Optimization of the maritime interisland transportation network in Canary Islands based on net social benefit and financial profits

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ABSTRACT

This article tries to assess, whether it is economically feasible and socially profitable to introduce some new maritime passenger and freight routes between some of the Canarian islands. The optimization framework is built in a long-term potential scenario, departing from the current supply levels. For this purpose, the potential travel demand on each pair of islands has been estimated using gravity models, as well as the current travel demand functions on each itinerary. Microeconomic models have also been used to calculate the variation of the consumers and transport companies' surpluses on each route. In addition, cost functions are used to calculate financial profits on each route. Both surpluses and profits are used as performance indicators to compare current links with the proposed alternatives. Results indicate that it is socially profitable to expand the supply of freight maritime transportation on all existing connections and the existing passenger and freight links should be developed further. Furthermore, the new routes would improve welfare in two of three cases but would reduce earnings of the producers in all three cases.

Keywords: Inter-Island Transportation, Transportation Demand, Modal Competition, Cost-Benefit Analysis,

JEL Classification: D61, N74, R41.

1. INTRODUCTION

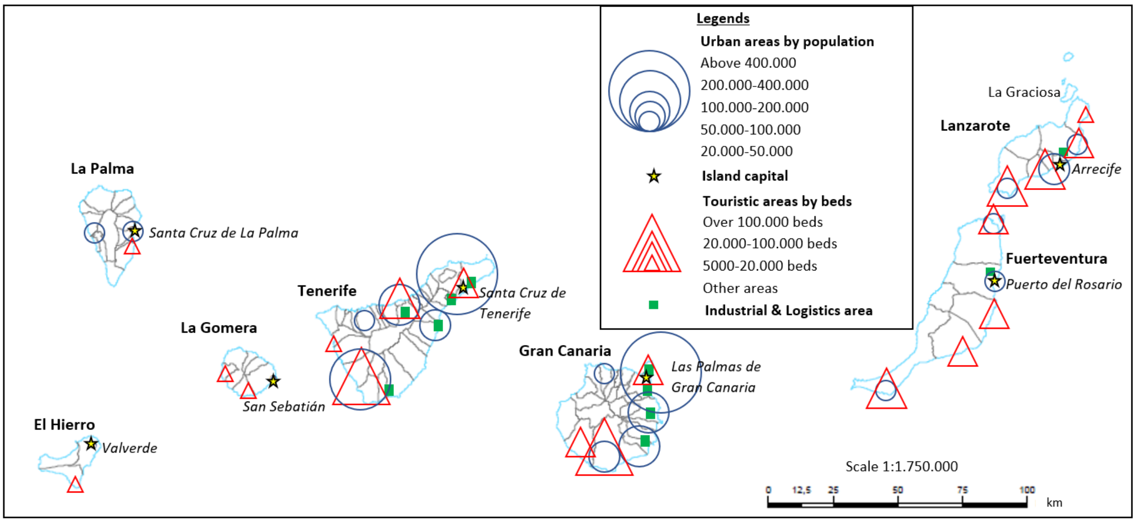
The aim of this paper is to analyse the feasibility of possible improvements in the existing air and maritime network within the Canarian archipelago, considering both passenger and freight transportation. Supply and demand functions are estimated, calculating consumers' and producers' surpluses, evaluating later the variations of those surpluses in a potential scenario 25 years ahead using cost-benefit analysis. In a last step, these routes are compared with a new scenario with new links. This paper is not about the development of a specific mobility model or planning, nor about the modelling of inter-island transportation in this archipelago. Our goal is not the estimation of specific passenger and freight quantities demanded and supplied in the present time, but to estimate present demand-price and supply-price functions and their evolution to their potential levels. This allows to calculate the fluctuations of net surpluses of consumers and companies, a measurement of their welfare that, applied to different alternatives of connections between several pairs of islands, is the main objective of this research. This puts aside of this work the four-step transportation model except from the phase related with generation and attraction of trips between islands, where we apply gravity models.

Estimations have been made with help of databases from several institutions and without surveys. This removes the sense of applying discreet choice models in this paper. The aim is neither the analysis of the distribution of trips. Therefore, growth factor models or entropy maximisation models are also discarded.

The Canarian archipelago is composed of eight islands and is located about 1.000 km southwest of the Iberian Peninsula in Europe and around 100 km west of the African continent. It belongs to Spain after the Castilian conquest along the 15th century, although it was inhabited by several isolated communities that had been living on the islands for several centuries. The region has today a surface of almost 7.500 km2 and has a population of around almost 2,2 million inhabitants. The main economic activity is tourism, reaching in 2019 around one third of the regional GDP. As it can be observed in Figure 1 the two central islands, Tenerife and Gran Canaria contain more than 80% of the population, shaping the territory as a bicephalous structure. Both metropolitan areas of the main islands, Santa Cruz de Tenerife and Las Palmas de Gran Canaria share the capital status of the region, concentrating administration services and main educational institutions and hospitals, as well as the main ports, with their associated logistics.

In the past decades this double-head is being corrected to some extent with a fast demographic growth of the two most oriental islands, Lanzarote and Fuerteventura. Historically their dry climate implied poor agricultural performance leading to an extremely thin population density in those islands. On the other hand, the western islands, La Palma, La Gomera and El Hierro have been losing population for decades since they are the only islands where mass tourism has not been developed, remaining as the most agrarian islands. A trend towards a more nature-oriented tourism observed in recent times might stop this decline to some degree.

Figure 1 Canary Islands: population, tourism, and Industry



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In this paper we will concentrate in the optimization of the connections between the following pairs of islands: Tenerife-Gran Canaria, Tenerife-La Palma and Gran Canaria-Lanzarote. It is structured in the following manner: Section 3 deals with the analysis of the supply of current inter-island connectivity, as well as the estimation of potential demand of both passenger and freight transportation. In Section 4 and Section 5 a cost-benefit analysis model is developed, to evaluate the variation of the surpluses of consumers and enterprises, applied individually for each connection. This allows the quantification of social benefits to fit the supply to the potential demand. Section 6 is devoted to financial profits while Section 7 contains the main application and results.

2. LITERATURE REVIEW

There is a significant amount of literature analysing transportation within archipelagos, some of them have been taken as references to perform this research on cost-benefit calculations associated to transportation in Canary Islands.

In this Canarian environment the descriptive works of (Ramos Pérez, 2001: 201-219) and (Hernández Luis, 2006: 361- 364) should be mentioned. Additionally, (Hernández Luis, 2002: 232-234) makes specific proposals on schedules to improve connectivity and (Hernández Luis, 2018: 557-559) introduces multimodal connectivity in his analysis on Canarian inter-island transportation, (Ramos, 2015: 137-159) analyses the effects of competition on pricing.

Our work takes also references from European intermodal transportation, like (Gollnick, 2004: 8-10) and (Steer Davies Gleave, 2006: 6-13), both focused on land and air connectivity. Regarding the maritime mode works of (Tsekeris, 2009: 269-272) and

(Tzannatos, 2005: 86-88) for Greece or (Rutz, W. y Coull, J., 1996: 283-285) for Indonesia should be mentioned. Quantitative approaches like (Garín, 2006: 285-288) estimate air transportation demand between Canary Islands and their touristic emitter markets, whereas air transit between the Canaries and the Spanish mainland has been investigated by (Gundelfinger-Casar and Coto-Millán, 2018: 83-90).

Those gravity models used in this research to estimate potential demand for both passenger and freight markets have been inspired by (Sen and Smith, 1995: 221-225), (Batra, 2004: 9-10), (Grosche et al., 2007: 177-178) and (Ortúzar and Willumsen, 2008: 263-268). Here potential demand has been estimated by aggregation of transportation demand of both resident passengers and tourists. Potential freight demand has been estimated for air and maritime modes, although the former has been discarded for later stages due to its little relative significance. The quantification of externalities related with the emission of gases has been done with support of references like (Eyring et al., 2010: 4735-4771), (Lee et al., 2010: 4720-4724) and (Uhereck et al., 2010: 4724-4777). For the monetization of these costs, information published in (Umweltbundesamt, 2014: 9-10) was used. Travel time savings have been quantified based on (Gwilliam, 1997: 2-6) and (García-Álvarez, 2016: 17- 32). The impact of accidentality is performed with results obtained by (Albert y Malo, 1995: 120-123) and (Miller, 2000: 182-184).

