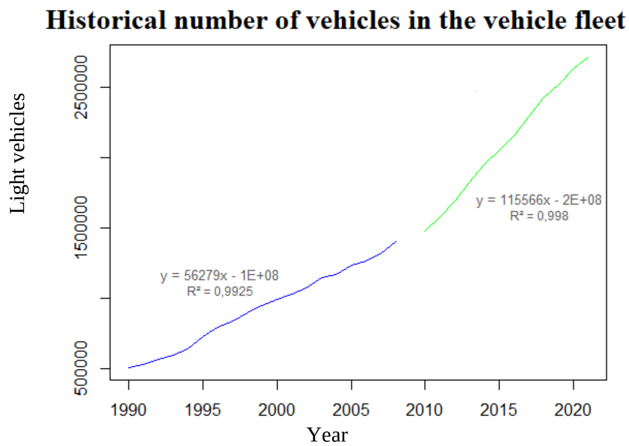

Fig. 8 Historical number of vehicles in the vehicle fleet, INEI source.

Another evidence that economic growth has modified the quality of the vehicle fleet is that since 2009 there has been a greater purchase of new vehicles than used vehicles, as shown in figure 9, since the entry of lower-cost Chinese brand vehicles and the facilities purchases are leading to greater acquisition of new vehicles. Figure 10, shows that there is a greater acquisition of SUV model vehicles, another sign that the purchasing power of the national market is increasing.

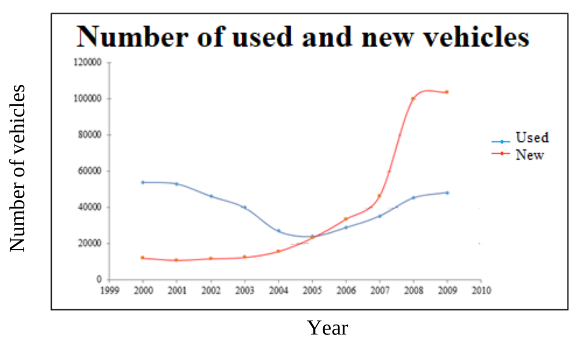

Fig. 9 Importation of used and new vehicles in the national market. INEI source, own elaboration.

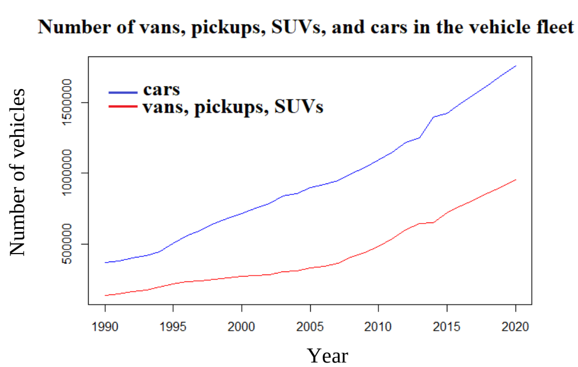

Fig. 10 Numbers of trucks and cars in the vehicle fleet. Source: INEI, own elaboration.

The growth rates of cars and trucks are similar as shown in Figure 9. It also shows that the Peruvian vehicle fleet has a greater number of cars compared to trucks. Figure 10 shows that the distribution between private and public transport remains almost constant.

2) Proposed scenarios

2.1. Scenario 1: Business-as-usual (BAU)

In this scenario, the year 2018 was selected as the base year and this scenario was selected as the base scenario. This scenario was based on a continuation of recent trends. Specifically in this scenario there is no penetration of electric vehicles. By extrapolating these trends, the values were projected through 2030 without any change.

2.2. Scenario 2: Growth equal to the global EV trend

In this scenario, it was assumed that the growth of electric vehicles in Peru will be the same as the penetration rate worldwide. Electric vehicles began to grow since 2010 and currently have a sales rate of 5.79% worldwide, representing 0.9% of light vehicles in the world.

