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Optimization of the inter-island maritime transport in the Canary Islands in terms of social benefit and profitability

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ABSTRACT

The objective of the paper is to analyse the feasibility of possible improvements of the existing maritime network served by Ro-Pax ships in the Canary Islands. Net social benefits and financial results of the operating companies are used as performance indicators, as well as a generalized travel cost. These magnitudes are projected onto a long-term potential scenario 25 years ahead. The net social profit is calculated with consumer and producer surplus, what requires a modelling of both demand and supply for all these markets. The potential demand for the future scenario is estimated using a series of gravity models for both tourists and local passengers, passenger vehicles and freight transported in Ro-Pax ships. Financial profits of producers are calculated by estimating pricing and cost structure of the industry, whereas the generalized travel cost is calculated with ticket prices and monetized door-to-door travel time. Alternatives to routes connecting Tenerife, Gran Canaria, La Palma and Lanzarote are analysed. Results show a combination of positive or negative net social surpluses or financial results of the companies.

1. Introduction.

The aim of this paper is to analyse the feasibility of possible improvements in the existing maritime network within the Canarian archipelago, considering both passenger and freight transportation. The Canarian archipelago is composed of eight islands, and it is located about 1.000 km of Europe and 100 km west of Africa and belongs to Spain. It has a surface of 7.447 km2 and 2,17 million inhabitants. The main economic activity is tourism, reaching in 2019 around one third of the regional GDP. The two central islands, Tenerife and Gran Canaria contain more than 80% of the population. In the past decades this double leadership is being corrected with a faster growth of Lanzarote and Fuerteventura. La Palma, La Gomera and El Hierro have been losing population for decades as mass tourism has not been developed. We will concentrate in the optimization of the connections Tenerife-Gran Canaria, Tenerife-La Palma and Gran Canaria-Lanzarote. The Canarian archipelago has a high-density network connecting 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 *jet-foil* passenger ship led to a switch of the dominant mode to the maritime in some connections, especially between both regional capitals. Further improvements like fast-ferries or new routes between closer ports have strengthened the tendency. However, both modes have achieved significant growth in absolute numbers. Several reasons explain this expansive behaviour: first, the rise of tourism turning the islands into one of the leading destinations in Europe. Second, the public sector has increasingly supported the development of a high-performance network in sev-

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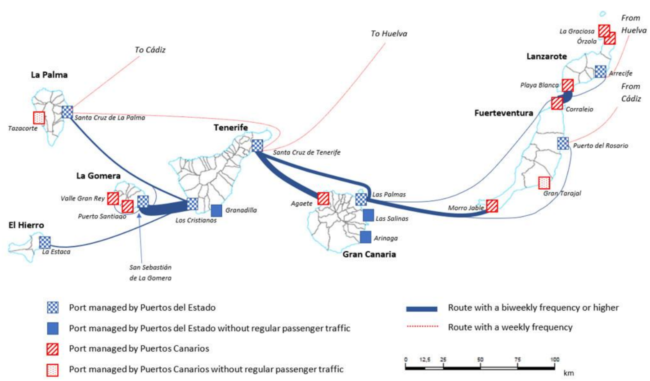
eral ways: building and enlarging infrastructures until present day, as well as subsidized the costs of passenger tickets and freight costs. There is at least an airport on each island but in la Graciosa, all managed by the partially state-owned company *Aena*. The main ports of the archipelago, those handling different kinds of freight and passengers depend on the state company *Puertos del Estado*. Smaller domestic-oriented ports manipulating only passengers and rolled freight depend on the regional government through the company *Puertos Canarios*. Figure 1 displays an overview of the port system and the existing direct passenger connections.

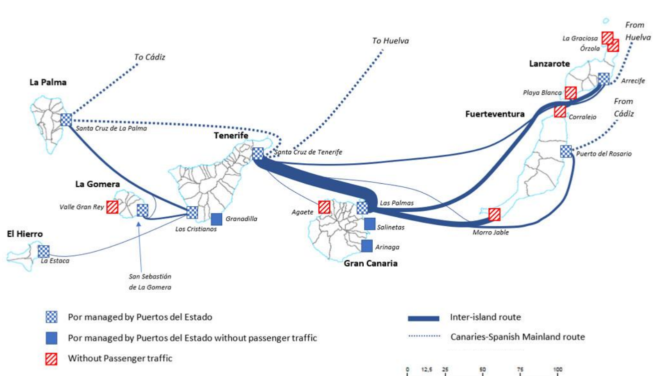
Figure 1: Canarian maritime inter-island passenger transportation network (2018).



