GHG mitigation in the electricity production system in Canary Islands. A proposal for a management and optimization tool in generation.

Juan Carlos Lozano Medina [(1)], Vicente Henríquez-Concepción [(1)], Alejandro Ramos-Martín [(1,2)], Fabian Alberto Déniz Quintana [(3)], Carlos Alberto Mendieta-Pino [(1,2)]

(1) Department of Process Engineering. University of Las Palmas de Gran Canaria (ULPGC)
(2) University institute for Environmental Studies and Natural Resources (i-UNAT), (ULPGC)
(3) University Institute of Intelligent Systems and Numeric Applications in Engineering (SIANI) (ULPGC)
+34609153268 juancarlos.lozano@ulpgc.es

Abstract:

The penetration of renewable energies in island environments poses a series of challenges such as stability, demand response and guarantee of supply, among others. Throughout this work, a study methodology will be presented based on the current conditions of electricity demand in the Canary Islands and their electricity production system to mitigate the emission of greenhouse gases and improve the penetration of renewable energies in island electricity systems. Based on the initial data, a tool will be proposed that optimizes the energy production system through combustion technology (non-renewable) and combines it with the production of energy through renewables that meet expectations both in dynamic response, safety, scaling and integration with renewable energy systems, in terms of efficiency and power. Resulting in a series of cases, under different operating conditions, providing different scenarios and an expansion of up to 36.78% of the renewable installed capacity in the Canary Islands (70% in Gran Canaria) with a reduction of 65.13% of tCO_{2eq} and a reduction in fuel consumption of 71.45%.

Keywords:

Thermodynamics; Energy; Canary; Generation; Island; Electric.

1. Introduction

1.1. Energetic overview.

All abound in the need for decarbonization [1], [2][3], [4][5], [6][7], in the need to increase the penetration of renewable energies, in the need for a broader vision of the management of our resources with better management of our technologies. The Canary electricity systems face challenges of environmental, economic, and social sustainability, largely dependent on imported fossil fuels for electricity generation [8]–[10]; this leads to an increase in the cost of electricity and CO_2 emissions; a reduction can be made using more renewable energy sources [11]–[13]. The penetration of renewable energies is in the phase of being the great challenge to become a half reality [14]–[16]. With the passage of time, environmental awareness has increased, this has driven the mobilization of island governments (promoting wind farms, and encouraging the installation of solar panels, etc.) and the mobilization of the end user of energy, with the installation of solar panels, use of electric vehicles, etc. [17]–[19]. This reality faces another not so beneficial environmentally in the production of energy and the age of the existing power generation equipment in the Canary Islands, with more than 30 years, as well as the type of fuel, Fuel Oil, Diesel, and Diesel Oil, and ignoring Natural Gas [20] [21][22]. For this study, energy data have been available until 2020, in this last year it is observed that the primary energy consumption of 3,541,855 toe (-27.49%) and 2,504,547 toe (-31.85%) of final energy, is not representative, that is why this article will refer to the data at a general level to the year 2019, last reference year before the COVID-19 pandemic [23].

It is about finding a balance between type of combustion energy production technologies, types of fuels, renewables and demand behavior that take us to the most optimal point of energy production to meet demand. That is, to produce energy through renewable energies, to make it as much as possible by optimizing and expanding all renewable systems, and for the production of energy through combustion technologies, that this is the lowest possible, with the lowest possible GHG emission, and with the least number of tons of fuel consumed possible and trying to make the fuel used the least polluting. We establish a tool that relates all these variables to us and inspect the situation with different hypotheses.

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1.2. GHG emissions overview

In relation to the emission of GHGs due to electricity generation, they are mainly due to the gases formed in combustion, so that, for these purposes, CO_2 and NO_2 emissions are considered. The emission factors provided by "Red Eléctrica de España" use the GWP (Global Warming Potential) value included in the IPCC Fifth Assessment Report (AR5) and shown in [24][25]**Table 1**.

Table 1. Emissions according to generation technologies in Spain.

Technology	CO_2 emissions *(tCO_2/MWh)*	NO_2 emissions *(tCO_2/MWh)*	*Non-peninsular territories system Greenhouse gas emissions ($tCO_{2\text{-}eq}/MWh$)*	Peninsular territories system Greenhouse gas emissions *($tCO_{2\text{-}eq}/MWh$)*
Combined cycle (diesel)	0.60	0.00	0.60	-
Combined cycle (natural gas)	0.41	0.00	0.41	0.37
Diesel (diesel, fuel oil)	0.65	0.03	0.68	-
Steam turbine (fuel oil)	0.90	0.00	0.90	0.77
Steam turbine (coal)	-	-	-	0.95
Steam turbine (nuclear)	-	-	-	0.00
Gas turbine (diesel)	1.12	0.00	1.12	-
Gas turbine (natural gas)	0.84	0.00	0.84	-
Solar-Photovoltaic	0.00	0.00	0.00	0.00
Wind	0.00	0.00	0.00	0.00

In the Spanish electricity systems of the island territories (Canary Islands and Balearic Islands) these CO_2 emission factors are basically the same as those used to determine the remuneration for costs of emission rights of generation groups and which is included in national legislation in Royal Decree 738/2015, which regulates the activity of electricity production and the procedure for dispatch in the electricity systems of the non-peninsular territories. Emissions per electricity consumption, in 2019, are 0.331 $kgCO_{2\text{-}eq.}$/kWh Final Energy and 2.368 $kgCO_{2\text{-}eq.}$/kWh Primary Energy for the peninsular system, and 0.776 $kgCO_{2\text{-}eq.}$/kWh Final Energy and 2.994 $kgCO_{2\text{-}eq.}$/kWh Primary Energy in insular systems (IDAE, 2016). In the Canary Islands, the mix of conventional technologies makes the average emission of 0.694 $tCO_{2\text{-}eq.}$/MWh, by comparison for 2019, the average emission of Spain was 0.190 $tCO_{2\text{-}eq.}$/MWh.