As specified in the beginning, the aim of current research is to evaluate if the introduction of new routes between the mentioned pairs of islands would be both socially and financially profitable, whereas optimum transportation for each link takes multimodality into account, which implies door-to-door transportation.

3. TRANSPORTATION SUPPLY AND DEMAND

The Canarian archipelago has a modern transportation infrastructure allowing a high-density network to connect each island with the surrounding ones in almost every case. Regular maritime lines were established in the early 20th century although with reduced frequencies and uncomfortable ships, which limited the attractive for leisure or frequent travellers. Thus, the first high performance network was woven by the flag airline Iberia in the 1960s, showing significant growth until the late 1970s. By that time a combination of economic crisis and the introduction of modern ships meant the stagnation of air transportation in detriment of the maritime mode. The appearing of a high-performance passenger *jet-foil* ship led to a switch of the dominant mode to the maritime in many connections, especially between both regional capitals. Further improvements like fast-ferries or new routes between closer ports have only strengthened that tendency. However, both modes have achieved significant growth in absolute numbers.

Several reasons can explain this expansive behaviour: first, the rise of tourism turning the islands into one of the leading destinations of touristic power like Spain has led to an increase of the floating population to around 400.000 people. This group has a high propension to mobility. Second, mainly because of the touristic industry, the archipelago has been showing a high demographic growth: its population has multiplied by factor 3,2 in the last 70 years. Third, the public sector has increasingly supported the development of a high-performance network in several ways: building and enlarging infrastructures like ports, airports or roads until present day; reducing most of port and airport fees in inter-island transportation for both passengers and freight; and subsidizing local consumers directly by carrying with 75% of the ticket prices for passengers and, in a similar way, with the freight costs.

Each island, except La Graciosa, has an airport, while Tenerife has two. La Gomera and El Hierro only admit regional airplanes, while the others receive flights from Spanish Mainland, the rest of Europe and in some cases from Africa and even America. These infrastructures are managed by the national operator *AENA*, a listed company with 51% of its capital owned by the state. Figure 2 shows the structure and relative importance of the air transport network. It is worth to be mentioned that the bigger Tenerife-South airport is mainly oriented to international flights while the smaller Tenerife-North is serving local population, concentrated in its surroundings, with most inter islands and domestic flights.

Figure 2 Canarian airport system and inter-island air transportation network

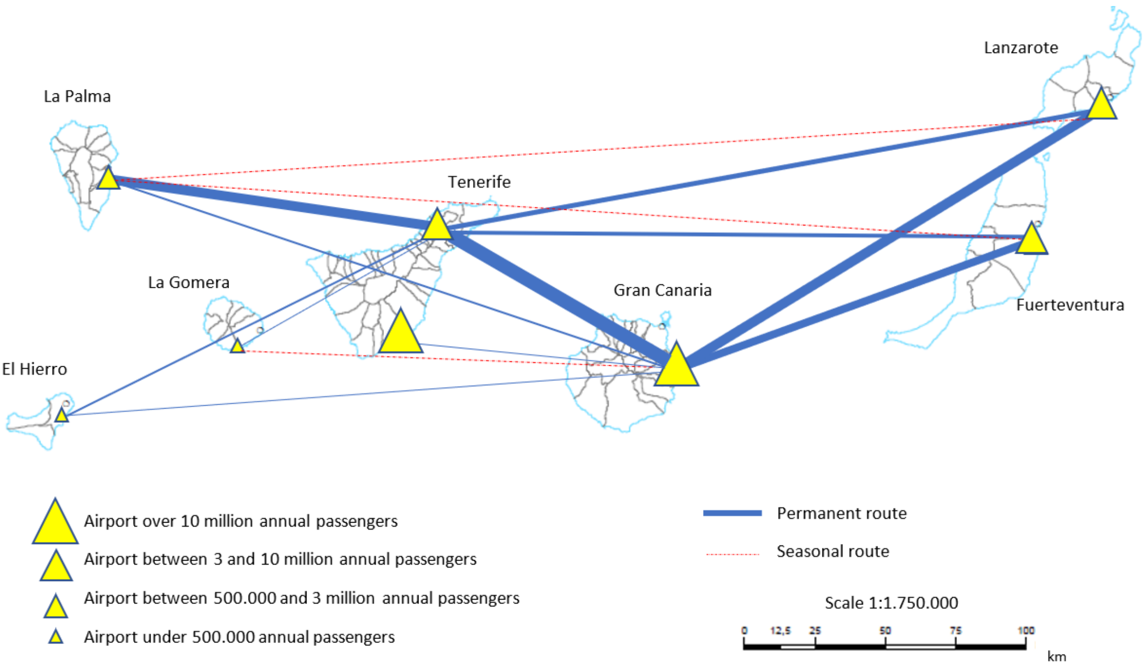

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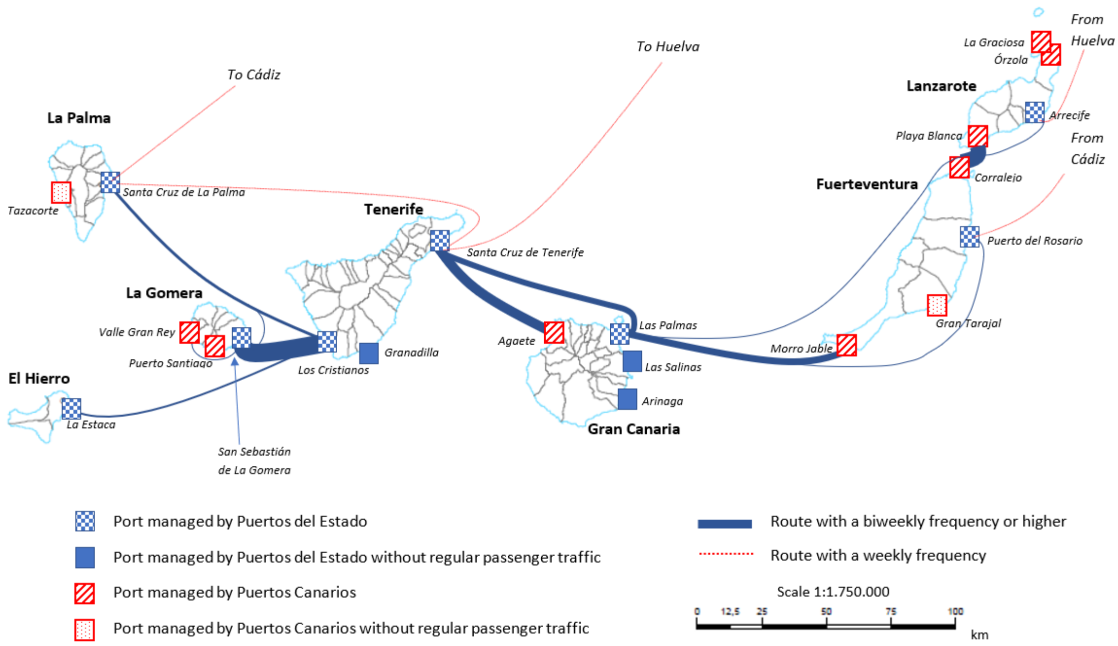
Figure 3 Canarian port system and maritime inter-island passenger transportation network



Source: own elaboration. This scheme shows the port system differentiating by its ownership and the main passenger routes, where the thickness is representative of the passenger volume.

The main ports of the archipelago, those handling different kinds of freight and passengers depend on the state company *Puertos del Estado*, although the two Port Authorities, Tenerife, and Las Palmas, enjoy an autonomous management. Smaller domestic oriented ports manipulating only passengers and rolled freight depend on the regional government through the regional public company *Puertos Canarios*. Figure 3 displays an overview of the port system and the existing direct connections.