Source: Authors.

Figure 2 shows the structure of the sea freight network, reflecting the demography of the archipelago. The port of Las Palmas is a relevant port at freight port at Spanish and international level, while the port of Santa Cruz, 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 for their supply.

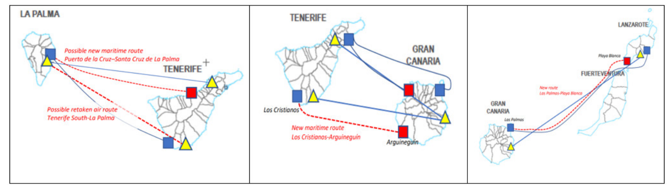
Figure 2: Canarian maritime rolled freight transportation (2018).



Source: Authors.

A direct maritime link between a port in the south of Tenerife and the southwest of Gran Canaria would avoid travellers driving to the opposed sides of the islands to take a ferry (Figure 3). In the case of Tenerife and La Palma we propose to restructure connections .

Figure 3: Existing and proposed links.



Source: Authors. Note: Proposed links in dashed red lines.

by: i) Recovering an air link between Tenerife-South Airport and La Palma. ii) A new maritime connection from a port in the north of the island (Puerto de la Cruz or Garachico) should be established. iii) Keeping a part of the frequencies of the existing lines. In the case of Gran Canaria and Lanzarote this research proposes the planned link between Playa Blanca and Las Palmas, while maintaining the ferry connection between the capitals.

There is a significant amount of literature analysing transportation within archipelagos, some of them have been taken as references to perform this research. In this Canarian environment the descriptive works of Hernández Luis (2006) should be mentioned. Hernández Luis (2002) makes specific proposals on schedules to improve connectivity and Hernández Luis (2018) introduces multimodal connectivity in his analysis, Ramos (2015) analyses the effects of competition on pricing. Our work takes also references from European intermodal transportation, like Gollnick, (2004), focused on land and air connectivity. Regarding the maritime mode works of Tsekeris (2009) and Tzannatos (2005) for Greece or Rutz et al. (1996) for Indonesia should be mentioned. Quantitative approaches like Garín (2006) or Gundelfinger-Casar et al (2018) estimate air transportation demand among Canary Islands. Gravity models are used in this research to estimate potential demand, being inspired in Batra (2004), Grosche et al. (2007) and Ortúzar et al. (2008). The quantification of externalities related with the emission of gases is supported by Eyring et al. (2010), Lee et al., (2010) and Uhereck et al. (2010). Monetization of these externalities is based on Umweltbundesamt (2014). Travel time savings are quantified based on Gwilliam (1997) and García-Álvarez (2016). The impact of accidentality is performed based on Albert et al., (1995) and Miller (2000). The structure of this article is as follows: Section 2 contains the development of the methods that are applied in section 3, which contains the main results. And the last section contains the main conclusions.

2. Methods.

Supply and demand functions have been 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 to 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. Growth factor models or entropy maximisation models are also ruled out. 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 Batra (2004), Grosche et al. (2007) and Ortúzar et al. (2008). Both passenger and freight data have been obtained from Aena (2020), Puertos del Estado, (2018) and Puertos Canarios (2018).

Table 1: Transported volumes (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*(176**)	210	857.702	146.134

Source: Authors elaboration based on Aena (2020), Puertos del Estado (2019). *Las Palmas - Arrecife. **Las Palmas - Playa-Blanca.

The basic gravity model has the following structure.

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

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 and η are three parameters to be estimated and G_{ij} is a parameter that is a pseudoconstant 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. The pseudoconstant acquires different values depending on 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. Model (1) has been subdivided into four applications: (1^{st}) Non-resident passengers and (2^{nd}) Freight: panel data and a random perturbation $\varepsilon_{i,j,t}$, showed during period 2007-2017 with sample size 27 and 47 respectively. (3^{rd}) Resident passengers: single year estimation with sample size 71. (4^{th}) Vehicles: single year estimation with sample size 14. Traffic data have been taken from Puertos del Estado (2019), Puertos Canarios (2019) and Aena (2020), GDP and populations have been taken from ISTAC (2019). To calculate the values of parameters k, α and η we have taken natural logarithms in (1) turning it into

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

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). Tables 2 and 3 show the estimations of the potential demands.