2. Energy situation in the Canary Islands in 2019.

2.1. Energy and environmental values.

The participation of the different sources and technologies in the coverage of electricity demand in terms of gross energy in the Canary Islands in 2019, by island and technology is shown in **Appendix A.** Note that the penetration of renewables is 15.9%.

In 2019 the Canary Islands had an installed capacity of 3,320.03MW, of which 623.67MW are renewable sources and 2,696.36MW are non-renewable sources. The installed power is shown in **Appendix B**.

Fuel consumption for electricity generation in the Canary Islands in 2019 was 1,702,166.0 MT (57.6% fuel oil, 41.2% diesel oil and 1.2% diesel-oil). By technologies, the steam units consumed 595,170 mt of fuel oil and 515 mt of diesel, the diesel units 384,935 mt of fuel oil and 18,826 mt of diesel and 21,259 mt of diesel-oil, the gas turbine units 12,995 mt of diesel and the combined cycle units 294,378 mt of diesel, all of which are substitute fuels as the design fuel in these units was natural gas. Fuel consumption and GHG emissions for 2019 are shown in **Appendix C** and are represented in the following graphs.

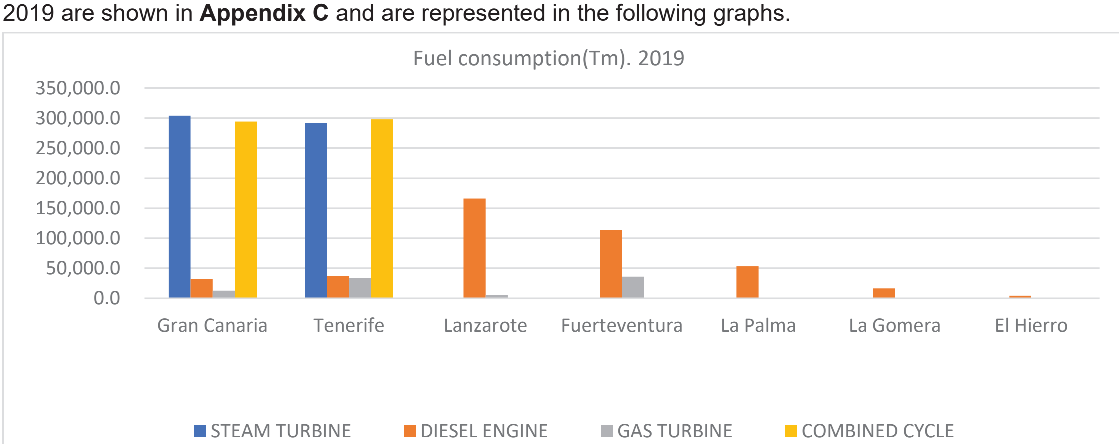

Figure1. Fuel consumption by islands and technology in the Canary Islands. Source: Canary Islands Energy Yearbook 2019.

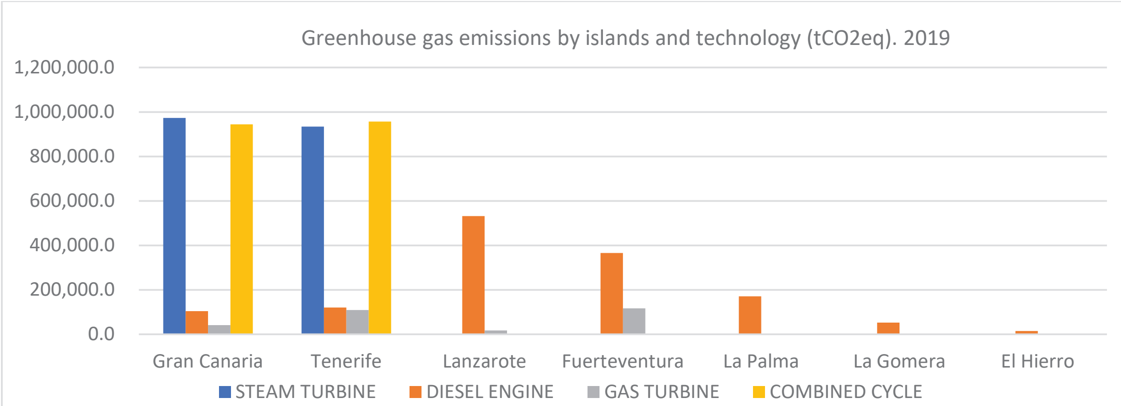

Figure2. Greenhouse gas emissions by islands and technology in the Canary Islands. Source: Canary Islands Energy Yearbook 2019.

As for emissions, for 2019 in the Canary Islands it was 5,454,911 $tCO_{2\text{-eq}}$. Of these, 99.7% was CO_2, 0.1% CH_4 and 0.2% NO_2. As for the emission factor ($tCO_{2\text{-eq}}$./MWh) calculated based on the energy produced, the results are shown in **Appendix D,** differentiated by islands and power equipment. It is worth mentioning the high emission factor of gas turbines and the fall of this factor in El Hierro due to renewable energies.

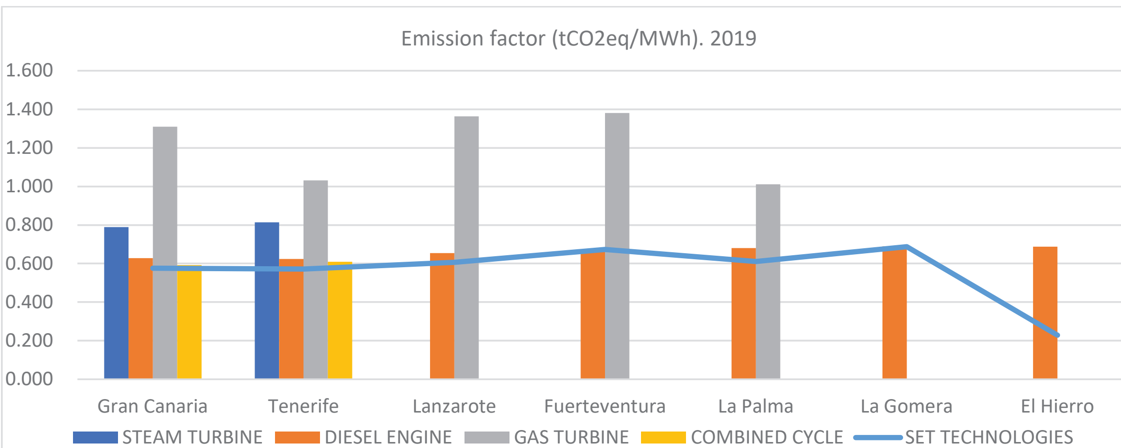

Figure3. Emission factor by islands and technology in the Canary Islands. Source: Canary Islands Energy Yearbook 2019.

