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Research paper

A methodological procedure for the energy transition in the land transport sector by quantifying renewable energy needs

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ABSTRACT

A significant increase in the electricity demand from the transport sector is expected in the coming years given the decarbonisation targets set by most countries. With a view to guaranteeing a sustainable transition, in this study a novel methodology with a cross-sectoral (transport and renewable energies) coordination is proposed to determine the renewable power required to meet the needs of the transport sector. Two scenarios are defined: a Trend Scenario and an Implemented Policy Scenario in which the regional targets in these areas must be achieved. The Implemented Policy Scenario entails a modal shift from private vehicle to other transport modes, such as collective or active. The methodology is applied to Tenerife Island (Canary Archipelago, Spain) where the Spanish government target of 28 % electrification of land transport is assumed. On the basis of a 2030 time horizon, the variation in the total number of vehicles ranges from a 19 % increase (Trend Scenario) to a 0.5 % reduction (Implemented Policy Scenario). The Trend Scenario results in a 2.5 % increase in the electricity demand compared to 2020, while the Implemented Policy Scenario would require a 19 % increase. This would mean an additional installed renewable capacity in Tenerife of 41 MW and 322 MW, respectively. Reaching the goals in this region would entail a reduction of around 430 kton $CO_{2\text{-eq}}$. The proposed methodology enables identification of key socioeconomic parameters, including vehicle purchase acquisition, vehicle annual operational costs, gross domestic product and population, as well as their impact on the land transport transition.

Abbreviations and nomenclature

E	Annual consumption of electric vehicle fleet (km)
EV	Electric vehicle
CF	Capacity factor (%)
c_j	Mean consumption of each electric vehicle (kWh/km)
FSM	Four Stage Model
GDP	Gross Domestic Product
GHG	Greenhouse gas (kton)
GREET	Greenhouse Gases, Regulated Emissions and Energy Use in Transportation model
HDV	Heavy duty vehicle
IEA	International Energy Agency
IPS	Implemented Policy Scenario
IRENA	International Renewable Energy Agency
LDV	Light duty vehicle
$l_{i,j}$	Annual mean mileage (i: by type of journey, j: type of vehicle) (km)
LEAP	Low Emissions Analysis Platform
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
MNL	Multinomial logic model
n	Each type of electric vehicle
$N_{journeys_{i,j}}$	Number of journeys (i: by type of journey, j: type of vehicle)
N_v	Number of vehicles by type
P	Installed power (MW)
pkm	Passenger - kilometre
RAE	Relative Absolute Error

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RRSE	Root Relative Squared Error
SNECP	Spanish National Energy and Climate Plan
t	Time period over which the energy is generated (1 year = 8760 h)
TIMES	The Integrated MARKAL – EFFOM System
TS	Trend Scenario
UKTCM	United Kingdom Transport Carbon Model
v_j	Number of vehicles – kilometres for each electric vehicle type
vkm	Vehicle - kilometre
$\alpha_{i,j}$	Daily number of journeys per passenger
$\beta_{i,j}$	Mean occupation rate by type of vehicle
γ	Proportion of solar energy with respect to the sum of solar and wind (fraction of unity)

1. Introduction

One of the main goals of the European Union is to promote the use of electric vehicles as well as large-scale changes in behavioural patterns. Shared transport services and active transport modes are key to enabling and facilitating the changes in travel behaviour that are essential for the reduction of carbon emissions (European Commission, 2019).

The changes required will need to be extensive and profound in terms of transport management. The modal shift in the way we travel and technological innovations will go hand in hand in the near future, with vehicles in turn having to undergo a notable evolution. An increased use of environmentally friendlier transport modes, such as public transport, vehicle sharing and active modes, will also form part of this transition. In this sense, numerous studies have been published for different locations where the modal shift will constitute a wake-up call in the transformation of the land transport sector. This is the case of Germany (7 % decrease in car use by 2040) (Winkler and Mocanu, 2020a), Flanders (8–9 % in light duty vehicles) (de Jong et al., 2010a) or Switzerland with an increase in public transportation from 19 % to 23 % in 2040 (F. O. for Spatial Development ARE, 2016), among others.

At the same time, the demand for electric vehicles (EVs) as a means of transport is growing worldwide. By 2023, more than 40 million EVs were already on the road, of which more than 14 million were sold that year, according to the International Renewable Energy Agency (IRENA) (IEA, 2024). This equates to nearly one in five of all the cars sold in 2023, although in countries such as China this EV share was as high as 38 %. According to Bloomberg (BloombergNEF, 2024) by type of vehicle, two/three wheelers account for the largest number of sales (47 % of EV sales), followed by buses (28 %) (BloombergNEF, 2024).

However, while sales have risen rapidly over the last few years, they are expected to undergo a much stronger increase in the coming years (Fraunhofer ISI, 2023). By 2030, it is estimated that there will be a thirtyfold increase in the number of such vehicles in circulation compared to 2020 (IEA, 2022).

Nevertheless, although the electrification of transport is widely implemented as the solution to reduce emissions from conventional vehicles, unless the introduction of EVs is accompanied by the adoption of renewable energies, a considerable number of contaminating emissions will continue to occur (Fraunhofer ISI, 2023). For this reason, studies on how to incorporate EVs in transport systems require exhaustive analyses of the corresponding electricity demand and the proportion of renewable energies that need to be installed.

In terms of the global electricity sector, it was estimated in an IRENA report published in 2020 that the worldwide contribution of renewables to electricity generation could be as high as 86 % by 2050, a value considerably higher than the 55 % that would correspond to current trends (IRENA, 2020), and that the transport sector will be responsible for 40 % of the electricity demand by 2050 (IRENA, 2020). It is therefore clear that a study of the electrification of the transport sector additionally requires joint analyses of its electricity consumption and the estimated renewable energies needed.

In the case of the Canary Islands (case study location in this research), the more than 1200 kton of petroleum products that were consumed in land transport in 2022 represented 35.4 % of final energy consumption in the archipelago (L. contra el C. C. y P. Territorial, 2021). This meant that 4399 kton $CO_{2\text{-eq}}$ were emitted into the atmosphere, representing 35.7 % of the total emissions of the archipelago. The island of Tenerife alone consumed more than 518,170 tons, emitting approximately 1941.9 kton $CO_{2\text{-eq}}$. The transport sector is the second most polluting sector (after the electricity sector), with land transport, which accounts for 71.6 % of the sector, the worst offender.

Such data show the urgent need to move towards a more sustainable and environmentally friendly mobility model. However, if the increase in demand for electricity due to the transport transition is not met by clean energy, a return to conventional energy dependence would occur. In short, the energy and transport transitions need to occur simultaneously.

With the above in mind, this research employs a prioritised mixed methodology for transport and renewables transitions considering environmental implications for any study region based on:

a. Prediction of fleet electrification.
b. The increase in renewable power required to meet the needs of the transport sector. The creation of a methodology for cross-sectoral (transport and renewable energies) coordination that meets the requirements of two scenarios: a trend scenario and in an implemented policy scenario.
c. Model validation with socio-economic and environmental parameters.

1.1. Research background

In the literature review that was conducted, various articles were found on vehicle number forecasting based on population, economic growth, vehicle ratio, etc. These articles apply mathematical forecasting models to the energy sector, either to forecast the whole energy demand (including the transport sector) or focusing only on transport.

For example, Haldenbilen and Ceylan (2005) used genetic algorithms to estimate the total transport energy demand from population, gross domestic product (GDP) and vkm data, bypassing the implementation of socio-economic parameters. Hammadou and Papaix (2015). employed a multinomial logit (MNL) model to estimate greenhouse gas (GHG) emissions from modal shift forecasts, although without including the indirect emissions of EVs produced by conventional generation. For their part, Kazancoglu et al. (2021). and Lu et al. (2009). applied the grey system theory to forecast the total energy demand of the transport sector and the associated GHG emissions, but did not consider modal shift estimations or the required renewable power to satisfy them, which are key novel aspects in this paper.

Several articles have included more socioeconomic parameters, such as cost or sustainability, in their calculation, using the TIMES (The Integrated MARKAL-EFOM System) model (Ismail et al., 2023; Herath, 2022; Pietrapertosa et al., 2010; Cosmi et al., 2009). The main drawback of TIMES is that this energy modelling tool is used to analyse and optimise energy systems on a national, regional or global level, but is not capable of focusing on a specific sector such as transport. Therefore, its customisation in terms of energy policies and strategies is limited. Other global energy demand models that have been used include LEAP (Ren et al., 2022; Ayuketah et al., 2023), EnergyPLAN (Li et al., 2023) and MESSAGE (Saeid Atabaki et al., 2023), with the cited papers focusing on GHG emissions and total energy demand by sectors.

Some authors have tried to apply these generic models specifically to the transport sector, as in the case of Bahn et al. (2013); Salvucci et al. (2018); Kannan and Hirschberg (2016). with the TIMES model. For their part, Rivera-González et al. used LEAP (Rivera-González et al., 2020) and Zeng et al. (2022); Yuan et al. (2021), enabling estimation of the consumption of the vehicle fleets in question. However, these types of predictions can be considered somewhat marginal when relying on a sector transition, as no modal shift analysis is considered and no classification of vehicles is performed by analysing their independent predictive behaviour. These forecasts also neglected to analyse the supply capacity of the new fleet through renewable energies. In contrast, in our study these metrics are incorporated as main inputs.

In the case of research using models developed only for the transport sector, Gupta et al. implemented the IMACLIM-IND model, which does not focus on electrification scenarios (Gupta and Garg, 2020). In addition (Steenhof and McInnis (2008). implemented the regional CanESS model, but it encompasses all transport (including the maritime and aviation sectors) without a detailed study in terms of the land transport sector.