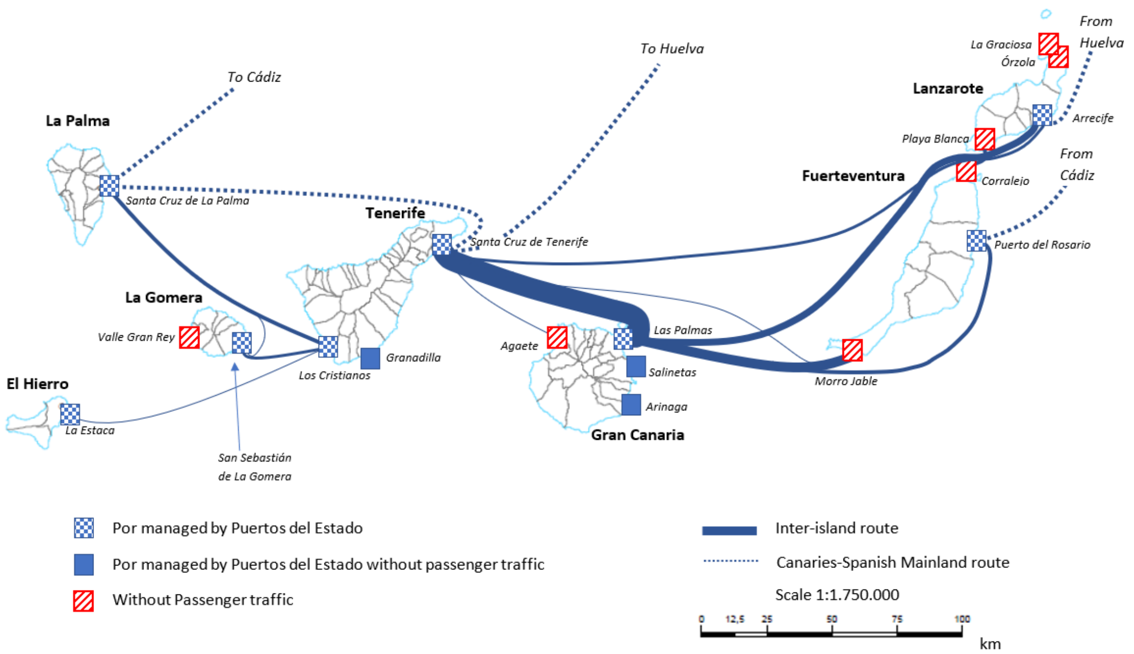
In 2018 the modal share of the airplane in the main connections was, regarding passenger transportation: 4% in Tenerife-La Gomera, 42% in Tenerife-Gran Canaria, 49% in Gran Canaria-Fuerteventura, 58% in Tenerife-El Hierro, 73% in Tenerife-La Palma, 89% in Gran Canaria-Lanzarote. The duration of the sea travel including access time is the main explanation factor of this distribution, being the available frequencies the second one.

Most of the routes are dominated by local passengers since they represent more than 90% of the air travellers. Only two maritime routes show a significant proportion of tourists: Tenerife-La Gomera and Lanzarote-Fuerteventura. Both make possible one-day excursions from the important touristic resorts existing at the ports. It is also worth mentioning that the ship is by large the main access for foreign tourists travelling to La Gomera, mostly arriving to Tenerife-South airport from continental Europe.

Figure 4 shows the structure of the sea freight network, which reflects the demography of the archipelago, concentrated in Tenerife and Gran Canaria. The port of Las Palmas is an important freight port at Spanish level and is connected to the international circuit, while the port of Santa Cruz, more modest, has a more domestic orientation. Lanzarote, Fuerteventura and La Palma have some direct supply from the Spanish mainland, while

La Gomera and El Hierro depend on the connections with Tenerife or Gran Canaria for their supply.

Figure 4 The port system and maritime inter-island rolled freight transportation network

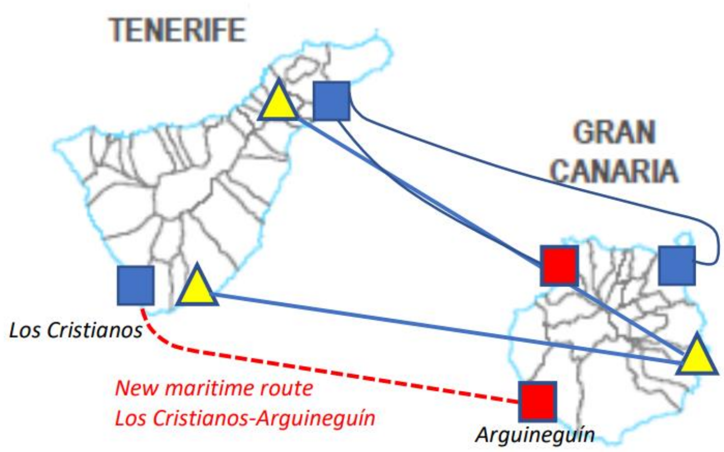


Source: own elaboration. This scheme shows the port system differentiating by its ownership and the main passenger routes, where the thickness is representative of the passenger volume.

A critical analysis of the distribution of population, economic activity, especially tourism and logistics and the existing connections (both air and maritime) leads us to find some leakages in the existing network, that we propose to overcome in the next paragraphs:

First: The South of Tenerife and Gran Canaria (Figure 5) account for around 250.000 and 200.000 inhabitants respectively. In addition, the most relevant tourists' resorts are in those areas.

Figure 5 Existing and proposed links between Tenerife and Gran Canaria



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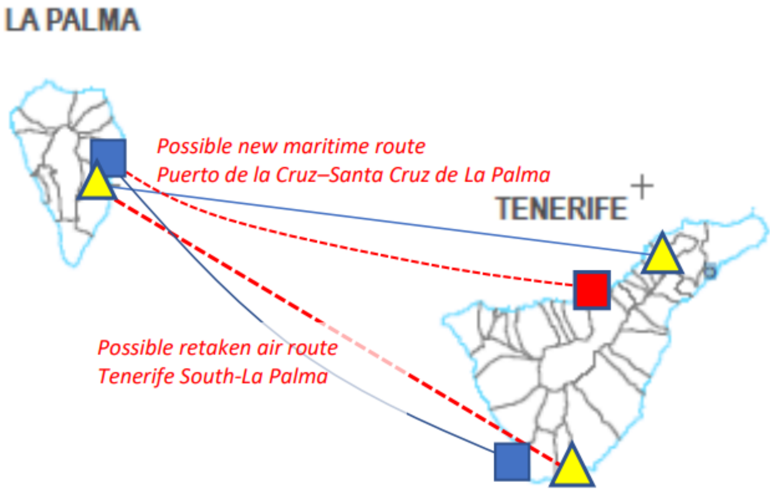
A direct maritime link between ports in the south of Tenerife (Los Cristianos) and the southwest of Gran Canaria (Arguineguín or El Pajar) would avoid travellers driving to the opposed sides of the islands to take a ferry. It could also induce new demand of tourist excursions between the main touristic areas in the Canaries: shorter access trips might promote one-day excursions. The existing air link between Tenerife-South Airport and Gran Canaria is limited to passengers and distances would be still relatively long to the populated areas in the south of Gran Canaria.

Second: In the case of Tenerife and La Palma (Figure 6), the bulk of the passenger traffic is done by airplane via Tenerife-North Airport, that serves the most populated area in Tenerife. Regarding the maritime link, its modal share is smaller due to the longer total travel time: The port Los Cristianos lies 75km away of the main metropolitan area and the sea trip travel time is about 3 hours. We propose to restructure connections by i) recovering an air link between Tenerife-South Airport and La Palma[1] ii) establishing a new maritime connection from a port in the north of the island (Puerto de la Cruz or Garachico) that would allow to reduce both access time and main trip time and iii) keeping a part of the frequencies of the existing lines.

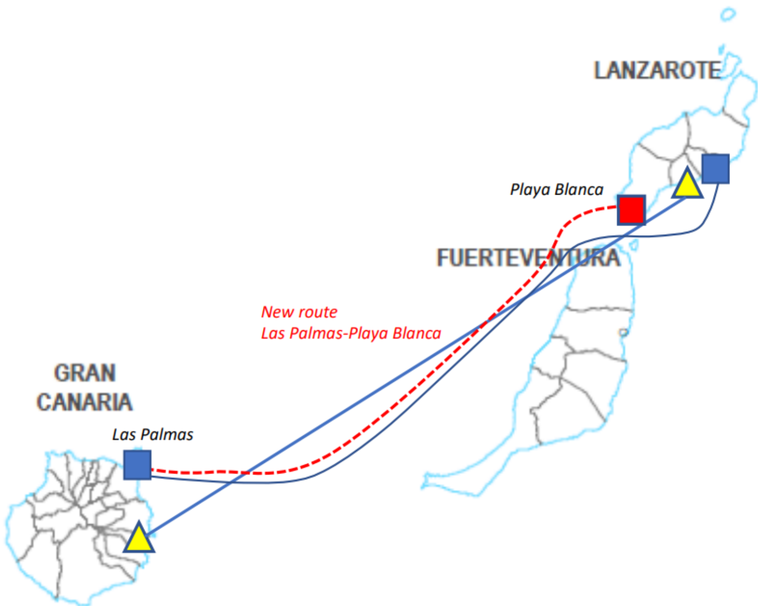
Figure 6 Existing and proposed links between Tenerife and La Palma



Source: own elaboration

And third: In the case of Gran Canaria and Lanzarote (Figure 7) the air mode is clearly dominant due to the long distance between both islands, which is even bigger if we consider the effective distance between the operated ports of Las Palmas and Arrecife, on the eastern shore of the island. There is a closer port in the south, Playa Blanca, which is undergoing a process of expansion that will allow it to host ships that can link Lanzarote with Gran Canaria. We take as a proposal the planned fast ferry link between Playa Blanca and Arrecife, while maintaining the legacy ferry connection between the capitals.