The lowest emission factor is that of combined cycle power plants (0.601 $tCO_{2\text{-eq}}$./MWh) and diesel engines (0.656 $tCO_{2\text{-eq}}$./MWh). An overall emission factor for the Canary Islands, including renewable production, is estimated at 0.584 $tCO_{2\text{-eq}}$./MWh. **Table 2** shows the date and time of highest demand by islands in 2019.

Table 2. Demand peaks. Source: Canary Islands Energy Yearbook 2019.

Island	date	hour	MW
Gran Canaria	02/10/2019	20:58	537.00
Tenerife	02/10/2019	20:21	576.00
Lanzarote	31/12/2019	19:06	139.00
Fuerteventura	17/08/2019	20:53	113.00
La Palma	19/08/2019	21:36	43.00
La Gomera	17/08/2019	21:59	12.10
El Hierro	20/08/2019	21:27	8.10

Specifically, in Gran Canaria, the moment of greatest demand was on October 2, 2019 (20:58h,) with emissions of 0.631 $tCO_{2\text{-eq}}$ MWh-1 and a peak of 537.0 MW (**Figure 4**). The demand curve is very similar to the rest of the days except for small fluctuations produced by particular cases. In turn, the different groups are programmed to meet that demand curve. That is why it is necessary to carry out a good programming for a correct functioning of the network. It is also worth emphasizing the difficulty of predicting the curve correctly, and the validity of the data obtained to provide the necessary power and specifically in systems based on renewable energies (wind and solar) existing on the island.

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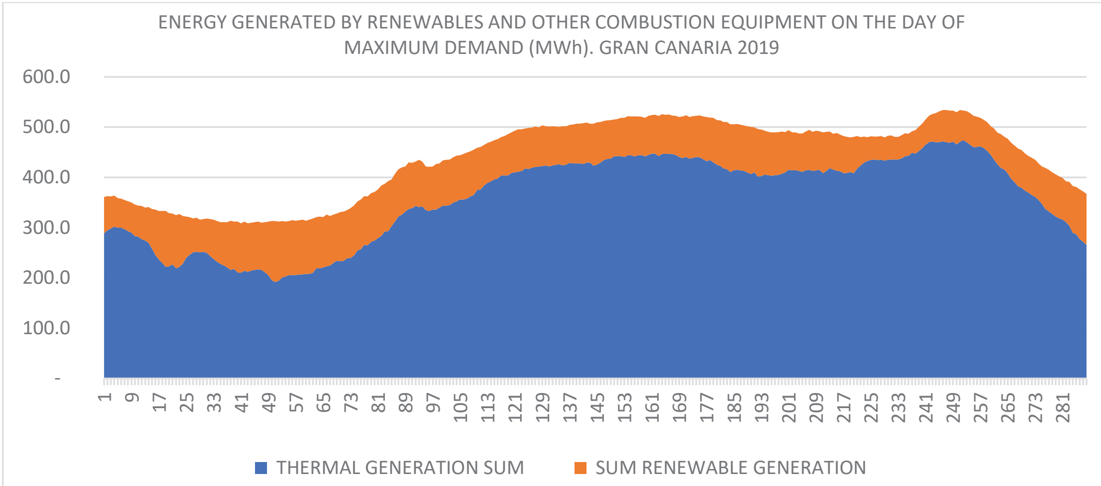

Figure 4. Demand curve Gran Canaria. Peak demand 2019. Thermal and renewable generation. Source: Canary Islands Energy Yearbook 2019.

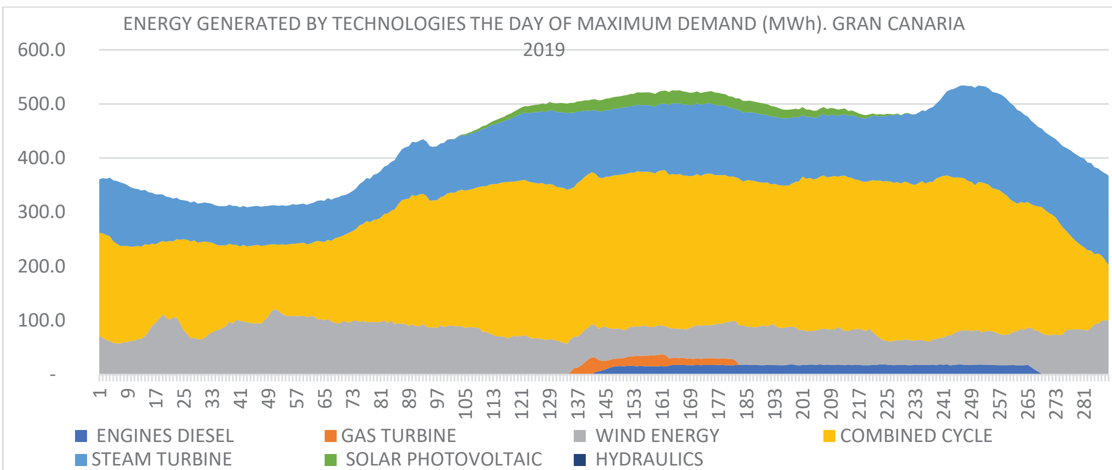

Figure 5. Demand curve Gran Canaria. Peak demand 2019. Generation differentiating technologies. Source: Canary Islands Energy Yearbook 2019.

For the peak demand day, the steam turbine and combined cycle groups contribute 33.35% and 51.28% of the electricity to the grid, leaving the Diesel and gas turbine groups for the tips and being the contribution of renewables (wind) of 11.83% (**Figure 5**).