Other specific models that have been used include the UKTCM (Brand et al., 2012), GREET (Sandy Thomas, 2009) and FSM (Carroll et al., 2019). However, these models mainly focus on the calculation of GHG emissions. Although the studies are more specific in terms of electrification, they are never accompanied by a coordinated energy self-supply design. Furthermore, the modelling does not allow for adaptation to the needs or policies of each region, including the difference between urban and interurban travel effects.

To our knowledge, the methodology proposed here is the only one that combines the electricity-transport transition in a coordinated way to achieve climate neutrality. It does so in a detailed way, by type of vehicle and journey, allowing at all stages the inclusion of targets and modal shifts customised to meet the strategies and objectives of each region. It constitutes a roadmap with a holistic and detailed approach that assesses the critical points and identifies the key parameters to ensure the successful implementation of new energy scenarios.

1.2. Key grey areas

This research is based on a methodology that differs from the models used to date by introducing the following specifications:

- Modal shift considerations: shifts from private vehicle to other transport modes quantified used the passenger-kilometre (pkm) unit which represents one passenger travelling a distance of one kilometre.
- Input data according to journey type (urban and interurban) and transport mode (private motor vehicle, active mode, public transport, and vehicle sharing).
- Consideration of governmental targets for land transport.
- Estimation of the renewable power needed to supply the electricity demand of the entire land transport.

The proposed methodology, based on predicting the number of vehicles (per transport mode), setting objectives for transport electrification, and calculating the modal shift, is described in Section 2. Thus, the present study provides an innovative approach to the analysis of active modes, the estimation of EVs together, the quantification of electricity needs and the renewables that would be needed to cover this demand. In Section 3, the proposed methodology is applied to a practical case, the island of Tenerife (Canary Islands, Spain). The results are given and validated in Section 4, using a multiple linear regression model, and discussed in Section 5. Future research lines are described in Section 6, and the conclusions of our study are explained in Section 7.

2. Methodology

2.1. Vehicle forecast in 2030

To estimate the vehicle fleet in 2030, two alternative scenarios are proposed: one in which the estimation is based on historical data of vehicles and population growth (Trend Scenario - TS), and a second based on proactive policies to promote sustainable modes of transport (Implemented Policy Scenario - IPS).

Both scenarios predict the fleet by identifying each type of vehicle to analyse behaviour on a personalised basis. Fig. 1 shows the types of vehicles considered.

In addition, the IPS scenario includes the identification of urban and interurban transport areas and modes (private motor vehicles, active mode, public transport and vehicle sharing). This is necessary to apply modal shift policies.

It is important to highlight that in this subsection no distinction is made between electric and conventional vehicles. This classification will be applied in subsection 2.2.

2.1.1. Trend Scenario (TS)

Key factors that have a major impact on the transport sector are the economy and population growth (Szekeres et al., 2008; Williams et al., 2016; Polzin et al., 2004). This scenario is based on population forecast and annual historical series of vehicles, including active mode EVs. The population forecast is based on economic growth projections, as suggested in (Lee and Tuljapurkar, 2000; Lee, 1998; Keyfitz, 1981; Dao, 2012). Fig. 2 summarizes the methodological approach adopted to determine this scenario. A detailed description of this procedure is included as Supplementary Information (Appendix A).

To validate the proposed procedure, a model was developed with multiple linear regression (MLR) techniques using Weka software (Frank et al., 2016). This model identifies the attributes and the independent variables in order to find a combination of them that provides the least error and avoids the collinearity of the dependent variables. To train the model, 10-fold cross-validation was used.

The selected input variables are the time period (years), the population and the GDP. The relationship between the annual historical datasets of these socio-economic parameters is obtained by the MLR in order to estimate the future annual vehicle fleet by vehicle type.

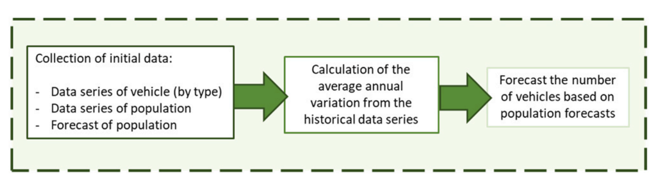


Fig. 2. TS methodology flowchart to estimate the number of vehicles (per type).

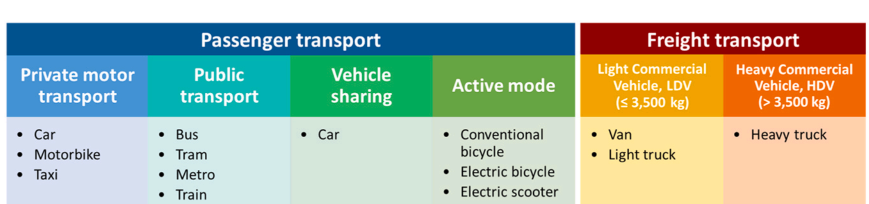


Fig. 1. Type of vehicles per transport mode.

Table 1
Assumptions adopted to determine the passenger-kilometre in private motorized vehicles.

Variable	Value	Unit
l_j (mean distance)	15 (urban)55 (interurban)	daily km
α_j (journeys per passenger in one day)	1.5 (Cabildo de Tenerife, 2012)	Passenger/journey x day
β_j (mean occupation)	1.55	Passenger/vehicle

2.1.2. Implemented Policy Scenario (IPS)

The IPS is based on the gradual substitution of private transport by other transport modes. Political regulation generally indicates the goals to be achieved in this modal change. The passenger-kilometre (pkm) unit is used to quantify the modal shift, in line with international reports and scientific articles (MITECO, 2019a; Ministry of the Environment and Protection of Natural Resources and the Sea, 2019; Federal Government of Germany, 2019; Lin et al., 2015; International Forum Transport et al., 2020; Maaouane et al., 2022; Ehrenberger et al., 2021). This concept relates the total number of passengers and the distance travelled per time unit. To apply this modal shift, pkm historical data should be calculated using Eq. (1), classified by journey type (urban - within cities; and interurban - between cities) and transport mode. Table 1 shows the main assumptions adopted for their calculation (customised for the case study).

$$pkm_{i,j} = \mathrm{N}_{\mathrm{journeys}_{i,j}} \times \mathrm{l}_{i,j} \Big/ \alpha_{i,j} \tag{1}$$

where:
i = type of journey
j = type of vehicle
pkm = Annual number of passenger − kilometre
$\mathrm{N}_{\mathrm{journeys}_{i,j}}$ = number of journeys
$\alpha_{i,j}$ = daily number of journeys per passenger (journey/pas)
$l_{i,j}$ = annual mean mileage (km).

Subsequently, to implement the political goals in the pkm forecast, a redistribution from private motorized vehicles to other alternative modes (collective and active modes) should be done. With this redistribution, the new vehicle fleet is calculated for the time horizon applied. Fig. 3 summarizes the methodological approach adopted. A detailed description of this procedure is included as Supplementary Information (Appendix B).

In the event that political targets do not implement the redistribution of pkm by transport modes, the following references (Salvucci et al., 2018; International Forum Transport et al., 2020; International Transport Forum, 2019, 2020a, 2020b; de Jong et al., 2010b; Winkler and Mocanu, 2020b) can be used to select the most appropriate values for each region. For the case study, Table 2 shows the values adopted, in line with the previous references.

To distribute the pkm of active mode in e-bicycles and e-scooters, Table 3 shows the assumption considered, in line with the trend of the data published by the Association of Brands and Bicycles of Spain (AMBE) (AMBE, 2021).

In terms of vehicle forecasting, the number of different types of vehicles is calculated through Eq. (2):

$$\mathrm{N}_v = \mathrm{pkm}_{i,j} \times \beta_{i,j} \Big/ \mathrm{l}_{i,j} \tag{2}$$

where:
i = type of journey
j = type of vehicle
N_v = number of vehicles by type
$pkm_{i,j}$ = number of pkm by type of vehicle
$\beta_{i,j}$: mean occupation rate by type of vehicle
$l_{i,j}$ = annual mean mileage (km).

For this scenario, an MLR model similar to that for the TS was created. In addition to the annual number of vehicles on the road, other parameters calculated by the model include the annual number of vehicle registrations and de-registrations. For this purpose, the input variables listed in Table 4 were considered and the ranges of values were set to simulate different scenarios and obtain the optimal one.

2.2. Calculation of the electricity demand in the transport sector

Once the number of vehicles has been estimated for the time horizons, it is necessary to classify them according to their technology (combustion and electric). In the case of the TS, a trend of the percentage penetration of EVs (in terms of vehicle registrations) is made. For the IPS, government targets must be assumed. Appendix C shows the electrification percentages assumed in the case study for both scenarios for a 2030 horizon. The specific consumption of each EV is also shown.

It should be noted that technological improvements in batteries were considered. Innovation in batteries is enabling continuous increases in efficiency, size and capacity (IEA, 2022; BloombergNEF, 2021). As a result, the average consumption of EVs will decrease in the coming years (De Cauwer et al., 2015; Zhang et al., 2020). To evaluate the expected decrease in terms of specific consumption, parameters such as energy density and efficiencies were recalculated in a percentual variation trend (Electric Vehicle Database, 2022; Kane, 2019; Alankus, 2017), giving a reduction of 11 % electricity specific consumption in 1o years horizon. This value is in line with that reported by the International Energy Agency (IEA) (IEA, 2022). The total electric consumption by vehicle type is calculated using Eq. (3):

$$\mathrm{E} = \sum\nolimits_{j=1}^{n} \mathrm{c}_j \times \mathrm{v}_j \tag{3}$$

where:
E = annual consumption of EV fleet (kWh)
n = each type of EVs
c_j = mean consumption of each electric vehicle (kWh/km)
v_j = vehicle −kilometre for each vehicle type (vkm).

The vkm value is the result of the product of the mean annual distance covered (in km) by each vehicle type and the estimated number of vehicles of each type.