Figure 7 Existing and proposed links between Gran Canaria and Lanzarote



Source: own elaboration

Table 1 Inter- Island transported volumes in 2018

Pairs of islands	Air Passengers	Maritime Passengers	Rolled freight [t]	Distance between airports [km]	Distance between ports [km]	Population Origin Island	Population at Destination Island
Tenerife-La Palma	609.838	235.440	180.353	139	125	920.253	83.159
Tenerife-Gran Canaria	792.087	1.423.741	1.393.778	112	95	920.253	857.702
Gran Canaria-Lanzarote	654.403	102.254	486.960	207	210	857.702	146.134

Source: Own elaboration based on AENA (2004-2018) and Puertos del Estado (2007-2018).

Once current connections between the affected islands have been examined, as displayed in Table 1, we will proceed to analyse the potential demand of inter-island passenger and freight transportation. To estimate it, we have applied a gravity model based on (Sen and Smith, 1995: 221-225), (Batra, 2004: 9-10), (Grosche et al., 2007: 177-178) and (Ortúzar and Willumsen, 2008: 263-268). Both passenger and freight data have been obtained from AENA (2018), Puertos del Estado, (2018) and Puertos Canarios (2018). The basic gravity model has the following structure.

$$q_{ij} = G_{ij} \cdot \left(M_i \cdot M_j\right)^{\alpha} \cdot {\delta_{ij}}^{\eta} \qquad (1)$$

Where q_{ij} is the number of passenger trips or the mass of transported freight, between islands i and j, while δ_{ij} is the distance between i and j. M_i and M_j are the populations in case of the transported resident passengers, the number of tourists in case of non-resident passengers or, for the freight, the GDP of the involved territories. k, α y η are three parameters to be estimated and G_{ij} is a parameter that is a pseudoconstant[2] in case of resident passengers (a factor of *cultural affinity)* or freight (*trade easiness factor*), while in case of non-resident passengers it is a constant. Model (1) has been subdivided into four applications:

- (1st) non-resident passengers and (2nd) freight: panel data and a random perturbation $\varepsilon_{i,j,t}$, showed during period 2007-2017 with sample size 27 and 47 respectively.
- (3rd) resident passengers: single year estimation with sample size 71.
- (4th) vehicles: single year estimation with sample size 14.

Traffic data have been taken from Puertos del Estado (2018), Puertos Canarios (2018) and Aena (2018); GDP and populations have been taken from ISTAC (2019). To calculate the values of parameters k, α y η we have taken natural logarithms in (1) turning it into

$$\ln q_{ij} = \ln G_{ij} + \alpha \cdot \ln\left(M_i \cdot M_j\right) - \eta \ln \delta_{ij} \qquad (2)$$

To estimate a long-term potential, projections of GDP, population and tourism have been made for year 2043 and introduced in the model, keeping the same parameters, which have shown significant stability along period 2007-2017. Similar conclusions can be made for passengers. In addition, when real GDP instead of population is used as an explanatory variable of the number of trips, we do not detect significant changes compared to the results of the former analysis. Final potential passenger demand obeys to aggregation of results obtained with model (1) for both resident and non-resident population (Garín, 2006: 285-288). Table 2 and Table 3 show the estimations of the potential demands.

Results displayed on Table 2 show the existence of certain unfulfilled demands. These deficiencies are in absolute terms especially relevant in case of the connections Tenerife-Gran Canaria (+1.783.000, +69%), Gran Canaria with Lanzarote (+579.000, +78%), with a potential growth above 500.000 passenger per annum. Tenerife with La Palma (+26%, 262.000) has the lowest potential growth. Regarding the freight transport potential (Table 3), Gran Canaria-Tenerife (+695.000t; +50%) shows an important increase compared to the modest growths of Gran Canaria-Lanzarote (+62.000t, +13%) and Tenerife-La Palma (+17.000t, +9,5%).

Table 2 Current and potential demands for resident passengers and tourists

Connections		Tourists		Residents		Total	
From	**To**	**Base**	**Potential**	**Base**	**Potential**	**Base**	**Potential**
Tenerife	La Palma	106.534	325.614	885.005	928.200	991.539	1.253.814
Tenerife	Gran Canaria	328.165	738.881	2.245.098	3.618.211	2.573.263	4.357.092
Gran Canaria	Lanzarote	66.124	348.260	675.573	972.923	741.697	1.321.183

Source: own elaboration based on data by AENA (2018), Puertos del Estado (2018) and Puertos Canarios.

Regarding passenger vehicles potentials traffic Tenerife-La Palma (+47.000, +103%) show significant growth possibilities, as well as Tenerife-Gran Canaria (+140.000, +29%) and while Gran Canaria-Lanzarote should have already reached its potential affect that questions the model, a fact that can be challenged with the establishment of shorter routes, as we propose in this research.

Table 3 Current and potential demands for freight and passenger vehicles

Connections		Freight [t]		Vehicles [-]	
From	**To**	**Base**	**Potential**	**Base**	**Potential**
Tenerife	La Palma	180.353	197.422	46.123	93.512
Tenerife	Gran Canaria	1.393.778	2.089.344	492.766	633.223
Gran Canaria	Lanzarote	486.960	549.205	42.953	38.923

Source: own elaboration based on data by AENA (2018), Puertos del Estado (2007-2018) and Puertos Canarios.

4. ANALYSIS OF SURPLUSES IN INTER-ISLAND TRANSPORTATION

To evaluate if the potential demand justifies the social costs of extending the inter-island transportation network in the archipelago, in this section a cost-benefit analysis (CBA) is developed with some simplifying hypothesis. The goal is to determine if the mentioned evolution is socially profitable with a model used to evaluate the variation of surpluses of those consumers and producers that participate in the connections listed above. Should the variation of those surpluses be positive, the consumers' welfare would increase; otherwise, it would decrease. This fact implies that projects would be socially profitable when their actualized net social present values (NPVs) were positive. Considering social benefits (SB) and costs (SC) and the project's initial investment, all valued at the social opportunity cost, the social net present value of a project will be:

$$NPV_s = -I_0 + \sum_{t=1}^{T} \frac{SP_t - SC_t}{(1+i)^t} \geq 0 \quad (3)$$

Where t is the number of years, and T the life cycle of the project, which in case of air and maritime transportation, the European Commission has set to 25 years (in our case the lifespan will be 2018-2043); i is the social discount rate; I_0 is the cost of the investment to be done at the beginning, SP_t are social profits in period t, which comprehend private profits plus the changes in the welfare of both consumers and producers, as well as SC_t, the social costs in period t. Consumers' welfare lies between the so called equivalent variation and compensatory variation; its value is equivalent to the area under the Hicksian or compensated demand function. Since the error committed in assimilating the area under the Marshallian demand curve or demand-price curve is small, normally the variation of welfare among consumers is measured by the change of their net surplus. Equally, the variation of welfare of producers is measured through the change of producers' net surplus.

Market structure: in case of passenger transportation, on each route we will find between one and four operating companies, two of them will be airlines, BINTER and CANARYFLY and the other two shipping lines, FRED. OLSEN and ARMAS[3]. For the freight market, air transportation plays a reduced role, and the operating companies will be normally the two shipping lines, with a couple of exceptions. Learner's index has been calculated for each route showing that, as it could be expected, values are higher in case of the freight market due to less intense competition. In the case of the passenger market, values show that air transportation offers a higher degree of competition reflected in prices closer to marginal costs, i.e., a smaller Learner's index.