2.2. Penetration values of renewable energies in the Canary Islands.

The data collected start from 2004, in that year, the Canary Islands had 138.22 MW installed and for Gran Canaria 75.85 MW. In this time horizon, with an average annual growth of 8%, two specific years stand out where there were very significant increases in installed capacity compared to the previous year, years 2008 and 2018, in the case of Gran Canaria, the technology that drove the development of the sector was wind generation. It is observed how the penetration of renewable energies has been slow during the years studied. As indicated above, the penetration of renewables in 2019 was 15.9%.

3. Material and methods. Non-renewable production system alternatives based on the expansion of the penetration of renewables and optimization of existing equipment.

3.1. Tool.

A tool is proposed that helps to regulate and optimize the energy production equipment and describes the different existing combinations in achieving an energy production that meets the demand, all this optimizing fuel consumption, reducing GHG emissions, increasing the penetration of renewables and reducing the CO_2

emission factor, (tCO_{2eq}/MWh). The following list has been defined that covers all the possibilities of operation of energy production equipment in the Canary Islands. With this ratio it is possible to obtain, for the different operating conditions, the power produced, GHG emissions, fuel consumption, etc.

$$E=\{[a x \alpha 1+a' x(1-\alpha 1)] x A+[b x \alpha 2+b' x(1-\alpha 2)] x B+[c x \alpha 3+c' x(1-\alpha 3)] x C+[d x \alpha 4+d' x(1-\alpha 4)] x D\} x(1+\beta)$$

where:

Table 3. Definition of parameters.

Technologies				Definition of parameters.
Steam turbine	Engines diesel	Gas turbine	Combined cycle	
a´	*b´*	*c´*	*d´*	Studied value of this technology running on 100% usual fuel
a	*b*	*c*	*d*	Studied value of this technology running on 100% natural gas
α1	*α2*	*α3*	*α4*	% use of natural gas in this technology
A	*B*	*C*	*D*	% of operation of this technology
Renewable		*β*		% contributed from this technology calculated on the total contributed by the rest of technologies not including renewables.
		R		% contributed from this technology calculated on the total contributed by all technologies, including renewables.

A variation of this expression, also interesting since it is a function of the percentage of penetration of renewables in the system (R), is:

$$E=\{[a x \alpha 1+a' x(1-\alpha 1)] x A+[b x \alpha 2+b' x(1-\alpha 2)] x B+[c x \alpha 3+c' x(1-\alpha 3)] x C+[d x \alpha 4+d' x(1-\alpha 4)] x D\}/(1-R)$$

The indicator "CO_2 *GREEN"* has also been defined. This indicator evaluates the status or situation of the objective " tCO_{2-eq} *ZERO*", the cancellation to 100% of the tCO_{2-eq}. In short, it is the amount of tCO_{2-eq} that has stopped being emitted into the atmosphere in the energy production process per person. This percentage increase in the *tCO_{2-eq}/inhabitant* that are no longer emitted, causes environmental damage to decrease in the same proportion, as well as damage to people's health.

3.2. Starting values 2019.

For this we start from the base that in 2019 as indicated we have in the Canary Islands the following indices:

Greenhouse gas emissions 5.454.911,00 tCO_{2eq}, Emission factor 0,584tCO_{2eq}/MWh and Fuel consumption estimation 1.702.166,00 Tn.

3.3. Procedure.

With this relationship we establish several hypotheses with the aim of reducing emissions, fuel consumption, and increasing the penetration of renewables. Applying the relationship established for the existing situation in 2019 for Gran Canaria, we obtain:

Fuel consumption =a´xA+b´xB+c´xC+d´xD = 643.814,00 Ton

Energy production ={a´xA+b´xB+c´xC+d´xD}x(1+β) = {a´xA+b´xB+c´xC+d´xD}/(1-R) = 3.581.933,00 MWh

Greenhouse gas emissions =a´xA+b´xB+c´xC+d´xD = 2.063.911,00 tCO2eq

It has been contemplated that there is no Natural Gas in 2019 in Gran Canaria and the respective data have been entered:

Table 4. Data for the situation in Gran Canaria 2019

	Steam turbine		Engines diesel		Gas turbine		Combined cycle	
	a´	*a*	*b*	*b´*	*c*	*c´*	*d*	*d´*
Fuel consumption estimation (Tn)	604.618,4	528.898,2	144.308,2	144.308,2	619.815,9	479.656,8	745.377,9	576.825,5
Energy Produced (MWh)	2.452.800	2.452.800	735.840	735.840	1.519.422	1.519.422	4.044.754	4.044.754
Greenhouse gas emissions (tCO2eq)	1.936.141	1.421.637	462.166	462.166	1.989.295	1.648.313	2.392.330	1.982.216
	α1	*A*	*α2*	*B*	*α3*	*C*	*α4*	*D*
Gran Canaria 2019	0,00%	50,24%	0,00%	22,50%	0,00%	2,09%	0,00%	39,49%

Being β= 18.29% and R= 15.46% for energy production.

3.4. Proposal of hypotheses of operation of equipment preserving the current type of fuel.

3.4.1. HYPOTHESIS 1: Reordering power plants with historical annual maximums. Penetration of renewables: 15.9%.

In this hypothesis, we proceed to work with the least polluting equipment in the different production centers of the islands, bringing them to a production ceiling marked by the maximum annual historical productions. The

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historical annual maximums of combined cycle plants (3,418,748MWh) and diesel engines (2,390,736.2MWh) which are the least polluting have been studied, proportionally rearranging the rest of the equipment. Preserving the penetration of renewables (1,480,634MWh, 15.9%). This results in an overall emission factor of 0.563 $tCO_{2\text{-}eq}$/MWh.

Table 5. Hypothesis 1.