2.3. Estimation of renewable power needs

To determine the renewable power that will need to be installed for the transport sector, firstly the renewable energy sources must be defined. A prior analysis of the current renewable energy mix of the region is recommended to determine the share of each renewable energy to be installed. In this case, only the two fastest growing renewable energy sources in Europe are considered: solar photovoltaic and wind energy (EMBER, 2025). To determine the renewable power needed, based on Torres et al. (2003), Eq. (4) and Eq. (5) are proposed:

$$\mathrm{CF}_{\mathrm{solar}} \times \mathrm{P}_{\mathrm{solar}} = \gamma \times \mathrm{E}/\mathrm{t} \tag{4}$$

$$\mathrm{CF}_{\mathrm{wind}} \times \mathrm{P}_{\mathrm{wind}} = (1-\gamma) \times \mathrm{E}/\mathrm{t} \tag{5}$$

where:
E = annual energy demand (MWh)
t = time period over which the energy is generated (1 year = 8760 hours)
CF_{solar} = solar capacity factor
P_{solar} = installed photovoltaic power (MW)
CF_{wind} = wind capacity factor
P_{wind} = installed wind power (MW)
γ = proportion of solar energy respect to the sum of solar and wind (fraction of unity).

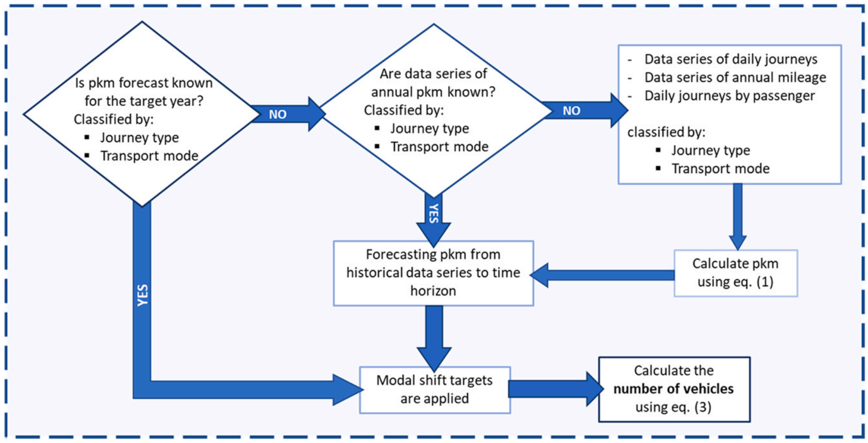


Fig. 3. Methodological flowchart of the IPS.

Table 2
Redistribution shares of private motorized vehicles in the other transport modes (distributed between urban and interurban journeys).

Transport mode	Urban (%)	Interurban (%)
Public transport	52	75
Vehicle sharing	21	24
Active mode	27	2

Table 5 shows the wind and solar photovoltaic distribution and capacity factor (CF) of the case study according to the 2020 Canary Energy Yearbook (contra el C. C. y P. T., 2022).

Table 3
Redistribution of active mode pkm (distributed between urban and interurban journeys).

Transport mode	Urban (%)	Interurban (%)
On foot	50	10
Conventional bicycle	15	25
e-bicycle	10	45
e-scooter	25	20

Table 4
Input data considered in the MLR model to predict the vehicle fleet in the IPS.

Input data	Influential parameters	Assumed value range
Vehicle purchase price	Manufacturing cost	Trend from historical data series
	Inflation	−1 % – 5 %
	Vehicle registration tax	0 % – 180 %
	General tax	13 % – 25 %
	Vehicle investment grant	0€ – 10000€
	Fiscal incentives	0€ – 5000€
	Household saving rate	−1.5 – 8.0
Vehicle operational costs	Fuel price	Trend from historical data series
	Fuel general tax	7 % – 25 %
	Fossil fuel tax	0.20 – 0.90 €/l
	Annual road tax	200€ – 800€
	Motor vehicle tax	0€ – 400€
	Electricity generation cost	Trend from historical data series
Population		Trend from historical data series Public authorities' projection
Gross domestic product (GDP)		Trend from historical data series Public authorities' projection

Table 5
Distribution and capacity factor of the different renewable technologies assumed in the case study.

Transport mode	Distribution (%)	Capacity factor (CF)
Wind	38	0.17
Photovoltaic	62	0.28

Table 6
Main targets in Spain's National Energy and Climate Plan (SNECP) (MITECO, 2019b).

Targets	Value
Reduction GHG emissions	23 %
Renewable electricity generation*	60 %
Reduction of mobility in private motorized transport	35 % of pkm in urban aeras1.5 % annual in interurban areas
Renewable share in energy transport demand	28 %

* Reduction of the contribution of fossil fuel power plants of 50 % by 2030 compared to 2020.

3. Results for the island of Tenerife as practical case study

The methodology described in the previous section was applied to Tenerife, part of the Canary Archipelago (Spain). Tenerife is the largest island of the archipelago (2034 km^2), with a population 928,604 inhabitants (ISTAC, 2022a) distributed across 31 municipalities. However, nearly 50 % of the population is concentrated in metropolitan areas (ISTAC, 2022a), including the main town, Santa Cruz de Tenerife, and the city of La Laguna (Turismo de Tenerife, 2022). In order to properly study the transport flows in urban and interurban areas, the island was divided into 9 macrozones.

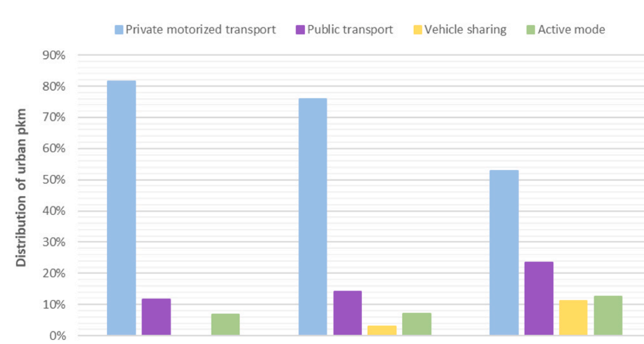


Fig. 4. Urban pkm evolution distributed by transport mode in IPS.

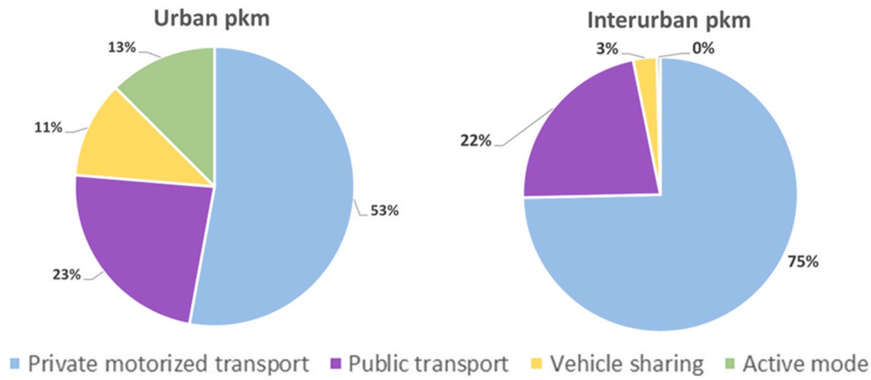


Fig. 5. Comparison between urban and interurban pkm distribution in 2030 in the IPS.

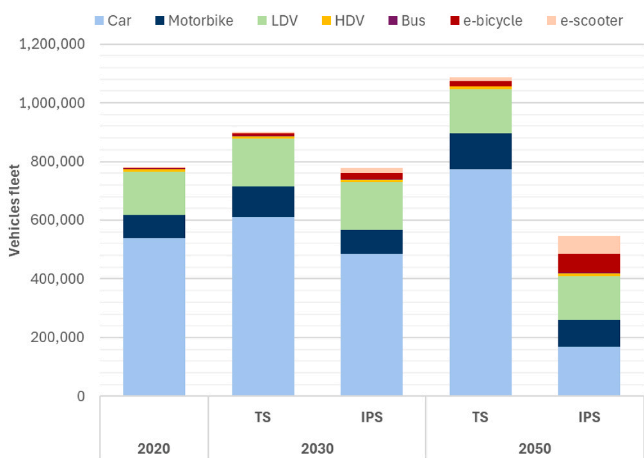


Fig. 6. Expected total vehicle fleet in 2030 and 2050 for the TS and IPS scenarios.

The analysis was extended to 2050 in order to take a closer look at the international targets. The main energy and transport targets are summarised in Table 6, which highlights the reduction of mobility (in terms of pkm) in private motorized transport and the penetration of 28 % renewable energy in the land transport sector. In this study, this target is equated to 28 % electrification of the fleet.

Fig. 4 shows the evolution of urban pkm during the period 2012–2030. Under the IPS, the share of private motorized transport pkm is forecast to decrease to 53 % of total pkm, while other transport modes will increase their proportion (public transport pkm to 23 %, vehicle sharing pkm to 11 % and active mode pkm to 13 %). These results are in line with those published in (Carroll et al., 2019; Pathak and Shukla, 2016; Bastida-Molina et al., 2020).

Fig. 5 shows the comparison of the expected distribution of urban and interurban pkm in 2030 under the IPS.

As can be deduced from Fig. 6, the vehicle fleet forecast for 2030 compared to the 2020 baseline represents an increase of 19 % in the TS (with cars corresponding to about 70 % of the total fleet), whereas in the IPS a reduction of 0.5 % is achieved (which is in line with that reported in (Ehrenberger et al., 2021). In numerical terms, the 2030 TS fleet rises to 888,890 vehicles, while in the IPS it is reduced to 777,600 vehicles. Comparing the two scenarios, Fig. 6 shows the expected fleet in both 2030 and 2050.