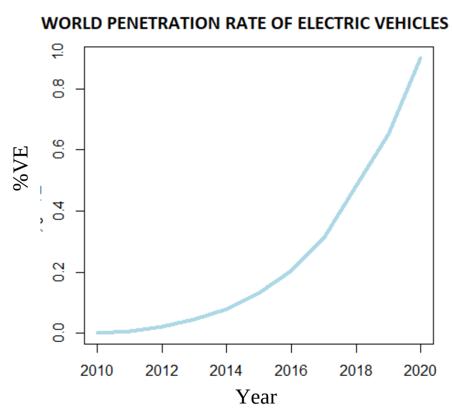

Fig. 11 Penetration rate of electric vehicles in the world.

2.3. Scenario 3: Growth equal to Natural Gas Vehicles (NGV)

The growth in the NGV sector can be taken as a reference, the introduction of gas vehicles began in 2005 and to date has a penetration rate in the vehicle fleet of 12%, and according to projections the percentage in 2030 will be 14.3%. The CNG scenario considered the replacement of gasoline and diesel engines in Station Wagons, cars, jeeps, SUVs and trucks in our vehicle fleet.

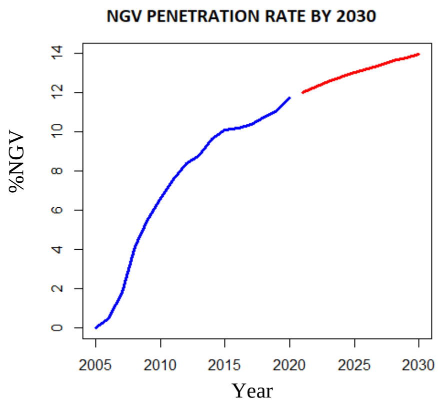

Fig. 12 NGV penetration rate in Peru, own elaboration.

2.4. Scenario 4: Automotive Association of Peru (AAP) Scenario

The automotive association of Peru was taken into consideration, according to this identity of transportation in Peru, the penetration rate of electric vehicles in Peru will be 5% in 2030.

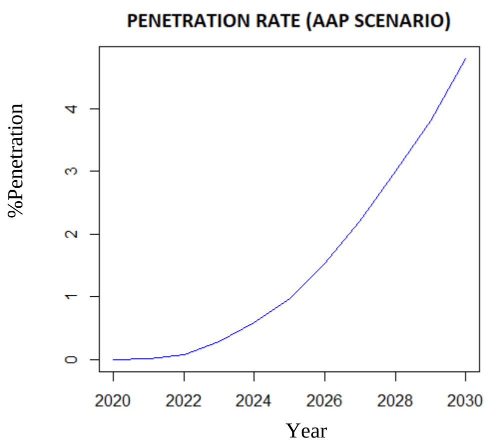

Fig. 13 AAP penetration rate in Peru.

2.5. Scenario 5: Optimistic growth (EV30@30)

An optimistic scenario, which took as a reference the European market, which aims to have a penetration rate of 30% in the vehicle fleet by 2030. It is important to promote light electric vehicles, since they can reduce emissions and use. of energy. If this measure is complemented with policies for the introduction and massification of private transport such as cars and motorcycles, a significant technological and energy transition of private transport is possible and desirable, it is also given to the public, especially buses, since they have a high rate of occupation. Therefore, in scenario 5, it was assumed that, if the change occurred at a maximum rate of 30%, this can only occur if there is a large increase in sales of cars and SUVs, and that these vehicles have become BEVs.

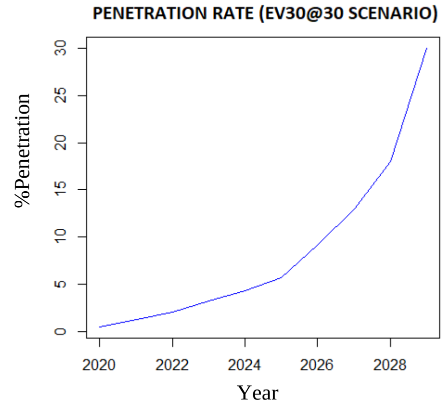

Fig. 14 EV30@30 penetration rate in Peru.

IV. RESULTS

As we know, fuel consumption and CO_2 emissions emitted due to the transportation sector are related to certain variables such as: population, economy, type and number of vehicles, and fuel prices.