In view of this we can expect that for each route the market could be assimilated to a duopoly or oligopoly, where each operator selects prices initially based on its costs and supply a product that is homogeneous to a certain point (passenger trips or freight). From this point of view, we consider that in this research competition will be imperfect, being it in the short term closer to Cournot's competition model, and, only in the long-term, equilibrate to Bertrand's (1883), where enterprises face not only the market but also the market's demand curve. Equilibrium in a Bertrand's model for two enterprises, 1 and 2, is obtained when prices imposed by the two interdependent companies become equal simultaneously to the marginal cost[4] $p_1 = p_2 = MGC$. Hence, Bertrand's equilibrium for two companies coincides with a market with perfect competition and two companies.

Since competition can be imperfect, the series of supply points of each company will be the respective growing segment of their cost marginal function, after minimum average costs, adding a mark-up obtained from the observed average prices. The series of supplied points of the industry will be the horizontal addition (in quantities) of the individual supplies.

Supposing a Bertrand type equilibrium would have the advantage of approaching to a competitive market, where prices would tend to reflect opportunity costs, as they would coincide with marginal costs plus a known mark-up. In case of Cournot's equilibrium, enterprises compete in quantities and the equilibrium price is defined by the number of competitors *N* following the formula $p_1 = p_2 = \frac{a+MGC\cdot N}{N+1}$. Price is bigger than marginal costs *MGC* and will be only equal when the number of enterprises *N* is infinite. *a* is the ordinate at the origin of the inverse demand function. In this market structure, demand and supply curves are defined and net social profit (SP_t) can be approached to the summation of surpluses of producers and consumers: $SP_t = CS_t + PS_t$ in a market where *t* is the number of trips or the tonnes of transported freight. being *p* the unitary price of the transport fee. Prices, as well as costs of investments and maintenance, should reflect the social opportunity costs. For this, we should calculate shadow prices that reflect the value of marginal costs. To simplify the calculation of the total surplus we will suppose that supply and demand can adjust lineally.

The definition of the potential demand for passenger trips and transported freight between the islands will be done adjusting and calibrating the gravity models mentioned above. Regarding the estimation of the demand functions, we will suppose that there will be three different types of demand 1) resident consumers, 2) tourists, later added to the residents and 3) demand of freight transportation.

Demand functions of passenger transportation: it is not trivial to determine functions that are totally consistent with Microeconomics Theory and guarantee, henceforth, the

fulfilment of those properties that ensure that the demand functions is derived from a specific utility function, whereas that demand function can be easily estimated from available data. Some trials have been made with the obtention of complete demand systems like the Rotterdam model (Theil, 1965: 67-87), Translog model (Christensen et al, 1975: 367-383), or AIDS[5] model (Deaton & Muellbauer, 1980: 312-326), and other complete and incomplete demand systems. Since the idea underlying to this research is the determination of consumers' and producers' surplus, it is inconvenient for us the use the mentioned model, because its variables are in logarithms and the parameters to be estimated reflect slopes and not elasticities.
In this research we will suppose for simplicity lineal demand functions derived from a utility function with cuasilineal preferences, which implies that the value of consumer surplus will equate to both compensatory variation and equivalent variation. This means that the change in the consumer surplus is a reliable measurement of the changes in the consumer's welfare. A pioneer work related to the obtention of demand functions was performed by (Stone, 1954: 511-527) based on the use of Stone-Geary utility functions in his LES[6] model.

Passenger transportation demand is derived from maximalization of consumers' utility when they choose between three types of goods: leisure, work, and transportation, conditioned to two kinds of constraints: time and budget. Consumers work to obtain consumption goods. Under the assumption that time dedicated to leisure comes from labour agreements we can suppose that the consumer finally chooses between quantities of a compound good C and quantities of transportation q, according to a utility function that we will assume to be cuasilineal, of the type:

$$U = C - \frac{b}{2}\left(\frac{a}{b} - q\right)^2 \qquad (4)$$

Where a and b are two positive parameters. Supposing that the price of the compound good C is unitary and the price per unity of q is p, the maximisation of utility U, conditions to the budgetary constraint $m = C + pq$, where m is the nominal consumer's income, it implies that $U'_q / U'_C = p/1 = . a - bq$, and, hence, $p = a - bq$ will be the inverse demand-price function of the travel consumers. The fact of having supposed a cuasilineal utility function has the secondary consequence of eliminating the income-effect, meaning that the consumer's monetary income *(m)* is not to be found in the generalized demand function. However, m is one of the responsible variables of translating the inverse demand-price function, as m is normally not a constant. Consequently, the estimated inverse generalised passenger travel demand function will have the following shape:

$$p_t = \lambda_0 - b \cdot q_t + \lambda_1 \cdot m_t + \varepsilon_t \qquad (5)$$

where ε_t is a random perturbation and m the per capita income of the country or region where the passengers come from.

Demand function of freight transportation: this function is derived from the producers' profit maximisation, considering transport as a production factor. Supposing that companies that produce the compound good *C* are in a perfect competition environment, and their production is based on two production factors: 1) factor of production *R* with unitary price and 2) transportation q to the price *p*, according to a production function with cuasilineal isoquants of the type:

$$C = R - \frac{b}{2}\left(\frac{a}{b} - q\right)^2 \tag{6}$$

Under the assumptions that the price of *C* is unitary, and the market of production factor *R* is for simplicity also in perfect competition, and knowing that the price *p* of transportation q comes in this case by the marginal cost of Bertrand's model, the earnings of the producer of *C*, π, will be:

$$\pi = C(R, q) - wR - pq - c_f \tag{7}$$

Where c_f are fixed costs and *w* the price of factor *R*. It is supposed that the enterprise that produces the compound good *C* maximises its profit, thus $\partial\pi/\partial q = 0 = \partial C/\partial q - p$, where from (7) $\partial C/\partial q = a - bq$, and consequently: $p = a - bq$ results to be the inverse demand-price function of freight transportation. As in the former case, the generalized inverse-demand function for freight transportation to be estimated can contain explanatory variables related to local production levels, coming from the gravity model used in the prediction of the potential demand. Hence, the function to be estimated finally will have the following shape:

$$p_t = \mu_0 - bq_t + \mu_1 y_{it} + \mu_2 y_{jt} + \varepsilon_t \tag{8}$$

Where y_{it} and y_{jt} are the respective real production levels (real GDP) in period *t* in island *i* and island j, between which the trip is performed. The economical reason to introduce this variable as an explanatory variable is that changes in real production of the origin and destination islands will change in the same direction as the volume of the island external trade (imports plus exports). This will cause a variation in the demand of freight travel demand, translating the demand inverse function.

Variations of the social benefit: gains and losses of welfare. Once both inverse generalized demand and supply functions have been estimated for each track, and considering average levels for *m*, y_{it} and y_{jt}, inverse demand-price and supply-price functions, which we suppose lineal, and from where we will extract the social surplus, will take the following form, according to Perea y Barreiro (2015: 114-115):

$$\left.\begin{aligned} Supply&: \ p = e + h \cdot q \\ Demand&: p = a - b \cdot q \end{aligned}\right\} \text{from where } p = \frac{ah + b}{b + h} \ and \ q = \frac{a - e}{b + h}$$

The value of the total social surplus (*SS*) will be:

$$SS = \frac{(a-e)^2}{2(h+b)} \quad (9)$$

where a, b, e y h are the coefficients to be estimated and will determine the lineal supply and demand functions.