Technology	Energy Produced (*MWh*)	Greenhouse gas emissions (tCO_{2eq})	Emission factor (tCO_{2eq}/MWh)	Fuel consumption estimation (*Tn*)
Steam turbine	2.045.977,0	1.641.421,5	0,802	512.582,8
Diesel engine	2.390.736,2	1.562.556,1	0,654	488.206,3
Combined cycle	3.418.748,0	2.052.294,4	0,600	639.433,0
Renewable (15,9%)	1.480.634,0	-	-	-
Total	9.336.095,2	5.256.271,9	0,563	1.640.222,1

3.4.2. HYPOTHESIS 2: Rearrangement of power plants working exclusively with the least polluting. Penetration of renewables: 15.9%.

In this hypothesis, we proceed to continue working with the least polluting equipment in the different production centers of the islands, but we work exclusively with them, ignoring the rest of the equipment. All this entails producing 5,428,740.4MWh in the combined cycle plants and 2,426,720.8MWh diesel engines, which are the least polluting, leaving the rest of the equipment in disuse or as reserves. Preserving the penetration of renewables (1,480,634MWh, 15.9%). All this results in an overall emission factor of 0.519 $tCO_{2\text{-}eq}$/MWh.

Table 6. Hypothesis 2.

Technology	Energy Produced (*MWh*)	Greenhouse gas emissions (tCO_{2eq})	Emission factor (tCO_{2eq}/MWh)	Fuel consumption estimation (*Tn*)
Diesel engine	2.426.720,8	1.585.013,5	0,653	495.218,0
Combined cycle	5.428.740,4	3.259.874,3	0,600	1.015.678,5
Renewable (15,9%)	1.480.634,0	-	-	-
Total	9.336.095,2	4.844.887,8	0,519	1.510.896,4

3.4.3. HYPOTHESIS 3: Reorganization of power plants working exclusively with the least polluting, but incorporating the Chira-Soria project. Penetration of renewables: 29.5%-36.8%.

In this hypothesis, we proceed to continue working with the least polluting equipment in the different production centers of the islands, but we work exclusively with them, ignoring the rest of the equipment. The Chira-Soria power plant is incorporated. With this addition, a global penetration in renewables in Gran Canaria is expected between 51% and 70%.

If we estimate 51% in Gran Canaria **(HYPOTHESIS 3a),** which affects the overall figure of penetration of renewables in the Canary Islands, rising to 29.1%. All this entails producing 4,307,822.1MWh in the combined cycle plants and 2,310,552.60MWh diesel engines, which are the least polluting, leaving the rest of the equipment in disuse or as reserves. The penetration of renewables would be (2,717,720.5MWh, 29.1%). This results in an overall emission factor of 0.440 $tCO_{2\text{-}eq}$/MWh.

Table 7. Hypothesis 3a.

Technology	Energy Produced (*MWh*)	Greenhouse gas emissions (tCO_{2eq})	Emission factor (tCO_{2eq}/MWh)	Fuel consumption estimation (*Tn*)
Diesel engine	2.310.552,6	1.512.050,4	0,654	472.435,9
Combined cycle	4.307.822,1	2.596.890,5	0,603	809.112,7
Renewable (29,1%)	2.717.720,5	-	-	-
Total	9.336.095,2	4.108.940,9	0,440	1.281.548,5

If we estimate 70% in Gran Canaria **(HYPOTHESIS 3b),** which affects the overall figure of penetration of renewables in the Canary Islands, rising to 36.8%. All this entails producing 3,658,707.6 in the combined cycle plants and 2,243,280.5MWh diesel engines, which are the least polluting, leaving the rest of the equipment in disuse or as reserves. The penetration of renewables would be (3,434,107.1MWh, 36.8%). This yields an overall emission factor of 0.394 $tCO_{2\text{-}eq}$/MWh.

Table 8. Hypothesis 3b.

Technology	Energy Produced (*MWh*)	Greenhouse gas emissions (tCO_{2eq})	Emission factor (tCO_{2eq}/MWh)	Fuel consumption estimation (*Tn*)
Diesel engine	2.243.280,5	1.469.798,2	0,655	459.242,9
Combined cycle	3.658.707,6	2.212.962,0	0,605	689.492,2
Renewable (36,8%)	3.434.107,1	-	-	-
Total	9.336.095,2	3.682.760,2	0,394	1.148.735,1

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3.4.4. Summary of these 5 hypothesis:

The following is a summary of the improvements produced by these 4 variants of hypothesis:

Table 9. Summary and comparison of the hypotheses planted

Hypothesis	% Renewable penetration	Greenhouse gas emissions *(tCO_{2eq})*	Emission factor *(tCO_{2eq}/MWh)*	Fuel consumption estimation *(Tn)*	% improvement	Green CO_2 *(tCO_{2eq}/inhabitant* year)
2019	15,86%	5.454.911	0,58	1.702.166	-	2,50
1	15,86%	5.256.271	0.56	1.640.222	-3,8%	2,41
2	15,86%	4.844.887	0.52	1.510.896	-12,6%	2,22
3a	29,11%	4.108.940	0.44	1.281.548	-32,8%	1,89
3b	36,78%	3.682.760	0.39	1.148.735	-48,1%	1,69

Logically, we improve the green CO_2 index by incorporating more renewables and stop producing CO_2. It is worth mentioning the significant improvement with the entry of the Chira-Soria project. If we compare green CO_2 between islands and by hypothesis we obtain:

Table 10. Island Green CO_2 (tCO_{2eq}/inhabitant year)

Hypothesis	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro	Canarias
2019	2,42	2,28	3,52	4,02	2,06	2,42	1,25	2,50
1	2,34	2,21	3,46	3,51	2,06	2,42	1,25	2,41
2	2,11	1,98	3,46	3,51	2,06	2,42	1,25	2,22
3a	1,25	1,98	3,46	3,51	2,06	2,42	1,25	1,89
3b	0,75	1,98	3,46	3,51	2,06	2,42	1,25	1,69

We can see that the worst situation is in terms of Green CO_2 is on the island of Lanzarote and Fuerteventura and the best in El Hierro. Gran Canaria approaches El Hierro from the 3rd hypothesis and Tenerife in the 4th hypothesis, like the rest of the islands.

3.5. Proposal of hypotheses of operation of equipment changing the type of current fuel.

We continue with more Hypotheses, but now we make a variant on the previous Hypotheses. This variant consists of the modification of the fuel. As far as possible and allowed the equipment will move to use Natural Gas.