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: Authors elaboration based on Aena (2020), Puertos del Estado (2019), Puertos Canarios (2019).

Results displayed on Table 2 show the existence of certain unfulfilled demands. Regarding the freight transport potential (Table 2), Gran Canaria-Tenerife shows an important potential. Concerning passenger vehicles, Tenerife-La Palma shows significant growth possibilities, as well as Tenerife-Gran Canaria.

Table 3: Base scenario 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: Authors elaboration based on Puertos del Estado (2019), Puertos Canarios (2019).

To evaluate if the potential demand justifies the social costs of extending the inter-island transportation network in the archipelago, a cost-benefit analysis (CBA) has been developed, based on the variation of surpluses of consumers and producers. Should the variation of 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. The social net present value of a project will be:

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

Where the life cycle of the project T is set to 25 years; i is the social discount rate; I_0 is the cost of the initial investment, 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. Consumer 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 are measured by the change of their net surplus. Equally, the variation of welfare of producers is measured through the change of producer net surplus.

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. Between Lanzarote and Fuerteventura there is a third company, ROMERO, with-only-passenger ships. For the freight market the operating companies will be normally the two shipping lines. We expect, hence, that for each route the market could be assimilated to a duopoly 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). We consider that in this research competition will be imperfect, being it in the short term closer to Cournot (1838) competition model, and, only in the long-term, equilibrate to Bertrand (1883), where enterprises face the market's demand curve. Since competition is imperfect, the series of supply points of each company will be the respective growing segment of their cost marginal function, after minimum average variable 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. 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 $p_1 = p_2 = (a + MGC \cdot N)/(n+1)$. 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. 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 demands: 1) resident consumers, 2) tourists and 3) demand of freight transportation. In this research we will suppose for simplicity linear demand functions derived from a utility function with quasilinear 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. 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. Under the assumption that time dedicated to leisure comes from labour agreements we can suppose that the consumer finally chooses between quantities of a composite good C and quantities of transportation q, according to a utility function that we will assume to be quasi-linear:

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

Where a and b are two positive parameters. Supposing that the price of the composite 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 quasi-linear 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 variables responsible for the shift in the inverse demand-price function, so we assume that $a = a\ (m)$. Consequently, the estimated inverse generalised passenger travel demand function will have the following shape:

$$p_t = \lambda_0 - b \cdot q_t + \lambda_1 \cdot m_t + \varepsilon_t \tag{5}$$

where ε_t is a random perturbation and m the per capita income of the country or region where the passengers come from. The demand function of freight transportation is derived from the producers' profit maximisation, considering transport as a production factor. Supposing that companies that produce the composite good C are in a perfect competition, and their production are 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 quasi-linear isoquants:

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

Under the assumptions that the price of C is unitary, and the market of production factor R is for simplicity also in perfect competition, the earnings (π) of the producer of C, are:

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

Where c_f are fixed costs and w the price of factor R. It is supposed that the enterprise that produces the composite 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 estimate 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 estimate 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. 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 linear, and from where we will extract the social surplus, will take the following form, according to Perea et al. (2015):

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

and

$$q = \frac{a - e}{b + h}$$

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

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

where a, b, e and h are the coefficients to be estimated and will determine the liner supply and demand functions. We will introduce now 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:

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

According to De Rus et al. (2003), Inglada et al. (2004), EU (2006) and De Rus (2009), we have assumed that i) prices p take the values of the marginal costs plus a mark-up μ; ii) We assume that the social discount rate is the one calculated by Florio et al. (2008) 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 equation (9) can be expressed as:

$$SS = \frac{a-\xi e}{\xi h+b}\left\{\frac{a-\xi e}{\xi h+b}\left[\frac{b}{2}+h\left(\mu-\frac{1}{2}\right)\right]+e(\mu-1)\right\} \tag{11}$$

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

$$PS = pq-eq-\frac{1}{2}hq^2=\frac{a-\xi e}{\xi h+b}\left[e(\mu-1)+h\frac{a-\xi e}{\xi h+b}(\mu-\frac{1}{2})\right] \tag{12}$$