We will introduce three coefficients to approach the model to reality: i) a mark-up on the prices $\mu \geq 1$, which will impact the supply points line; *ii*) a subsidy coefficient applied to the ticket prices of resident travellers $0<\sigma\leq 1$, which will impact on the demand function, ($\xi=\mu\sigma$ combines both to simplify some expressions later); and iii) ω will note the quotient passenger cars to passengers, allowing us to include cars in the model with an extra-fee to the passengers' tickets. After these modifications the equilibrium will take the following shape:

$$q = \frac{a-\xi e}{\xi\omega h + b} \quad (10)$$

$$\sigma p = \mu\left(g + \omega h \frac{a-\xi e}{\xi\omega h + b}\right) \quad (11)$$

The net social surplus (SS) is the addition of the producer surplus (PS) and the consumer surplus (CS). According to Coto e Inglada (2003), De Rus et al. (2003), EU (2006: 96-98) and De Rus (2009: 187-210), we have assumed that i) prices p take the values of the marginal costs plus a mark-up μ ii) there are not any secondary markets iii) we assume that the social discount rate is the one calculated by Florio y Maffi (2008: 84-86) for the evaluation of projects in the European Union between 2008 and 2030, which in the case of Spain would be $i=0{,}06$. This implies that the total social surplus given by equation (9) is expressed from now on like:

$$SS = \frac{a-\xi e}{\xi h + b}\left\{\frac{a-\xi e}{\xi h + b}\left[\frac{b}{2} + h\left(\mu - \frac{1}{2}\right)\right] + e(\mu - 1)\right\} \quad (12)$$

The value of the producer surplus (PS) will be:

$$PS = pq - eq - \frac{1}{2}hq^2 = \frac{a-\xi e}{\xi h + b}\left[e(\mu-1) + h\frac{a-\xi e}{\xi h + b}(\mu - \frac{1}{2})\right] \quad (13)$$

And the consumer surplus (CS):

$$CS = \frac{1}{2}(a - \mu p)q = \frac{(a-\xi e)^2 b}{2(\xi h + b)^2} \quad (14)$$

The forecasts of the demand, calculated with the gravity model shown above, make the base scenario surpluses increase or decrease, as the slope (b) of the inverse demand function changes. A growth in the number of consumers of travellers for a specific route, being the final demand the horizontal addition of the individual demands, which we assume to be identical, will imply that an increase in travels will cause a more horizontal aggregate inverse demand function. We assume that the inverse demand-price function is the one of N_0 agents from the base: $p = a - bq$. If in period t the number of consumers has grown to N_t, being $N_t > N_0$, and we suppose that individual demands are identical, then the inverse demand function will have become to be more horizontal in period t and its expression will be $p = a - b(N_0/N_t)q$. The variation of the slope b is $b(N_0/N_t) - b$ and the variation of b will be, hence, $\Delta b = (N_0/N_t) - 1$. If $N_t < N_0$ the behaviour will be the opposite. The demand will also translate parallel with a change in coefficient a due to an increase or decrease of the nominal available income of the potential passengers, and regarding freight transportation, according to trade flows related to the production levels of countries and regions. Another aspect to be considered are forecasts of costs, which influence the market supply, making both consumer and producers surpluses to grow or shrink. In our model this would change the ordinate at the origin e of the inverse supply-price function in the base scenario with increases or decreases of energy prices, normally fossil, or the total bulk of production factors used, fundamentally work, or by eventual savings or dissavings in costs due to changes in the size of the fleets.

Moreover, we must add to the surpluses of the base scenario the monetization according to the shadow price of their variations suffered by diverse externalities, many of them do not have a market but impact in form of changes in the coefficients of the inverse demand function (a) and the inverse supply function (e). The demand is influenced by a reduction or growth of travel times of passengers and goods, by reduction or increase of glasshouse gas emissions[7], acoustic pollution and congestion. The supply function is affected by changes in the costs caused by possible accidents. Thus, variations of externalities ΔX will modify parameters a and e, and these the total surplus (ΔSS). Deriving partially a and e respect X and through (12), we will be able to know the changes of a and e with the changes of SS due to variations in Externalities (ΔX).

$$\frac{\partial a}{\partial X} = \frac{\partial a}{\partial SS}\frac{\partial SS}{\partial X} = \frac{\xi h + b}{e(\mu - 1) + \frac{a - \xi e}{\xi h + b}\left[2h\left(\mu - \frac{1}{2}\right) + b\right]}\frac{\partial SS}{\partial X} \tag{15}$$

$$\frac{\partial e}{\partial X} = \frac{\partial e}{\partial SS}\frac{\partial SS}{\partial X} = \frac{\xi h + b}{(a - \xi e)\left[\frac{a - 2\xi e}{a - \xi e}(\mu - 1) - \frac{\xi[h(2\mu - \omega) + b]}{\xi h + b}\right]}\frac{\partial SS}{\partial X} \tag{16}$$

Considering the variation of the surpluses, if the supply and change functions are lineal, the net present values (*NPV*) given by equation (3) can be expressed as:

$$NPV = -I_0 + \sum_{t=1}^{T} \frac{\Delta(PS_t) + \Delta(CS_t)}{(1+i)^t} \geq 0 \tag{17}$$

Whose value must be positive to be socially profitable and hence to accept the project. Another additional criterion to verify the feasibility of the project is the calculation of the internal return rate (*IRR*) of the project. The *IRR* is the discount rate *i* resulting of equating (3) or (16) to cero. The criteria to accept the project are i) *NPVs>0*, together with ii) *IRR>i*. In case of contradiction criterion i) should prevail.

Variation of the consumer and producer surpluses: deriving from Table 4 and Table 5, we can calculate the variations of the producer and consumer surpluses, according to changes in *a*, *b*, *e* and *h*, due to the presence of externalities, as well as changes in the demand of travels, by only deriving partially the surpluses of consumer and producer respect these parameters. Results are displayed in Table 4 and Table 5.

Table 4 Variation of the producer surplus with changes in a, b, e and h

Variation in	Variation in the producer surplus ΔPS (including externalities)
a	$\left[\frac{e(\mu-\omega)}{\xi\omega h+b}+2\omega h\frac{a-\xi e}{(\xi\omega h+b)^2}\left(\mu-\frac{\omega}{2}\right)\right]\Delta a$
b	$\frac{(a-\xi e)}{(\xi\omega h+b)^2}\left[2\omega h\frac{a-\xi e}{\xi\omega h+b}(\mu-\frac{\omega}{2})-e(\mu-\omega)\right]\Delta b$
e	$\frac{a-\xi e}{\xi\omega h+b}\left[(\mu-\omega)\left(1-\frac{\xi e}{a-\xi e}\right)-\frac{2\xi\omega h}{\xi\omega h+b}(\mu-\frac{\omega}{2})\right]\Delta g$
h	$\frac{\omega(\mu-\frac{\omega}{2})(b-\xi\omega h)(a-\xi e)^2}{(\xi\omega h+b)^3}\Delta h$

Source: own elaboration.

Table 5 Variation of the consumer surplus with changes in *a*, *b, e* and *h*

Variation in	Variation in the consumer surplus $\boldsymbol{\Delta CS}$ (including externalities)
a	$\left\{e(\mu-1)\frac{1}{\xi h+b}+2h\frac{a-ke}{(\xi h+b)^2}(\mu-\frac{1}{2})\right\}\Delta a$
b	$\frac{-(a-\xi e)}{(\xi h+b)^2}\left\{e(\mu-1)+2h\frac{a-ke}{\xi h+b}(\mu-\frac{1}{2})\right\}\Delta b$
e	$\frac{a-\xi e}{\xi h+b}\left[(\mu-1)\left(1-\frac{\xi e}{a-\xi e}\right)-\frac{2\xi h}{\xi h+b}(\mu-\frac{1}{2})\right]\Delta e$
h	$\frac{(a-ke)}{(kh+b)^2}\left[h\left(\mu-\frac{1}{2}\right)(a-\xi e)\frac{b-\xi h}{\xi h+b}-\xi e(\mu-1)\right]\Delta h$

Source: own elaboration.

The abscise in the origin *e* and the slope *h* of the supply function are obtained by linearization of the horizontal addition of the cost curves of the enterprises ARMAS, FRED. OLSEN, ROMERO, BINTER and CANARYFLY, depending on their presence in each market, since we have supposed that they work in a Cournot oligopoly on each route. These curves of marginal costs are obtained from the variable cost data for every enterprise for each route where each enterprise is operating. Variable costs data are obtained from the expenses in fuel, salaries and fees depending on the load during period 2007-2018 Infrastructure fees and remaining official data come from databases of AENA (2004-2018), y Puertos del Estado (2007-2018). The estimation of the inverse demand functions (5) and (8) have been done for each route and transportation mode for period 2007-2018 through maximum likelihood method, which allows to directly obtain the slope *b* of the inverse demand function for each route and mode.

The ordinate in the origin, a, corresponds to the inverse passenger travel demand function, obtained by estimation of equation (5): $a = \hat{\lambda}_0 + \hat{\lambda}_1 \bar{m}$, where $\hat{\lambda}_0$ and $\hat{\lambda}_1$ are the two estimators of $\hat{\lambda}_0$ and $\hat{\lambda}_1$ respectively, being $\bar{m}$ the average income per capita in countries or regions of residence of those passengers travelling on each route in year 2018. In case of the ordinate in the origin, a, corresponding to the initial inverse demand function of freight travels, obtained through estimation of equation (8) $a = \hat{\mu}_0 + \hat{\mu}_1 y_i + \hat{\mu}_2 y_j$, where $\hat{\mu}_0$, $\hat{\mu}_1$y $\hat{\mu}_2$ are the estimators of μ_0, μ_1 y μ_2 respectively, being y_i e y_j the real income (real GDP) of the origin and destination islands, taking 2018 as the initial year.