Natural gas produces CO_2 emissions 40-50% lower than those of coal and 25-30% lower than those of fuel oil. As for NOx, the nature of the gas (its combustion takes place in the gas phase) allows to achieve a more perfect mixture with the combustion air which leads to complete and more efficient combustion, with less excess air. Methane, which is the main component of natural gas, is a more potent cause of the greenhouse effect than CO_2, although methane molecules have a shorter lifetime in the atmosphere than CO_2. De according to independent studies, direct losses of natural gas during extraction, transport and distribution worldwide, they have been estimated at 1% of the total gas transported, the CO_2 emission in the combustion of Natural Gas is 58 $kgCO_2$/GJ compared to that of Fuel Oil or Diesel which is 79 $kgCO_2$/GJ and 70 $kgCO_2$/GJ respectively. On the other hand, we have that the calorific value of natural gas is higher than that of the other fuels usually used in the Canary Islands.

Table 11. Calorific power.

Fuel type	Higher calorific power (Kcal/Kg)	Lower calorific power (Kcal/Kg)
Fuel	10.430,00	9.850,00
Diesel	9.265,00	8.713,00
Diesel oil	10.790,00	10.140,00
Natural gas	12.474,00	11.259,00

All this makes the convenience of using Natural Gas double since we need to burn less fuel to produce the same electricity and less CO2 is generated by electricity produced. The distribution of fuel for the current situation (starting situation) where all equipment except diesel engines switch to Natural Gas is as shown in **Appendix E** as well as the new emission distribution (tCO_{2-eq}) expected for this new situation. As a result of the change of fuel we managed to reduce emissions of polluting gases by 16.17%, from 5,454,911.4 tCO2-eq to 4,573,053,30 tCO_{2-eq} and reduced fuel consumption by 13.44%, from 1,702,166.00 tons to 1,473,468.48 tons. The new emission factor is 0,490 tCO_{2eq}/MWh.

3.5.1. NG-HYPOTHESIS 1: Rearrangement of power plants with historical annual maximums. Penetration of renewables: 15.9%.

As already indicated above, in this hypothesis we proceed to work with the least polluting equipment in the different production centers of the islands, bringing them to a production ceiling marked by the maximum annual historical productions. The historical annual maximums of combined cycle plants (3,418,748MWh) and diesel engines (2,390,736.2MWh) which are the least polluting have been studied, proportionally rearranging

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the rest of the equipment. Preserving the penetration of renewables (1,480,634MWh, 15.9%). With all this we obtain a global emission factor of 0.563 $tCO_{2\text{-eq}}$/MWh to 0.479 $tCO_{2\text{-eq}}$/MWh.

Table 12. NG-Hypothesis 1.

Technology	Energy Produced (*MWh*)	Greenhouse gas emissions (*tCO_{2eq}*)	Emission factor (*tCO_{2eq}/MWh*)	Fuel consumption estimation (*Tn*)
Steam turbine	2.045.977,0	1.205.228,3	0,589	448.391,4
Diesel engine	2.390.736,2	1.562.554,0	0,654	488.206,3
Combined cycle	3.418.748,0	1.700.472,5	0,497	494.837,9
Renewable (15,9%)	1.480.634,0	-	-	-
Total	9.336.095,2	4.468.254,7	0,479	1.431.435,6

3.5.2. NG-HYPOTHESIS 2: Rearrangement of power plants working exclusively with the least polluting. Penetration of renewables: 15.9%.

In this hypothesis, we proceed to continue working with the least polluting equipment in the different production centers of the islands, but we work exclusively with them, ignoring the rest of the equipment. All this entails producing 5,428,740.4MWh in the combined cycle plants and 2,426,720.8MWh diesel engines, which are the least polluting, leaving the rest of the equipment in disuse or as reserves. Preserving the penetration of renewables (1,480,634MWh, 15.9%). With all this, we went from a global emission factor of 0.519 tCO2-eq/MWh to 0.459 $tCO_{2\text{-eq}}$/MWh.

Table 13. NG-Hypothesis 2.

Technology	Energy Produced (*MWh*)	Greenhouse gas emissions (*tCO_{2eq}*)	Emission factor (*tCO_{2eq}/MWh*)	Fuel consumption estimation (*Tn*)
Diesel engine	2.426.720,8	1.585.011,2	0,653	495.218,.0
Combined cycle	5.428.740,4	2.701.038,7	0,498	786.002,9
Renewable (15,9%)	1.480.634,0	-	-	-
Total	9.336.095,2	4.286.049,9	0,459	1.281.220,9

3.5.3. NG-HYPOTHESIS 3: Reorganization of power plants working exclusively with the least polluting but incorporating the Chira-Soria project. Penetration of renewables: 29.5%-36.78%.

In this hypothesis, we proceed to continue working with the least polluting equipment in the different production centers of the islands, but we work exclusively with them, ignoring the rest of the equipment.

The Chira-Soria power plant is incorporated. With this addition, a global penetration in renewables in Gran Canaria is expected between 51% and 70%.

If we estimate 51% in Gran Canaria **(GN-HYPOTHESIS 3a),** which affects the overall figure of penetration of renewables in the Canary Islands, rising to 29.1%. All this entails producing 4,307,822.1MWh in the combined cycle plants and 2,310,552.60MWh diesel engines, which are the least polluting, leaving the rest of the equipment in disuse or as reserves. The penetration of renewables would be (2,717,720.5MWh, 29.1%). With all this, we went from an overall emission factor of 0.440 $tCO_{2\text{-eq}}$/MWh to 0.392 $tCO_{2\text{-eq}}$/MWh.

Table 14. NG-Hypothesis 3a.