For 2030, the number of vehicles is 17 % fewer in the IPS compared to the TS. These results are similar to those published in (Instituto Tecnológico de Canarias, 2020) for Spain. In both scenarios, buses, e-bicycles and e-scooters see an increased use compared to cars, motorbikes, light duty vehicles (LDVs) and heavy duty vehicles (HDVs).

In terms of type of vehicle, under both scenarios, cars continue to account for 62–70 % of total vehicles, followed by LDVs (18–22 %) and motorbikes (10–12 %). A higher share of electric motorcycles is expected in 2030 under both scenarios, increasing by 33.5 % in the IPS and by 10 % in the TS.

The number of electric cars corresponds to the most representative change, with values reaching 150,167 units in the IPS and 55,574 in the TS, becoming the main electric means of transport by 2030 in Tenerife.

Active mode EVs (e-bicycles and e-scooters) are expected to increase to 7900 units in the TS and to 24,550 in the IPS. However, HDVs and freight transport would be clearly behind in electrification, and electric HDVs would still have practically no presence on the island.

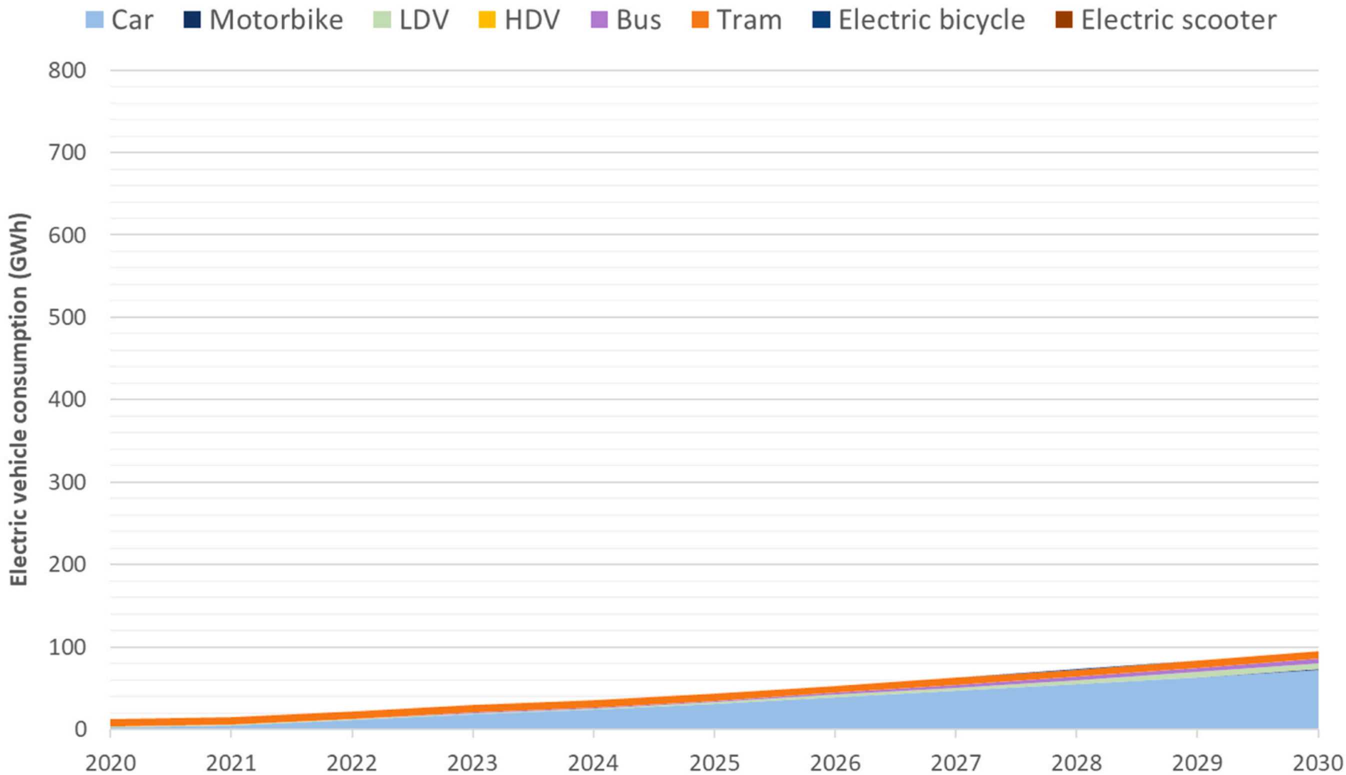
In summary, in 2030 under the IPS an EV fleet of 202,380 units (excluding active mode EVs) is forecast to achieve the SNECP goals. Conversely, under the TS only 73,150 vehicles will be electric in 2030 if active policies are not developed.

The electricity consumption of the transport sector in the island of Tenerife is forecast to range between 670 GWh (IPS) and 96 GWh (TS) in 2030 (see Fig. 7). Irrespective of the scenario, these values reflect the importance of appropriate planning as far as electricity generation and its sources are concerned. Electricity consumption for the transport sector will require between 2.5 % (TS) and 19 % (IPS) more energy fed into the grid than in 2019, in line with the results published in (Kannan and Hirschberg, 2016). This situation may be even more concerning for the 2050 horizon, when land transport electricity demand is expected to increase to 576 GWh in the TS and 1193 GWh in the IPS, with the latter corresponding to more than one third of the island's current electricity demand.

The electricity demand of cars represents the largest amount of the expected electricity consumption increase (between 76 % and 80 %, depending on the scenario). The other two vehicle types that represent a significant consumption in the 2030 share are LDVs (10–12 %) and buses (5–8 %). Despite the large number of motorbikes, their low consumption and their priority use in urban journeys imply a tiny percentage of the electricity consumption compared to cars. In the same way, e-bicycles and e-scooters represent negligible consumption compared to other EVs.

Finally, in terms of renewable distribution, the IPS will require an additional 192 MW of wind power and an additional 127 MW of solar power in 2030, corresponding to an 85 % increase for both technologies (see Fig. 8). In the case of the TS, the renewable power required is lower, corresponding approximately to an additional 25 MW of wind power and an additional 17 MW of photovoltaic power.

For the 2050 horizon, the renewable power needs increase to 573 MW in the IPS, where 230 MW of photovoltaic power and 343 MW of wind power will be required. In the case of the TS, the renewable power needs are 111 MW of photovoltaic and 165 MW of wind power.



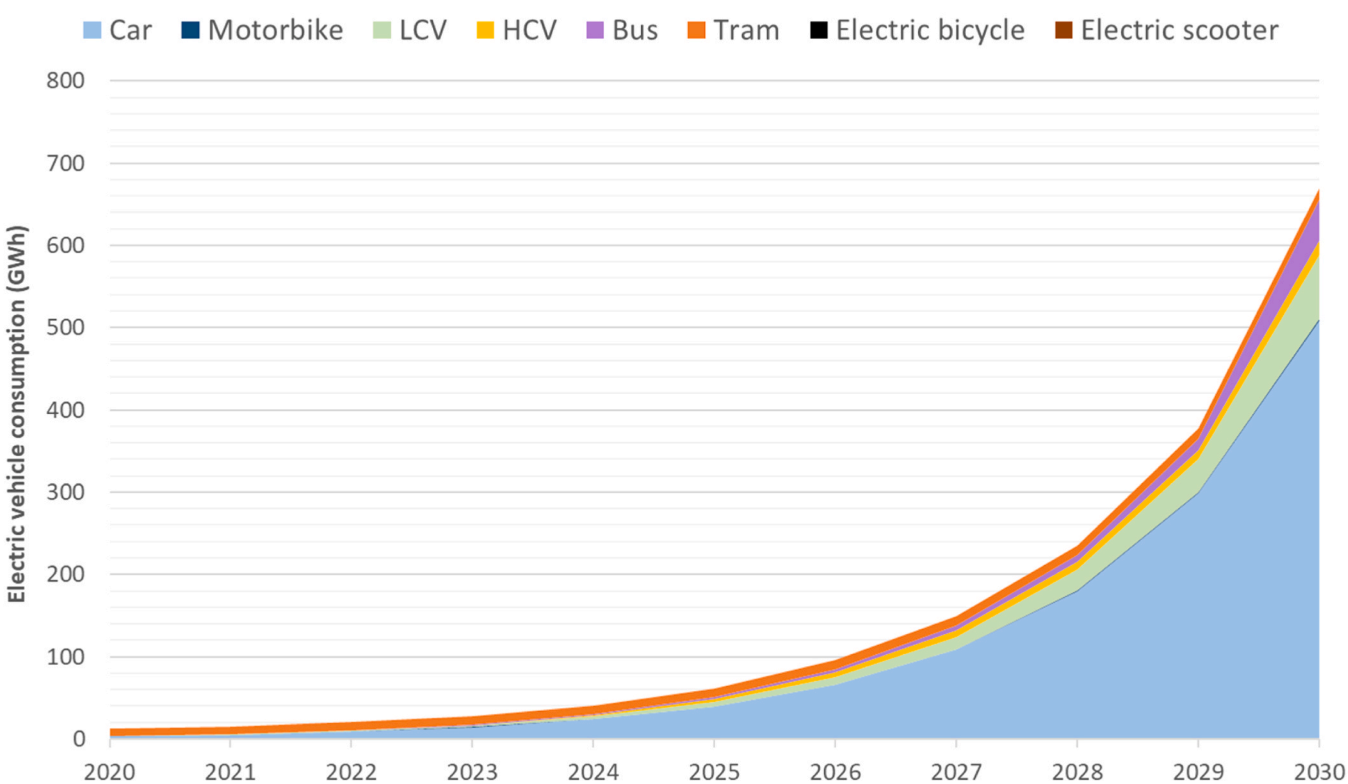


Fig. 7. Expected electricity demand by electric vehicle types. Above, electricity demand forecast in the TS. Below, electricity demand forecast in the IPS.