And the consumer surplus (CS):

$$CS = \frac{1}{2}(a-\mu p)\, q = \frac{(a-\xi e)^2 b}{2(\xi h+b)^2} \tag{13}$$

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. The demand is influenced by a reduction or growth of travel times of passengers and goods, by reduction or increase of glasshouse gas emissions, acoustic pollution and congestion. 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. The supply function also is affected by changes in the costs caused by possible accidents. Thus, variations of externalities (X) will modify parameters a and e, and these the total surplus SS. Deriving partially a and e respect X and through (11), we will be able to know the changes of a and e with the changes of SS due to variations in Externalities (X). Considering the variation of the surpluses, if the supply functions are linear, the net present values (NPV) given by equation (3) can be expressed as:

$$NPV = -I_0 + \sum_{t=1}^{T} \frac{\Delta(PS_t) + \Delta(CS_t)}{(1+i)^t} \geq 0 \tag{14}$$

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 firm for each route, where each firm 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 (2020), and Puertos del Estado (2019). 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.

3. Application and Results.

Results of the previous analysis are displayed hereafter. Tables 4 and 5 show 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 firms' surpluses. In Table 4 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.

Table 4: Parameters of 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: Authors.

Based on the coefficients shown in Tables 4 and 5, considering the equations (12) y (13), we calculate the consumers' and producers' surpluses as well as their variations. Results are displayed in Table 6 to Table 8.

Table 5: Parameters of supply functions.

Route	Air		Maritime	
	e	*h*	*e*	*h*
Tenerife-La Palma (current)	2,0	0,000016	2,5	0,000030
Tenerife-La Palma (new)	1,9	0,000016	2,4	0,000019
Tenerife-Gran Canaria (current)	1,7	0,000011	1,8	0,000012
Tenerife-Gran Canaria (new)	1,7	0,000012	1,8	0,000012
Gran Canaria-Lanzarote (current)	2,0	0,000037	3,7	0,00015
Gran Canaria-Lanzarote (new)	2,5	0,000037	3,6	0,00014

Source: Authors.

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 effects are carried by the consumers 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 6 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*.

Table 6: Present values of surpluses and 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

Source: Authors.

This can be explained by the high degree of direct subsidies for resident passengers, who represent about 95% of the market. 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. Tables 7 and 8 show the allocation of surpluses between passenger and freight maritime transportation.

Table 7: Present values of surpluses and 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

Source: Authors.

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 8 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 7.

Table 8: 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

Source: Authors.

The worse values of the consumer surpluses are mainly due to negative externalities. Adaptation of current infrastructure to the larger potential markets requires certain investments. Results are to be found on Table 9 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 9: Feasibility considering investment (I_0) – maritime transportation.

2018-2043 (Data in € 2018)	I_0	NPV	Feasibility
Tenerife-La Palma	16.800.000	1.731.659.785.826	Yes
Tenerife-Gran Canaria	50.820.000	5.652.054.291.508	Yes
Gran Canaria-Lanzarote	20.000.000	626.783.220.425	Yes

Source: Authors.

The last step of this analysis compares two alternatives of the potential scenario: the baseline, which has been displayed above, joint with the proposed improved network consisting of additional links as displayed in Figure 3. As mentioned, we propose an alternative long-term potential scenario with new links for three pairs of islands, which needs a redistribution of the payload between existing and new links. Table 10 displays the redistributions for each pair of islands.

Table 10: Payload allocation.

Pair of islands	Mode	Payload	2018		Potential (2043)	
			Current	Proposal	Current	Proposal
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: Authors.

Results on Table 11 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. Financial profits of producers are calculated by estimating pricing and cost structure of the industry, whereas the generalized travel cost is calculated with ticket prices and monetized door-to-door travel time. Connections between Tenerife and La Palma 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. Recommendations for the policymakers would be the same as for Tenerife-Gran Canaria. In Table 11 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.

Table 11: Comparison of surpluses and profits.

	Scenario	Mode	ΔSS	Earnings 2043
Tenerife-Gran Canaria	Current	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**
	Proposal	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**
	Scenario	**Mode**	**ΔSS**	**Earnings 2043**
Tenerife-La Palma	Current	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**
	Proposal	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**
	Scenario	**Mode**	**ΔSS**	**Earnings 2043**
Gran Canaria-Lanzarote	Current	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**
	Proposal	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: Authors. Note: Quantities in EUR 2018.

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 cancel this route to reduce the risk of overcapacity and increase efficacy. This would raise both social surplus and operational profits.

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. 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. Evaluation and analysis of these results could be useful in decision-making on inter-island transportation in the Canary Islands.

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