Technology	Energy Produced (*MWh*)	Greenhouse gas emissions (*tCO_{2eq}*)	Emission factor (*tCO_{2eq}/MWh*)	Fuel consumption estimation (*Tn*)
Diesel engine	2.310.552,6	1.512.048,9	0,654	472.435,9
Combined cycle	4.307.822,1	2.151.709,3	0,499	626.147,9
Renewable (29,1%)	1.480.634,0	-	-	-
Total	9.336.095,2	3.663.758,3	0,392	1.098.583,8

If we estimate 70% in Gran Canaria **(NG-HYPOTHESIS 3b),** which affects the overall figure of penetration of renewables in the Canary Islands, rising to 36.8%. All this entails producing 3,658,707.6 in the combined cycle plants and 2,243,280.5MWh diesel engines, which are the least polluting, leaving the rest of the equipment in disuse or as reserves. The penetration of renewables would be (3,434,107.1MWh, 36.8%). With all this, we went from an overall emission factor of 0.394 $tCO_{2\text{-eq}}$/MWh to 0.354 $tCO_{2\text{-eq}}$/MWh.

Table 15. NG-Hypothesis 3b.

Technology	Energy Produced (*MWh*)	Greenhouse gas emissions (*tCO_{2eq}*)	Emission factor (*tCO_{2eq}/MWh*)	Fuel consumption estimation (*Tn*)
Diesel engine	2.243.280,5	1.469.797,0	0,655	459.242,9
Combined cycle	3.658.707,6	1.833.597,1	0,501	533.577,2
Renewable (36,78%)	3.434.107,1	-	-	-
Total	9.336.095,2	3.303.394,1	0,354	992.820,1

3.5.4. Summary hypothesis, production with teams working with natural gas:

As a summary of these 4 new hypotheses, a summary of the improvements produced by these 4 variants of hypotheses is shown below:

Table 16. Summary and comparison of the hypotheses planted

Hypothesis	% Renewable penetration	Greenhouse gas emissions *(tCO_{2eq})*	Emission factor *(tCO_{2eq}/MWh)*	Fuel consumption estimation *(Tn)*	% improvement	Green CO_2 *(tCO_{2eq}/inhabitant* year)
2019	15,86%	5.454.911	0,58	1.702.166	-	2,50
NG 2019	15,86%	4.573.053	0,49	1.473.468,48	-	2,10
NG-1	15,86%	4.468.254	0,48	1.431.435,58	-2,3%	2,05
NG-2	15,86%	4.286.049	0,46	1.281.220,92	-6,7%	1,97
NG-3a	29,11%	3.663.758	0,39	1.098.583,77	-24,8%	1,68
NG-3b	36,78%	3.303.394	0,35	992.820,10	-38,4%	1,52

Logically, the trend shown of improvements without the incorporation of Natural Gas increases with the incorporation of this fuel. We improve the green CO_2 index by incorporating more renewables and stop producing CO_2. It is worth noting the significant improvement with the entry of the project Chira-Soria. If we compare the green CO_2 between islands and by hypothesis we obtain:

Table 17. Island Green CO_2 (tCO_{2eq}/inhabitant year)

Hypothesis	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro	Canarias
2019	2,42	2,28	3,52	4,02	2,06	2,42	1,25	2,50
NG 2019	1,92	1,81	3,50	3,85	2,06	2,42	1,25	2,10
NG-1	1,89	1,78	3,46	3,51	2,06	2,42	1,25	2,05
NG-2	1,79	1,68	3,46	3,51	2,06	2,42	1,25	1,97
NG-3a	1,06	1,68	3,46	3,51	2,06	2,42	1,25	1,68
NG-3b	0,63	1,68	3,46	3,51	2,06	2,42	1,25	1,52

We can see that the worst situation is still in terms of Green CO_2 that of the island of Lanzarote and Fuerteventura and the best in El Hierro. Gran Canaria approaches the Iron and improves from the GN-Hypothesis 3ª and Tenerife in the 4th Hypothesis, like the rest of the islands.

3.6. Results.

As a summary of the results we have:

Hypothesis 2: this approach is what offers immediate results at the lowest cost. As indicated in its approach, it consists of working exclusively with the least polluting equipment in the different production centers of the islands, combined cycle and Diesel engines. We subject this equipment to greater mechanical stress, but bearable with good maintenance according to its use. The most affected would be the combined cycles of Gran Canaria and Tenerife that their use would be 67.83% and 67.10%, and the Diesel Engines of Fuerteventura and Lanzarote that their use would be 67.35% and 55.57%. The rest of the equipment would have a use of less than 45%. With all this we lower total GHG emissions ($tCO_{2e}q$) by 12.59% and fuel consumption (Ton) by 12.66% and the economic and temporary cost is practically zero.

Execution Time: Immediate; Economic cost: Minimum; Decrease in total GHG emissions (tCO2eq):12.59%; Decrease in fuel consumption (Ton):12.66%; Renewable penetration: 15.86%.

NG Hypothesis 2: this second approach described in the GN. hypothesis2, consists of working exclusively with the least polluting equipment in the different production centers of the islands, combined cycle and Diesel engines, but we also change the fuel used in the combined cycle, going from diesel to natural gas.

We subject these teams to a mechanical stress like that of the previous hypothesis, although it is somewhat lower in the combined cycle. As a result, we obtain:

Execution Time: Average; Economic cost: medium; Decrease in total GHG emissions (tCO2eq):2 2.08%; Decrease in fuel consumption (Ton):1 8.91%; Renewable penetration: 15.86%.

Hypothesis 3a: third approach for our objective is the one described in hypothesis3a, to work exclusively with the least polluting equipment in the different production centers of the islands, combined cycle and Diesel engines, with their usual fuel, but we also incorporate the Chira-Soria project that incorporates the Chira-Soria plant and that foresees a penetration in renewables overall in Gran Canaria between 51% and 70%. In this hypothesis, 51% was estimated in Gran Canaria (the minimum expectation of this project), which affects the overall figure of penetration of renewables in the Canary Islands, rising to 29.1 1%.

Execution Time: Medium-High; Economic cost: medium-high; Decrease in total GHG emissions (tCO2eq):3 2.76%; Decrease in fuel consumption (Ton): 32.82%; Renewable penetration: 29.11%.