4. Validation model

The methodology implemented by the authors was validated based on the MLR model. Table 7 shows the results of the evaluation and validation of the MLR model based on different prediction accuracy metrics. Three variables were analysed: total fleet, total annual vehicle registrations and annual EV registrations, all with correlation coefficients higher than 0.90 and R^2 values higher than 0.85.

Regarding the main errors analysed, the prediction of the fleet and registrations have a mean absolute percentage error (MAPE) lower than

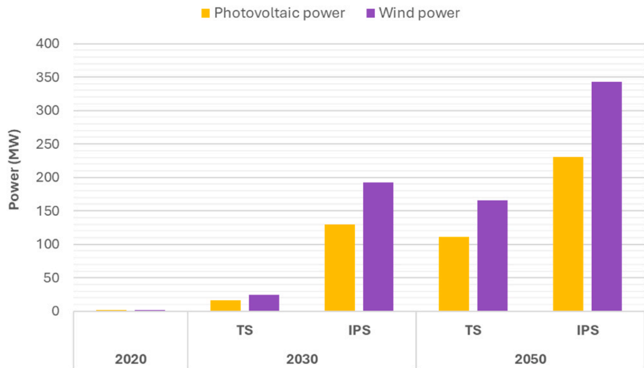


Fig. 8. Renewable power needs in the 2030 and 2050 horizons for the TS and IPS scenarios.

Table 7
Statistical parameters of the MLR model.

Statistical parameters	Vehicle fleet	Vehicle registration	EV registration share
Correlation coefficient	0.979	0.918	0.972
R^2	0.959	0.853	0.944
MAPE	3.84 %	9.16 %	26.55 %
RAE	4.41 %	9.94 %	19.40 %
MAE	7328	2003	0.32
RRSE	11.92 %	9.94 %	21.69 %

10 %, demonstrating the validity of the model.

The input variable with the highest weight for predicting the total vehicle fleet was population (see Table 4), demonstrating the validity of the methodology proposed in this article. In the case of vehicle registration, the variables with the highest weights were GDP and vehicle operating costs, and for increasing EV registration vehicle acquisition costs was the independent variable. The rest of the inputs were eliminated to avoid collinearity between variables, allowing the model to be refined. This was the case of GDP in the total fleet forecast, for example.

A standardisation of the independent variables was also carried out with the aim of determining which have the greatest weight in the prediction of the model. In addition, these independent variables were permuted among them to study the effect on model prediction and thus reduce the prediction error. In the case of vehicle fleet prediction, for example, this was done by permuting the variable 'population' for 'GDP', with the MAPE increasing to 23 % and the correlation coefficient falling to 0.74.

When analysing all inputs from a socio-economic perspective, the variables were more sensitive to the registration tax and fuel costs (purchase cost and taxes). This effect even exceeded the socio-economic effect of subsidies for the purchase of electric vehicles. On the other hand, general and road taxes had little impact on the results obtained.

Fig. 9 shows a comparison of the results obtained from the MLR model and the proposed methodology. For this purpose, the prediction of total annual fleet and share of EVs was analysed. In all cases the results are very similar.

Several scenarios were simulated to obtain the most accurate one for governmental regulations, varying the input parameters according to expectations of costs, prices and taxes. The values obtained reflect the policies and actions needed to bring about a paradigm shift in the land

Fig. 9. Comparison between the results obtained using the own methodology and the MLR model. (a) Total fleet forecast in the TS; (b) Total fleet forecast in the IPS; (c) EV share in the TS; and (d) EV share in the IPS.

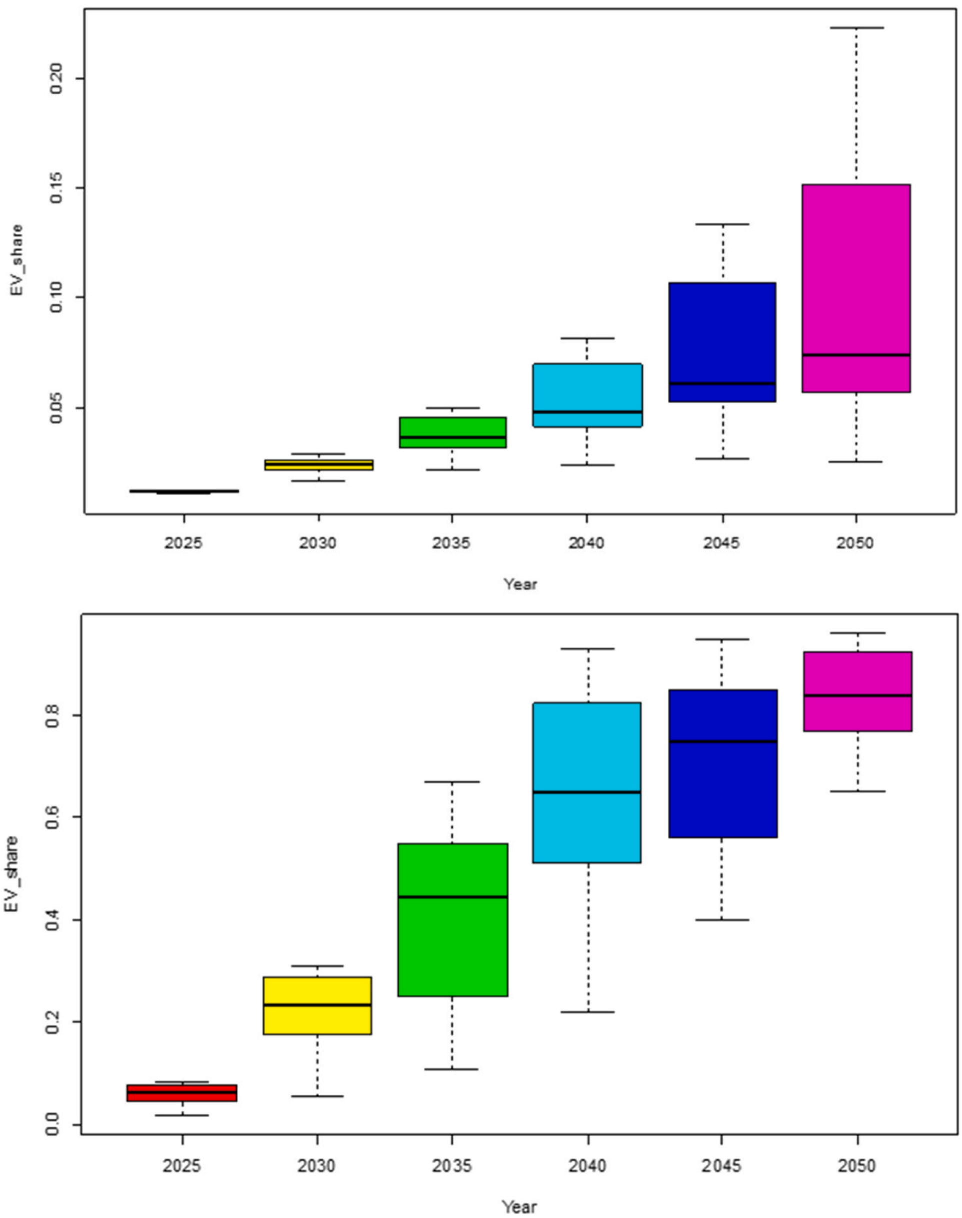


Fig. 10. EV share range in the time horizons considered. Above: EV forecast in the TS. Below: EV forecast in the IPS.

transport sector.

Fig. 10 shows the predicted penetration of EVs up to 2050. In the case of the TS, the degree of uncertainty is higher over time, reaching a penetration of only 1.7 % – 2.8 % in 2030, and in the range of 3 % – 22 % in 2050, far from the Spanish regulatory targets.

This is because the Spanish government has taken relatively few measures to massively promote the introduction of EVs in comparison with other countries. In the IPS, EVs are predicted to correspond to up to 96 % of the total fleet after application of different political measures which promote them to the detriment of conventional vehicles. To achieve such a level of penetration, the most notable of the main measures taken are as follows: i) increasing vehicle registration tax to 120 % for conventional vehicles (compared to 0 % – 14.75 % currently); ii) increasing the economic support for EVs to 10,000€; and iii) establishing a fossil fuel tax of up to 0.90 €/l. These actions would make it possible to achieve the Spanish government's 2030 targets. All these values were obtained from cross-validation with real data from Denmark, one of the countries with the highest EV penetration.

The results with respect to environmental impacts are significant in the transport transition. Fig. 11 shows the $CO_{2\text{-eq}}$ emissions for each simulated scenario. For the TS projections, emissions are expected to continue increasing to a range of 1800–2700 ktons yearly, while emissions avoided by EVs would only be in the range of 75–490 ktons. In 2020, according to the Canary Energy Yearbook (contra el C. C. y P. T., 2022) emissions in Tenerife were estimated to be around 1700 ktons.

However, in the IPS it would be possible to reduce emissions to 70–280 ktons of $CO_{2\text{-eq}}$ in 2050, a reduction of more than 96 %. To achieve full decarbonisation, the introduction of hydrogen vehicles or other e-fuels would be necessary to cover those vehicles that cannot be electrified (mainly HDVs and some LDVs). This would mean that around 15,250 vehicles would be equipped with hydrogen technology.