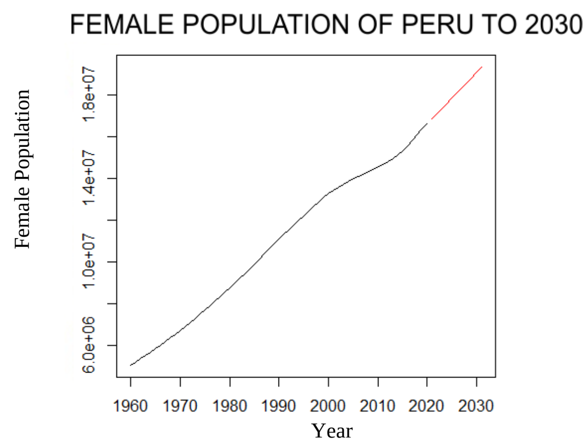

Fig. 15 Female population of Peru in 2020 and projected to 2030.

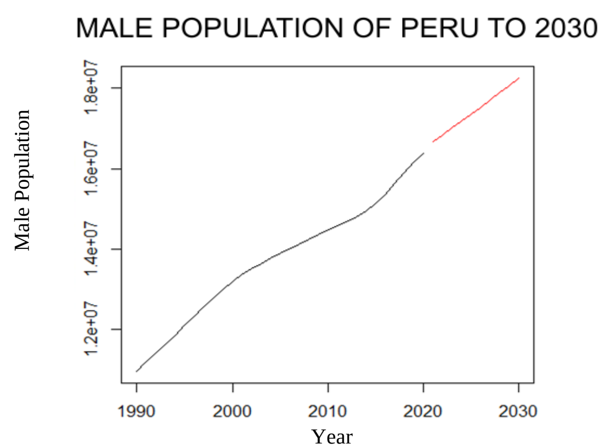

Fig. 16 Male population of Peru in 2020 and projected to 2030.

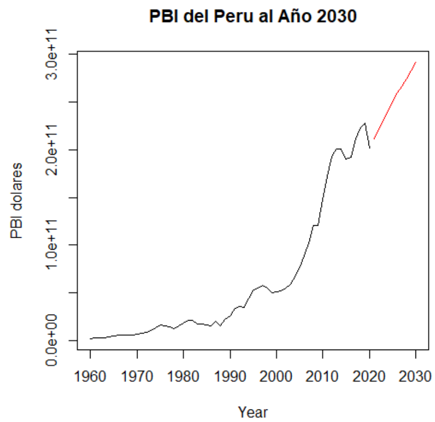

Fig. 17 GDP of Peru from 1960-2020 and projected to 2030.

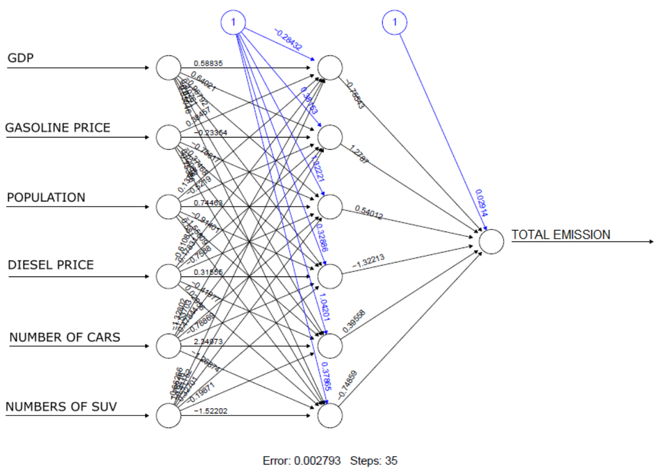

Fig. 18 Structure of the neural network (input variables) for the case of emissions, carried out in the Rstudio program.