NG Hypothesis 3a: a fourth approach to our objective is that described in the GN. hypothesis3a, to work exclusively with the least polluting equipment in the different production centers of the islands, combined cycle and Diesel engines, changing the fuel of the combined cycle to natural gas, but we also incorporate the Chira-

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Soria project that incorporates the Chira-Soria plant with a penetration in renewables global in Gran Canaria between 51% in Gran Canaria (the minimum expectation of this project), which affects the overall figure of penetration of renewables in the Canary Islands, rising to 29.1 1%.

Execution Time: Medium-High; Economic cost: medium-high; Reduction of total GHG emissions (tCO2eq): 48.89%; Decrease in fuel consumption (Ton):54.94%; Renewable penetration: 29.11%.

NG Hypothesis 3b: a fifth approach and the most optimal of all for our objective is the one described in the GN. hypothesis3b, working exclusively with the least polluting equipment in the different production centers of the islands, combined cycle and diesel engines, changing the fuel of the combined cycle to natural gas, but we also incorporate the Chira-Soria project that incorporates the Chira-Soria plant with a penetration in renewables global in Gran Canaria between 70% in Gran Canaria (the maximum expectation of this project), which affects the global figure of penetration of renewables in the Canary Islands, rising to 36.78%.

Execution Time: Medium-High; Economic cost: medium-high; Reduction of total GHG emissions (tCO2eq):65.13%; Decrease in fuel consumption (Ton): 71.45%; Renewable penetration: 36.78%.

3.7. Conclusions.

There are several measures that can be taken because of the result of this study through the tool proposed to achieve our environmental objective. All these measures to be taken depend in turn on several factors:

Economic factor: The measures to be taken can be very expensive with a satisfactory result or less expensive and obtain to a lesser degree a satisfactory result. Although not always the investment is directly proportional in a linear way to the result.

Temporal factor: If we take into account this factor, we can find several situations ranging from the immediacy of the actions to be taken or the other extreme that is to go to several years of delay in achieving completion of that action, and of course all intermediate situations are also valid.

The results will improve as these two factors grow, that is, we have more time and more investment.

Appendix A

TableA.1. Energy produced (MWh). Source: Canary Islands Energy Yearbook 2019.

Technology	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro	Canarias
Steam turbine	1.233.316	1.146.979						2.380.295
Diesel engine	1.657.552	192.784	813.663	552.146	251.332	76.696	20.738	2.072.911
Gas turbine	31.758	105.645	12.791	841.585	603			235.382
Combined cycle	1.597.427	1.569446						3.166.873
Renewable	553.880	696096	79.623	80.108	29.081	154	41.692	1.480.634
Total	3.581.933	3710950	906.077	716.839	281.016	76.850	62.430	9.336.095

Appendix B

Table B.1. Installed capacity (MW). Source: Canary Islands Energy Yearbook 2019.

Technology	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro	Canarias
Steam turbine	280,00	240,00						520,00
Diesel engine	84,00	84,00	166,76	107,92	82,84	21,17	14,91	564,60
Gas turbine	173,45	265,70	62,50	79,10	22,50			603,25
Combined cycle	461,73	456,80						918,53
Refinery-Cogen.	24,88	65,10						89,98
Renewable	199,92	314,54	32,41	41,42	12,18	0,37		623,67
Total	1.223,98	1.426,14	264,67	228,44	117,52	21,54	22,83	3.320,03

Appendix C

Table C.1. Fuel consumption in the thermal power plants of the Canary Islands (Ton) and greenhouse gas emissions (tCO_{2eq}) per fuel used. Source: Canary Islands Energy Yearbook 2019.

Technology	Fuel consumption (Ton)				Greenhouse gas emissions (tCO_{2eq})			
	Fuel	Oil	Dieseloil	Total	Fuel	Oil	Diesel oil	Total
Steam turbine	595.170	515	-	595.685	1905.884	1.652		1.907.536
Diesel engine	384.935	18.826	21.259	425.020	1.232.665	60.423	67.103	1.360.191
Gas turbine	-	88.944	-	88.944	-	285.467		285.467
Combined cycle	-	592.517	-	592.517	-	1.901.715		1.901.715
Total	980.105	700.802	21.759	1.702.166	3.138.549	2.249.257	67.103	5.454.909

Appendix D

Table D.1. Greenhouse gas emissions (tCO_{2eq}) by type of technology in the thermal power plants of the Canary Islands and emission factor (tCO_{2eq}/MWh). Source: Canary Islands Energy Yearbook 2019.

Technology	Energy Produced (MWh)	Greenhouse gas emissions (tCO_{2eq})	Emission factor (tCO_{2eq}/MWh)
Steam turbine	2.380.295,0	1.907.536,0	0,801
Diesel engine	2.072.911,0	1.360.192,0	0,656
Gas turbine	235.382,0	285.468,0	1,213
Combined cycle	3.166.873,0	1.901.715,0	0,601
Renewable	1.480.634,0		-
Total	9.336.095,2	5.454.911,0	0,584

Appendix E

Table E.1. Estimation of fuel consumption in the thermal power plants of the Canary Islands (Ton)

Technology	Fuel consumption (Ton)				
	Natural gas	Fuel	Oil	Diesel oil	Total
Steam turbine	521.086,4	-	-	-	521.086,4
Diesel engine	-	384.935,0	18.826,0	21.259,0	425.020,0
Gas turbine	68.831,1	-	-	-	68.831,1
Combined cycle	458.531,0	-	-	-	458.531,0
Total	1.048.448,5	384.935,0	18.826,0	21.759,0	1.473.468,5

Table E.2. Estimation total greenhouse gas emissions (tCO_{2eq}) per fuel used.

Technology	Greenhouse gas emissions (tCO_{2eq})				
	Natural gas	Fuel	Oil	Diesel oil	Total
Steam turbine	1.400.625,8	-	-	-	1.400.625,8
Diesel engine	-	1.232.665,0	60.423,0	67.103,0	1.360.191,0
Gas turbine	236.529,8	-	-	-	236.529,8
Combined cycle	1.575.706,7	-	-	-	1.575.706,7
Total	3.212.862,3	1.232.665,0	60.423,0	67.103,0	4.573.053,3

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