5. Discussion and scope of the results

The model proposed in this research fills an important gap found in the rest of the models analyzed. Appendix D shows in detail the main differences between each model and the one developed in this research. These differences can be summarized as follows: the implemented model

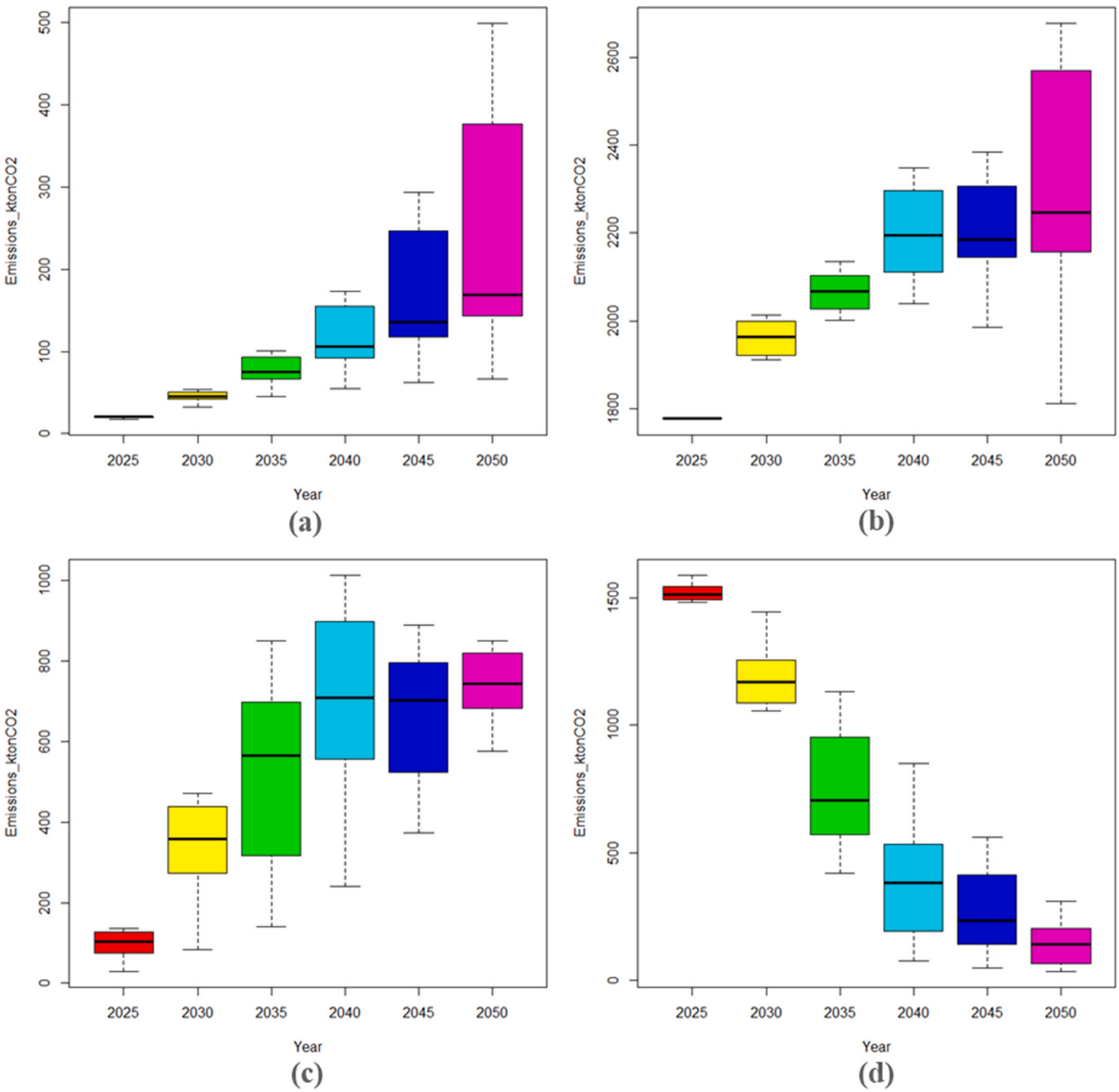


Fig. 11. $CO_{2\text{-eq}}$ emissions in the TS and IPS. (a) Emissions saved thanks to EVs in the TS; (b) Emissions generated by conventional vehicles in the TS; (c) Emissions saved thanks to EVs in the IPS; and (d) Emissions generated by conventional vehicles in the IPC.

allows the introduction of fleet electrification and modal shift objectives, as well as the determination of the renewable energy needed to meet the expected electricity demand. It also allows the introduction of socio-economic factors such as the price of each vehicle or taxes on new registrations to achieve the objectives of EV penetration.

Although the model was designed for an isolated region, it is easily adaptable to urban environments and countries with high population densities. Cities such as Madrid, Paris, Berlin or Mumbai could apply the model implemented for urban trips. It is only necessary to define the boundaries of the study region and to know the modal shift and electrification targets. The electrified fleet can then be estimated for the time horizons. In the case of the MLR model, it would first be necessary to determine the standard parameters listed in Table 4, which for most regions are published in their institutional databases. This would enable densely populated areas and continental regions to plan transportation more efficiently and identify the most effective measures to more quickly achieve fleet electrification and transition to more sustainable modes of transportation.

The results obtained from this research show the importance of carrying out in-depth studies in the transport sector in order to achieve an adequate energy planning. In the case of Tenerife (Canary Islands), with a low penetration of renewable energy (around 20 % of its energy mix) and high mobility, the electrification of vehicles would require a doubling (322 MW) of the current installed renewable energy on the island if the national targets are to be met in 2030. By 2050, this renewable power would need to be increased to 573 MW.

Achieving the fleet electrification target of 28 % would mean electricity consumption on the island increasing by 19 % in the next 5 years. Comparing the electrical demand predicted in the Canary Islands Electric Vehicle Strategy (SENDECO2, 2023) (which does not analyse modal shift), the results are quite similar, as according to the referenced document an increase of 724 GWh by 2030 is forecast, compared to 670 GWh with the methodology implemented.

However, the achievement of these objectives will require the involvement of all institutions and society to develop a more ecological, responsible and sustainable mobility. Scientific analyses which employ a holistic approach, as in the present study, help to understand the paradigm shift in society and technology. The rapid growth in electricity demand will require a restructuring of the entire island electricity system, from small households and distribution networks to the transmission lines themselves. Energy companies and governments will need to work together to ensure that this evolution takes place in an orderly and planned manner.

In this sense, the massive deployment of rapid chargers on public roads is of vital importance, as well as the promotion of charging in homes and workplaces. Fast charging stations require additional reinforcement of the electricity distribution networks as well as high levels of economic investment. The profitability of charging stations in Spain is currently under discussion, so to encourage their expansion by private companies it would be necessary to reduce their operating costs. An exemption from the access tariff could be granted for their rapid expansion, which would also provide an incentive for private investment in their development.

An increase in electricity demand also means increasing the supply of renewable power. The rapid penetration of these intermittent technologies in isolated electricity systems (as in the case of Tenerife) will be a challenge for the energy sector, which will have to improve the robustness and reliability of the electricity system. This is undoubtedly one of the key points for future research: to be able to increase the penetration of renewables without the problems that arise as a result of their intermittent nature.

This study highlights the difficulty of achieving the SNECP targets, where the reduction in private motorized transport and the increase in EVs will require significant investments and considerable administrative agility to ensure that the increase in electricity demand is met by renewable sources. To promote the uptake of EVs and the modal shift, government institutions can choose between two paths: i) providing economic benefits to those who choose to abandon their conventional vehicle; and ii) penalising the use of private combustion vehicles.

Currently, the Spanish government has opted for the first option, offering tax benefits and investment subsidies of up to €7000 for the purchase of EVs. However, there has been no observable exponential growth in EVs or a modal shift. More drastic measures will have to be taken to meet the government's targets, combining financial support with measures to penalise the use combustion vehicles. The results of the MLR model show that meeting the targets would require significant increases in vehicle registration and fossil fuel taxes, in this way penalising the purchase of a conventional vehicle.

Similar measures have been implemented in other countries with good results. Denmark, for example, has abolished the registration tax for EVs (which can amount up to 150 % of the value of combustion vehicles) and introduced different taxes on fossil fuels. In Germany, subsidies have been introduced for the purchase of EVs by companies, allowing them to deduct 40 % of the cost of the vehicle. And in the UK, the government has required car manufacturers to sell at least 22 % EVs, with stiff financial penalties if the target is not met.

However, the implementation of these measures in Spain, and in particular in Tenerife, faces a number of obstacles. The high price of EVs, combined with the low GDP per capita and the low savings capacity of households, prevents access to these vehicles in many cases. In addition, there is a lack of charging stations and low social and environmental awareness of their purchase. Achieving the 28 % electrification target would reduce land transport emissions by more than 30 %.

Regions such as Tenerife have a clear disadvantage compared to mainland areas in that the rugged orography is an obstacle for electric technology. In many cases, more powerful vehicles with sufficient autonomy are needed to overcome the island's orography, making EV penetration more difficult. For this reason, the incorporation of alternative renewable energy sources such as hydrogen or e-fuels is necessary to achieve complete decarbonisation in land transport.

In terms of modal shift, orography is also a key factor, especially for inter-urban journeys, which makes the transition to active modes (e-bicycles and e-scooters) difficult. In urban areas, the most prominent measure to discourage the use of combustion vehicles is prohibiting the use of private cars in certain areas and providing park and ride facilities. These measures need to be accompanied by massive investment in public transportation and bicycle lanes, adapted for use by other modes of transport in addition to bicycles (e.g., scooters), as has occurred in many other urban areas in Europe.

Research studies like the one presented in the present paper can help guide public institutions and serve as a roadmap for a planned energy evolution towards decarbonization. Estimating the number of vehicles that will be on the road in 5 years' time or forecasting the renewable energy that will be needed to supply them facilitates the work of governments in terms of taking appropriate economic, social and fiscal measures. Among many others, these could include parking deterrents, road planning, and subsidies for the public transport system, energy self-consumption and the development of renewable energy.