5. SOCIAL BENEFITS IN INTER-ISLAND TRANSPORTATION

Results of the previous analysis are displayed hereafter. Table 6 shows the estimated coefficients e, h, a and b of the inverse supply and demand functions of passenger and freight transportation for each route and mode, which are necessary for the calculation of the consumer' and enterprises' surpluses.

Table 6 Estimated coefficients of the supply and demand functions.

Route	Passengers				Freight	
	Air		Maritime		Maritime	
	a	*b*	*a*	*b*	*a*	*b*
Tenerife-La Palma	93	-0,00012	58	-0,00015	75	-0,00012
Tenerife-Gran Canaria	43	-0,00003	43	-0,00002	53	-0,00002
Gran Canaria-Lanzarote	60	-0,00006	54	-0,00044	125	-0,00024

Source: own elaboration.

In Table 6 it can be observed that for air transportation the slope b of the demand function is more elastic on two of the three cases; freight transportation has a less elastic demand than passenger transportation. Based on the coefficients shown in Table 6, considering the equations of Table 4 and Table 5, we calculate the consumers' and producers' surpluses as well as their variations. Results are displayed in Table 7 to Table 9.

Table 7 Present values of surpluses CS and PS with their variations ΔCS and ΔPS

2018-2043 Data in € 2018	Passengers (Air Transportation)			
	Base Scenario		Potential Scenario	
	CS	PS	ΔCS	ΔPS
Tenerife-La Palma	18.637.377	3.551.801	260.217.159.457	616.966.090.297
Tenerife-Gran Canaria	19.689.114	**-14.961.518**	1.442.408.714.251	2.714.044.428.752
Gran Canaria-Lanzarote	19.186.808	**-9.862.763**	672.419.524.630	1.304.739.061.075

Own source. CS = Consumer Surplus; PS = Producer Surplus.

Some comments about externalities must be done since their impact can be of the same order of magnitude than the internal effects. Thus, when incorporated to the surpluses, they change the sign of the surpluses, turning a positive surplus into a negative quantity.

Among the externalities considered, costs are predominant, which imply reductions in welfare not included in the price: accidents, atmospheric pollution, acoustic pollution, up- and downstream effects, landscape effects, land occupation, public sector subsidies and cross subsidies. Positive externalities are limited to the profits obtained by the infrastructure operators. We neglect the possible beneficial effects of induced trade and touristic activities since they lie beyond the aims of this work. Some of them might be already internalized in the demand function to a certain degree.

Some effects are carried by the consumer and their monetized values are added to the consumer surplus, like those caused by the access to ports and airports, or direct subsidizing received from the public sector. Most of the polluting effects caused during the main trip are assigned to the producer and thus are added to the producer surplus.

In case of passenger air transportation, Table 7 shows that in the base scenario most of air routes have positive social surpluses ($SS = CS + PS$), while PS tends to have lower values than CS. This can be explained by the high degree of direct subsidies for resident passengers, who represent about 95% of the market. The evolution to the potential scenario is almost everywhere positive since the effect of externalities is significantly more positive in the future. In addition, the rise of both population and the income per capita with constant relative costs displace the inverse-demand function to the right and thus, shrinking the effort to buy a ticket.

Differences between Tenerife-Gran Canaria and Tenerife-La Palma can be attributed to the more intense competition of the maritime mode in the former connection than in the latter. This can result in a lower occupation factor and thus, lower operational efficiency and higher average prices compared to Tenerife-La Palma, where the maritime connection is less attractive for many passengers.

Table 8 Present values of surpluses CS and PS with their variations ΔCS and ΔPS

2018-2043 Data in € 2018	Passengers (Maritime Transportation)			
	Base Scenario		Potential Scenario	
	CS	PS	ΔCS	ΔPS
Tenerife-La Palma	**-10.743.469**	**-1.588.303**	41.099.912.544	117.403.361.714
Tenerife-Gran Canaria	6.489.490	**-24.366.054**	1.346.487.359.826	3.806.478.499.547
Gran Canaria-Lanzarote	**-3.134.212**	**-3.821.689**	6.515.862.856	14.125.917.159

Own source. CS = Consumer Surplus; PS = Producer Surplus.

Table 8 and Table 9 show the allocation of surpluses of routes between passenger and freight maritime transportation. In the present scenario, surpluses of maritime passenger transportation are negative. This is explained by the high impact of negative externalities (mainly air pollution) and a certain overcapacity in the network. Upcoming innovation towards a cleaner maritime transportation will improve the balance.

We see in Table 9, that freight transportation has in present time more negative social surpluses than positive, except for the most passenger-dense route. However, values tend to be better than in Table 8. The worse values of the consumer surpluses are mainly due to negative externalities. Density and high load factors improve the efficiency of a trip and hence the surpluses. Evolution towards the potential scenario improves the impact of transportation in the same way as for the other two markets.

Table 9 Present values of surpluses CS and PS with their variations ΔCS and ΔPS

2018-2043 Data in € 2018	Freight (Maritime Transportation)			
	Base Scenario		Potential Scenario	
	CS	PS	ΔCS	ΔPS
Tenerife-La Palma	**-18.032.572**	4.805.224	5.455.730.146	13.768.550.491
Tenerife-Gran Canaria	4.007.801	11.635.364	143.888.144.349	524.584.963.193
Gran Canaria-Lanzarote	**-25.952.451**	19.078.631	11.883.418.893	68.536.212.218

Own source. CS = Consumer Surplus; PS = Producer Surplus.

Adaptation of current infrastructure to the larger potential markets requires certain investments. To determine their feasibility on those connections that show social benefits in their evolution towards their long-term potential, formulas (3) or (17) are applied, displaying the results on Table 10 and Table 11.

Table 10 Feasibility considering initial investment (I_0) – Air transportation

2018-2043	I_0	NPV	IRR	Feasibility
Tenerife-La Palma	73.634.226	4.517.649.201.904	47745%	Yes
Tenerife-Gran Canaria	47.062.886	2.140.634.862.664	35421%	Yes
Gran Canaria-Lanzarote	51.852.652	10.182.831.251.640	152615%	Yes

Own source. I_0 = initial investment, NPV = net present value, IRR = internal return rate

In the second column of Table 10 we display the required investments to adapt the existing infrastructure to the long-term potential traffic volumes. In the next columns the net present value and the internal return rate are displayed. For the air transportation we see that growth combined with the expected innovation on several areas is desirable and investment will pay off. Similar results are to be found on Table 11 for maritime transportation, where some of invested amounts to improve part of the existing deficiencies are also large but will be recovered in the long term.

Table 11 Feasibility considering investment (I_0)–maritime transportation

2018-2043	I_0	NPV	IRR	Feasibility
Tenerife-La Palma	16.800.000	1.731.659.785.826	80149%	Yes
Tenerife-Gran Canaria	50.820.000	5.652.054.291.508	86473%	Yes
Gran Canaria-Lanzarote	20.000.000	626.783.220.425	24434%	Yes

Own source. I_0 = initial investment, NPV = net present value, IRR = internal return rate

The last step of this analysis compares two alternatives of the potential scenario: the baseline, which has been displayed above, with the proposed improved network consisting of additional links as displayed in Figure 5, Figure 6 and Figure 7.