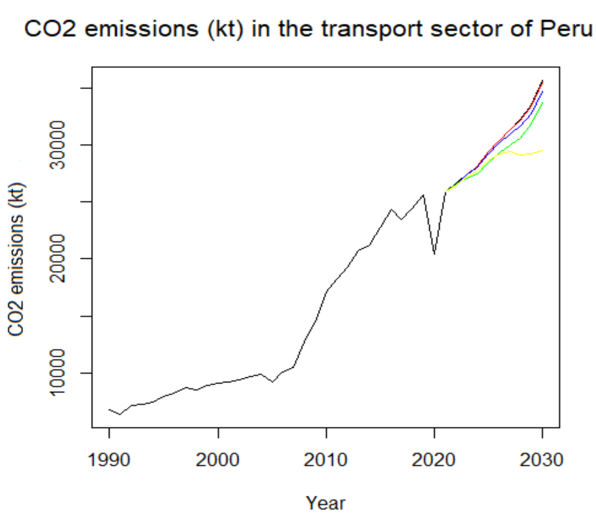

Fig. 19 Projection of CO_2 emissions (1960-2020) and projected to 2030.

With this structure as shown in figure 19, scenarios were created with the introduction of electric vehicles, the price of oil and the price of gasoline, obtaining the following results, as shown in figure 20.

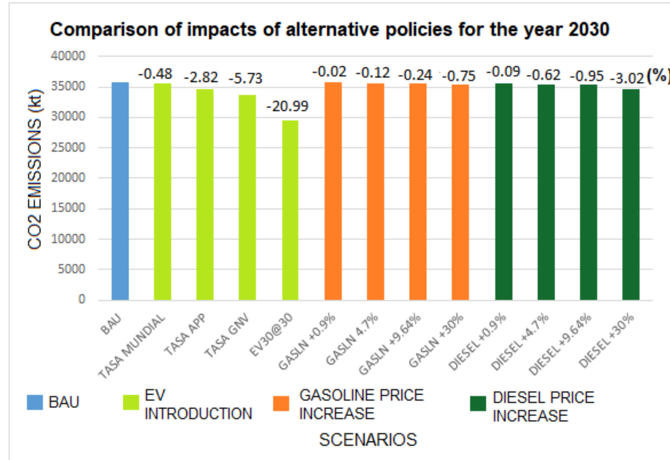

Fig. 20 Result of the projection of CO_2 emissions for each scenario, for 2030.

IV. Discussion

The government and relevant institutes can provide various channels for people to recognize environmental issues widely and comprehensively, i.e. awareness and publicity policies to learn about the benefits of electric vehicles. Rapid development of the use of electric vehicles requires public acceptance. This study provides some implications for increasing intention to use.

The environmental benefit of electric vehicles will depend on the type of electricity generation, since if the generation is based on coal and other polluting fuels, they can cause electric vehicles to have higher emissions. Since, in many cities and countries, it has been shown that the electrical grid, which has a combination of coal and natural gas generation, produces higher emissions from electric vehicles than from conventional vehicles. That is why generation with renewable sources must be promoted, as well as promoting clean fuels such as hydrogen or the use of ethanol, since it generates fewer environmental impacts than gasoline.

Electric vehicle technology costs are an issue at first, but can decline to allow payback periods of less than 5 years and very competitive CO_2 reduction costs, provided market barriers can be overcome through targeted policy support that primarily address their cost penalty.

With the evaluated scenarios we can affirm that the energy policy that will have the greatest environmental impact will be the introduction of electric vehicles, while with policies to raise prices for fossil fuels such as gasoline and/or diesel, the introduction of vehicles is much lower in comparison. electric, as shown in figure 20, in addition the increase in fuel prices is not pleasing to the public, generating social unrest and the economy of many families.

V. Conclusion

Regarding the environmental benefit, in the reduction of CO_2 emissions, for light vehicles (cars), by 2030 in all scenarios a reduction in emissions has been demonstrated by 0.48% for the world rate, 2.82% for a scenario AAP, of 5.73% for a NGV scenario and a reduction of 20.99% for the very optimistic EV30@30 scenario. Taxes on fuel also achieve the effect, but for high tax values. However, this measure causes loss of social well-being. Many researchers indicate that the degree of environmental impact will depend on the type of electricity generation, although emissions can be zero for renewable sources, that is, there will be a positive impact, but for batteries, it is recommended to regulate and comply with the life cycle. of batteries, from mining to reuse, recycling and disposal. Electric vehicles will have a positive impact, since they reduce emissions, but batteries can generate some negative impact. Establish transportation sector goals as part of national commitments to reduce greenhouse gas emissions. It is recommended to promote the use of renewable energies for charging electric vehicles as part of a low-emission energy strategy.

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