Such subsidies could even be financed with what the institutions would save each year in the cost of CO_2 emission fees. Based on an average price of 80 €/ton (ISTAC, 2022b), the savings in Tenerife alone could amount to 78 million euros in the IPS, and more than 490 ktons of $CO_{2\text{-eq}}$. With these savings in emission taxes, investments could be made in other assets that strengthen sustainable mobility, such as increasing the number of recharging stations, subsidizing investment in EVs, favouring collective vehicles over private transport, etc. In this way, economic investments would go hand in hand with policies that favour the transition to a more sustainable mobility. Without analyses of the type undertaken in the present paper, it will be very difficult to achieve national energy and mobility goals.

6. Future research lines

Important potential future research lines include:

- Studies on the demand for alternative fuels (e-fuels) and the energy consumption for their production as, in many cases, an EV is not the most suitable vehicle for displacements (especially for HDVs and some LDVs). These e-fuels could help to achieve 100 % climate neutrality in the land transport sector.
- The hybridization of spatial planning, transport transition and local distribution of renewable technologies. In isolated and land-scarce systems, it is essential to undertake in-depth studies on the integration of all these measures in the transport sector with the increased introduction of renewable energies. The siting of renewable energy farms, the transportation of electricity to urban centres, and the deployment of charging stations require integrated management by

all parties. All this must be combined with a modal shift from private car use to collective and active transport.
– In-depth analyses on the importance of introducing autonomous vehicles and shared vehicle use. The role of such vehicles requires further research, especially under modal shift scenarios.

7. Conclusions

Land transport is one of the most energy-intensive and GHG-intensive sectors in the world. The electric vehicle (EV) and renewable energy are postulated as the main alternatives to resolve the emissions problem. The main objective of this research is to estimate the renewable energy that will need to be installed in the coming years due to the growing demand for electricity from EVs.

Two scenarios are developed to determine the vehicle fleet for the land transport sector up to 2050: (1) a Trend Scenario (TS) based on historical data of vehicles and population forecast; and (2) an Implemented Policy Scenario (IPS), where the main targets of governmental institutions are considered (in terms of vehicle electrification, modal shift and active policy goals). In addition, a multiple linear regression (MLR) model based on various socio-economic aspects is developed to validate the proposed methodology.

The results applied to the island of Tenerife (Canary Islands, Spain) show that, following the current trend, the total number of vehicles could increase by 15 % in 2030 and by up to 36 % in 2050 (TS). However, in compliance with the energy and mobility targets of the Spanish government (IPS), the total fleet could be reduced by 0.5 % in 2030 and by 48 % in 2050. In the TS, only 2.8 % of the fleet would be electrified in 2030 and 14.7 % in 2050, while in the IPS electrification would increase to 28 % in 2030 and 96 % in 2050. This would mean an increase in electricity demand of up to 670 GWh by 2030 and 1193 GWh by 2050 in the IPS (more than one third of the current electricity demand of the island). To cover the 2030 IPS electricity demand with renewable technologies, it will be necessary to add 129 MW of photovoltaic power and 192 MW of wind power in just 5 years

A comparison of the two scenarios shows that the impact of active policies to foster the use of sustainable transport (public transport and vehicle sharing, as well as the so-called active mode journeys) constitutes an essential factor in the reduction of the number of vehicles in circulation and hence, of the energy demand.

Implementation of the IPS would reduce emissions by more than 25 % in 2030 and 96 % in 2050, meeting Spain's emissions targets. In the worst-case scenario, assuming that the current electricity mix is maintained and not all electricity demand is produced by renewables, emissions would be reduced by more than 19 % by 2030.

The results show the complexity of the task that face the institutions to achieve the agreed targets. Immediate action is required to promote a modal shift and the purchase of EVs, as well as the integration of transport and energy planning.

The MRL model was also used to analyse various socio-economic parameters that could influence the choice between purchasing a conventional vehicle or an EV. Increasing vehicle registration and fossil fuel taxes were found to be the measures with the greatest impact. The authorities would need to increase the registration tax on combustion vehicles to 120 % (as other European countries have done) and penalise fossil fuel consumption with a €0.90/l tax to comply with the IPS. This shows that economic impacts are the key to promoting a modal shift and EV purchases.

However, implementing these economic measures is not as easy as in other countries. The household saving capacity of Tenerife is some way below that of the Nordic countries, which makes it difficult to buy EVs. Therefore, a policy of restricting combustion vehicles must be accompanied by tax rebates and financial aid for the purchase of EVs. In addition to this, investment in charging stations and reinforcement of the transport and distribution networks, among other factors, are needed.

In terms of modal shift, under the IPS only 53 % pkm would be made by private motorized vehicles in 2030. However, abandonment of the private car requires a very efficient collective transport system, as well as greater use of active transport modes. This is easier to achieve in urban areas but, due to the complex orography of Tenerife and its population dispersion, the transition to alternative modes of transport is very complex and makes the modal more difficult in interurban areas.

In conclusion, regardless of which of the two scenarios is considered, a significant increase in renewable energy production will be required to satisfy the future electricity demand of the land transport sector should the energy and climate targets set by Spain for 2030 be met. Holistic research of the type undertaken in the present study is essential to set the roadmap for a greener, more equitable and sustainable transition.

Future research lines to enable a sustainable energy transition in the land transport sector need to be undertaken. Various issues in the transport energy transition need to be covered that include technological aspects (vehicle technology according to the transport range), policy aspects (enabling ambitious modal shift trends that, for example, enhance commuting options, public transport and alternative transportation modes) and planning aspects (facilitating the appropriate integration of the renewable power needed in the territory).

CRediT authorship contribution statement

Yánez Rosales Pablo: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Julieta Schallenberg-RodrÍguez:** Writing – review & editing, Validation, Resources, Funding acquisition, Formal analysis, Conceptualization. **del Rio-Gamero Beatriz:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Pablo Yanez-Rosales reports financial support and administrative support were provided by Spain Ministry of Science and Innovation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Forecasting the number of vehicles in TS

To estimate the number of vehicles, two different procedures are performed: (1) for the number of buses; and (2) for the numbers of the other vehicles.

The procedure to estimate the buses is different because the occupancy rate changes as a consequence of modal shift (Figure A.1). Firstly, it is necessary to estimate the current occupation rate, followed by an estimation of the occupancy rate in 2030 based on historical data. Based on the forecasted occupancy rate and the increase in public bus passengers due to the modal shift (Eq. (A.1), the additional buses needed are estimated using Eq. (A.2) and Eq. (A.3)). To estimate the numbers of the other types of vehicle, Eq. (2) is used:

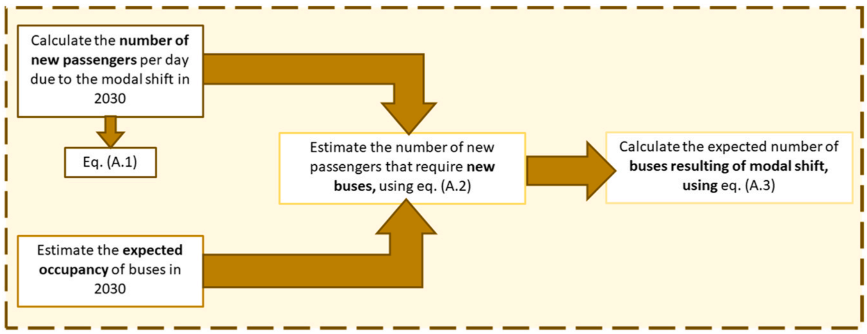

Figure A1. Procedure to estimate the number of buses

$$p_i = Pkm_i / l_i \tag{A.1}$$

$$p_{NBi} = p_{MSi} - p_{IOi} = p_{MSi} - \left[p_{busa} \times (O_e / O_a - 1)\right]_i \tag{A.2}$$

$$N_{busi} = p_{NBi} / \mu_i \tag{A.3}$$

where:

p_i = daily passengers by journey type
Pkm_i = passenger − kilometre by journey type
l_i = mean mileage (km)
p_{NBi} = daily passenger that require new buses
p_{MSi} = total daily passengers coming from cars (coming from Modal Shift)
p_{IOi} = daily passengers that increase the occupation rate in buses
p_{busa} = daily passengers with current occupation rate
O_e = expected occupation rate
O_a = current (actual) occupation rate
N_{busi} = increase of expected buses due to modal shift in 2030
μ_i = bus occupancy rate.

Motorized vehicles forecast

Table A.1 shows the annual average variation of each type of vehicle in the 2005–2021 period (ISTAC, 2022a; Consejo Económico y Social de Canarias, 2022), calculated following the procedure shown in Fig. 2.

Table A1
Average annual percentage variation of vehicles in the period 2005–2021

Car	Motorbike	LDV	HDV	Bus
1.0 %	4.3 %	0.1 %	−0.1 %	0.4 %

Figure A.2 shows the expected increase of each type of vehicle resulting from crossing the population forecasts for Tenerife (transportes interurbanos de T. Titsa, 2022) with the annual variation of vehicles.

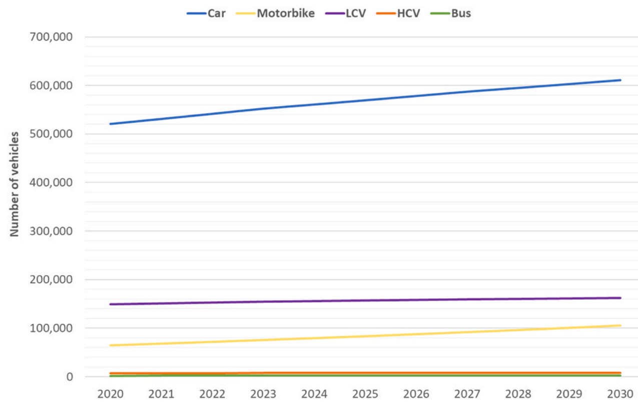

Figure A.2. Forecast of vehicle numbers per vehicle type (2030)

Public transport forecast

To determine the tram and bus fleet, historical passenger data series are used (MetroTenerife et al., 2020; OTLE, 2022). The pkm distribution between both types is based on the share of tram vs. bus passengers. In terms of occupation rate, buses are expected to reach 48 % (equating to the national mean (MetroTenerife et al., 2020); IGN, 2022) compared to 38 % in 2019.