6. EARNINGS IN INTER ISLAND TRANSPORTATION

The next step in this analysis is the evaluation of the profitability from the perspective of the transport companies. First, we will calculate operational profits in both present and potential scenario. To keep simplicity, we will differentiate by route and transport mode but not by enterprise; nor will we distinguish between freight and passenger traffic when both segments share vehicle. For a route between *i* and *j*, profits π are calculated as the subtraction of income *IN* minus total costs *C*:

$$\pi_{ij} = IN_{ij} - C_{ij} \tag{18}$$

The cost function of the market is known and is defined as the summation of the fixed costs plus the variable costs, calculated by integration of the marginal costs *MGC*.

$$C_{ij} = FC_{ij} + \int MGC_{ij}\, dq_{ij} = FC_{ij} + e \cdot q_{ij} + h \cdot \frac{{q_{ij}}^2}{2} \tag{19}$$

Fixed costs are distributed among routes depending on the number of transported units. To change from one scenario to the other we assume that a portion of the fixed costs is non variable, a 34%[8], while the rest will be long-term variable costs and will increase proportionately to the transported units.

$$FC_{2043} = w \cdot FC_{2018} + (1 - w) \cdot FC_{2018} \cdot \Delta q \tag{20}$$

The income is also known, as the product of the average price and the transported quantities, including the subsidies *SD* received by the transport companies.

$$IN_{ij} = \sum p_{ij} \cdot q_{ij} + SD_{ij} \tag{21}$$

Once we know the profit flows at the beginning and final periods of the time interval, we assume a lineal evolution of these quantities between both points. Hence, known initial investments that producers must undergo, the nominal interest rate and the cost of financing, the $NPV_{fin,ij}$ for each route between *i* and *j*, which must be positive, is calculated according to:

$$VAN_{fin,ij} = -I_{0,ij} + \sum_{t=1}^{25} \frac{\Delta\pi_{ij}}{(1 + i_{ij})^t} \geq 0 \tag{22}$$

The value of the interest rate is taken from Banco de España (2021), equal to 4,3%, assuming that the operating companies are Spanish. An additional criterion will be that the investment can be recovered with the profits generated in ten years or less. Hence, the payback *PB,* considering the flow of profits actualized with the nominal interest rate I and time t expressed in years, is calculated like this:

$$PB_{ij} = \frac{-I_{0,ij}}{N / \int_0^N \frac{\Delta\pi_{ij}(t)}{(1 + i)^t} dt} < 10 \tag{23}$$

N is the number of years to recover the initial investment. The payback must have a value lower than ten. If both criteria are fulfilled and the *IRR* is bigger than the nominal interest rate, producers should accomplish the project.

7. EVALUATION OF THE ALTERNATIVES PROPOSED

As mentioned, we propose an alternative long-term potential scenario with new links for three pairs of islands, that needs a redistribution of the payload between existing and new links. We have not considered that the new alternative may induce additional demand since we have already adapted the supply to the potential demand. The new distribution between modes has been done considering the location of resident population and tourists and logistics centre. Table 12 displays the redistributions for each pair of islands.

Table 12 Payload according to routes configuration and scenario (Tenerife-Gran Canaria)

Pair of islands	Mode	Type of payload	Scenario 2018		Potential scenario 2043	
			Current	With new	Current	New
Tenerife Gran Canaria	Air	Passengers [-]	841.609	817.150	2.179.308	1.743.446
	Mar.	Passengers [-]	1.423.741	1.448.741	2.177.784	2.334.821
		Vehicles [-]	492.766	502.766	633.223	762.545
		Freight [t]	1.393.778	1.393.778	2.089.344	2.193.811
Tenerife La Palma	Air	Passengers [-]	609.838	574.195	731.143	687.814
	Mar.	Passengers [-]	231.773	399.307	522.671	566.000
		Vehicles [-]	92.247	121.080	179.575	206.000
		Freight [t]	300.588	300.588	329.037	329.037
Gran Canaria Lanzarote	Air	Passengers [-]	654.403	489.990	105.999	482.384
	Mar.	Passengers [-]	99.427	263.841	858.769	482.384
		Vehicles [-]	42.953	103.427	38.923	152.597
		Freight [t]	486.960	486.990	549.205	549.205

Source: own elaboration

Results on Table 13 show that for Tenerife-Gran Canaria, welfare will increase with relatively small financial losses. In this case the establishment of a new route would be desirable from a social point of view but would require additional financial support by the public sector to make it attractive to the producers. Alternatively, these should undergo an extraordinary cost-cutting programme to enhance their efficiency, which could be as simple as a reduction of frequencies.

Table 13 Comparison of surpluses and profits (Tenerife-Gran Canaria)

Scenario	Mode	ΔSS	Earnings 2043
Current Routes	Air	4.156.453.143.003	90.632.417
	Maritime	5.821.438.966.915	48.635.572
	Total	**9.977.892.109.918**	**139.267.989**
With new Routes	Air	7.578.674.044.635	74.381.226
	Maritime	9.389.058.678.877	56.946.171
	Total	**16.967.732.723.512**	**131.327.397**
Difference		**6.989.840.613.594**	**-7.940.592**

Source: own elaboration

Connections between Tenerife and La Palma (Table 14) show qualitatively similar results as in the previous case, although the increase of social surplus is smaller and the operational loss bigger. This can be explained by the smaller weight of the maritime links, which is especially notorious in the freight segment. Lesser quantities often translate to lower occupation factors and thus lesser efficiency. Recommendations for the policymakers would be the same as for Tenerife-Gran Canaria.

Table 14 Comparison of surpluses and profits (Tenerife-Gran Canaria)

Scenario	Mode	ΔSS	Earnings 2043
Current Routes	Air	877.183.249.754	90.632.417
	Maritime	177.727.611.583	44.221.799
	Total	**1.054.910.861.337**	**134.854.216**
With new Routes	Air	916.986.743.120	11.646.479
	Maritime	352.781.466.837	55.400.619
	Total	**1.269.768.209.957**	**67.047.098**
Difference		**214.857.348.620**	**-67.807.119**

Source: own elaboration

In Table 15 results for the last pair of islands (Gran Canaria-Lanzarote) are displayed. We find that the new configuration implies a lower social surplus, though still positive, compared to the current scenario. It would also imply operational losses. These numbers suppose a challenge to the undergoing expansion project at the port of Playa Blanca and the plans to introduce the new fast-ferry connection. Some comments can be made to explain this contradiction: We assume that the ferry route between Las Palmas and Arrecife would still be operating, although with lesser frequencies. A possibility would be to finish this route to reduce the risk of overcapacity and increase efficacy. This would raise both social surplus and operational profits.

Table 15 Comparison of surpluses and profits (Gran Canaria-Lanzarote)

Scenario	Mode	ΔSS	Earnings 2043
Current Routes	Air	1.977.158.585.706	38.604.358
	Maritime	101.061.541.770	-4.652.959
	Total	**2.078.220.127.475**	**33.951.399**
With new Routes	Air	1.089.287.866.966	31.772.978
	Maritime	178.759.841.877	-42.018.537
	Total	**1.268.047.708.843**	**-10.245.560**
Difference		**-810.172.418.632**	**-44.196.959**

Source: own elaboration

8. CONCLUSIONS

In this research we analyse the possibility of improving connections between three pairs of Canarian islands in a long-term scenario, mainly through new maritime links. Performance indicators are the social surplus and the earnings of the producers. We have estimated the potential demand of passenger and freight transportation between the affected islands. We analyse the social feasibility of an adjustment of the supply to the long term the demand, which is assumed to be stable, within a period of 25 years. Potential demand has been estimated with a gravity model. The social feasibility study of the adjustment between present supply and potential demand has been performed through a cost-benefit analysis where the variation of consumer and producer’s surplus has been evaluated. The financial analysis on the producers’ side is done through estimation of the earnings for the existing routes and the new ones within a long-term scenario.

Results obtained show that an expansion of the transportation between the analysed pairs of islands can be socially profitable in all cases since *NPVs* are positive. Additionally, the new routes would mean an improvement of welfare in two of three cases. Earnings would shrink with the new configuration of routes. Evaluation and analysis of these results could be useful in decision-making on inter-island transportation in the Canary Islands.

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10. REFERENCES

[1] This link has been introduced recently again after and intermittent existence. We consider it "new" since it was not operated in the time of preparation of this paper.

[2] The pseudoconstant acquires different values depending of the regions involved in the trading. When applied to Canary Islands the value of G_{ij} constant, as all points belong to the same region.

[3] Between Lanzarote and Fuerteventura there is a third company, ROMERO, with-only-passenger ships.

[4] In transportation, optimal management of the generalized cost should tend to the social marginal cost, and in absence of congestion Price should equate to the social marginal cost of vehicle and its infrastructure.

[5] Almost Ideal Demand System

[6] Linear Expenditure System

[7] According to ICAO (2016), an airplane flying Tenerife-Gran Canaria the airplane emits 6 kg CO2 per passenger; a ship would generate around 15 kg (subject to a certain freight-passenger distribution). The CO2 to burned kerosene/oil ratio is approximately 3.2.

[8] This magnitude has been calculated with the cost function. The part of the fixed costs that is less likely to change in the long term.