Historical tramway data series focus on electricity consumption and number of passengers (2012–2019) (OTLE, 2022). To calculate the expected electricity consumption in 2030, Eq. (A.4) is applied. Both the average electricity consumption and the expected number of passengers are calculated from linear projections.

$$E_{tram} = \delta \times p_{tram} \tag{A.4}$$

where:

E_{tram} = expected tram consumption in 2030 \\(MWh\\)

δ = expected mean consumption by passenger in 2030 \\(MWh/passenger\\)

p_{tram} = expected tram passengers in 2030.

Active mode vehicles forecast

For the calculation of active mode vehicles (bicycles and electric scooters), since no historical data is available for this specific island an extrapolation is made based on active mode data from similar islands (such as Gran Canaria).

Appendix B. Forecasting the number of vehicles in the IPS

The modal shift of the Spanish National Energy and Climate Plan (SNECP) is based on a reduction in private transport pkm (MITECO, 2019a). T calculate the pkm for this mode, the data used are the number of journeys distributed by type (Cabildo de Tenerife, 2012). To distribute them by transport mode, Eq. (B.1) and Eq. (B.2) are used:

$$V_{Ti} = V_{Pi} + V_{Ci} \tag{B.1}$$

$$V_{Ci} = \sum\nolimits_{k=1}^{j} \varphi_{i,j} V_{vj} \tag{B.2}$$

where:

V_{Ti} = total journeys by type (urban or interurban)

V_{Pi} = private motorized transport journeys by type

V_{Ci} = public transport journeys by type

$\varphi_{i,j}$ = journey type share by type of vehicle (%)

V_{vj} = journeys by type of public vehicle.

The procedure used to estimate the number of vehicles in the IPS is explained in Figure B.1.

The pkm in private motorized transport for the year 2012 is calculated using Eq. (1). To project this pkm to 2019, (International Forum Transport et al., 2020; Zhang et al., 2021) were used for urban journeys and (International Transport Forum, 2020b) for interurban journeys. From the two scenarios published in both reports, an intermediate scenario is proposed, as the geographical and political characteristics of the island of Tenerife lie between the two. Table B.1 shows the pkm in 2012 and the projection to 2019.

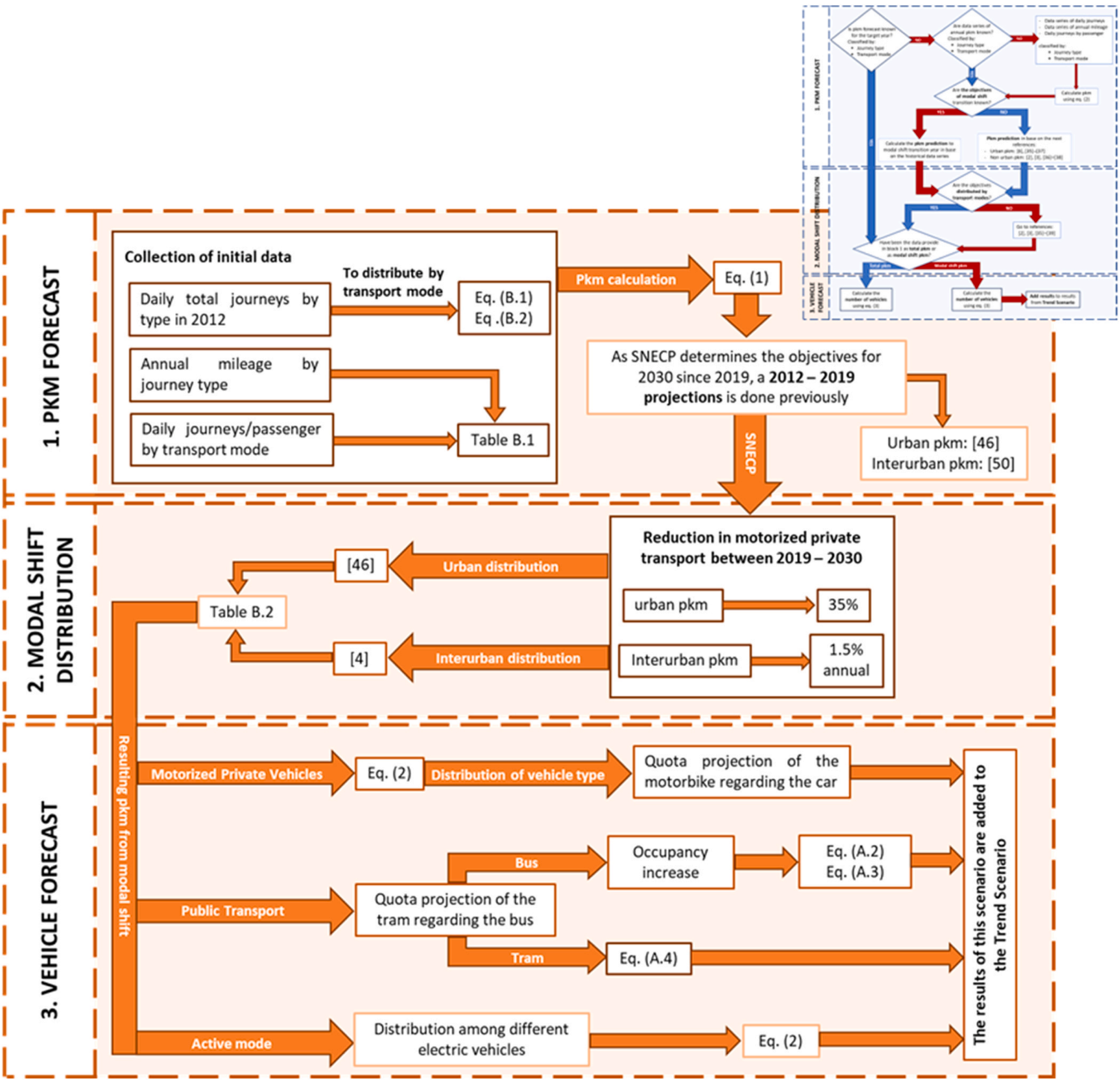

Figure B1. Procedure to estimate the number of vehicles in the IPS

Table B1
Passenger-km in private transport distributed between urban and interurban pkm

Factor	Total	Urban	Interurban	Unit
Passenger-km in 2012	9.3 x 10^9	2.8 x 10^9	6.5 x 10^9	pkm/year
Passenger-km in 2019	9.9 x 10^9	2.7 x 10^9	7.2 x 10^9	pkm/year

The SNECP set a target of a 35 % reduction in private motorized vehicle passenger – kilometres (pkm) for urban journeys and a 1.5 % annual reduction in private motorized vehicle pkm for interurban journeys by 2030 (MITECO, 2019a).

Appendix C. Electrification forecast in each scenario and specific consumption for the island of Tenerife

Table C.1 shows, for the specific case of Tenerife, the electrification forecast for each type of vehicle in the proposed scenarios. It also shows the specific consumption forecast for each type. The other following consumptions were assumed: Tram (540 kWh/100 km); Bicycle (0.5 kWh/100 km); and Scooter (1.1 kWh/100 km).

Table C1
Share of electrical vehicles per type under the trend and implemented policy scenarios (TS and IPS) and expected consumption by type of electrical vehicle in 2030

Scenario	Car	Motorbike	LDV	HDV	Bus	Total
TS	3.4 %	1.4 %	1.3 %	0.2 %	2.9 %	**2.8 %**
IPS	31 %	33.5 %	14.3 %	4.8 %	21.4 %	**28 %**
Consumption (kWh/100 km)	17.3	2.9	22.9	100.1	129.2	**-**

Appendix D. . Comparison of the proposed model with other transport planning models

Table D.1. shows a comparison between the model implemented in this research and other land transport planning models used in the literature reviewed.

Table D1
Disadvantages of different transport planning models compared to the proposed model

Comparative model	Disadvantages with respect to the proposed model
TIMES	Non-specific model for the road transport sector.Does not allow input of fleet electrification targets.Does not allow calculation of renewable power to satisfy electricity demand.Does not allow input of modal shift targets.
LEAP	Non-specific model for the road transport sector.Does not allow input of fleet electrification targets.Does not allow calculation of renewable power to satisfy electricity demand.Does not analyze the socio-economic measures needed to achieve government targets.Does not allow input of modal shift targets.
EnergyPLAN	Non-specific model for the road transport sector.Does not analyze the socio-economic measures needed to achieve government targets.Does not allow input of modal shift targets.
MESSAGE	Non-specific model for the road transport sector.Does not allow input of fleet electrification targets.Does not allow calculation of renewable power to satisfy electricity demand.Does not allow input of modal shift targets.
IMACLIM – IND	Does not allow input of fleet electrification targets.Does not allow calculation of renewable power to satisfy electricity demand.Does not allow input of modal shift targets.Does not analyze the socio-economic measures needed to achieve government targets.
CanESS	Does not allow input of fleet electrification targets.Does not allow calculation of renewable power to satisfy electricity demand.Does not allow input of modal shift targets.Does not analyze the socio-economic measures needed to achieve government targets.The forecast is not based on economic parameters such as fuel prices or vehicle purchase costs.
UKTCM	Does not allow input of fleet electrification targets.Does not allow calculation of renewable power to satisfy electricity demand.Does not allow input of modal shift targets.
GREET	Does not allow calculation of renewable power to satisfy electricity demand.Does not allow input of modal shift targets.Does not analyze the socio-economic measures needed to achieve government targets.
FSM	Does not allow input of fleet electrification targets.Does not predict the fleet energy demand.Does not allow calculation of renewable power to satisfy electricity demand.

Data availability

The data that has been used is confidential.

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