Canary Islands Institute of Technology

Renewable Energy Department

Canary Islands Green Hydrogen roadmap

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Canary Islands energy system

Canary Islands energy system | Year 2021

Load demand: 8.055 GWh/year
Load demand coverage with RES: 19,5%

La Palma

Peak power:	44,5 MW
Load demand:	246 GWh
Load demand coverage with RES:	10,3 %

Tenerife

Peak power:	529 MW
Load demand:	3.225 GWh
Load demand coverage with RES:	21,0 %

Projected Subsea Interconnection

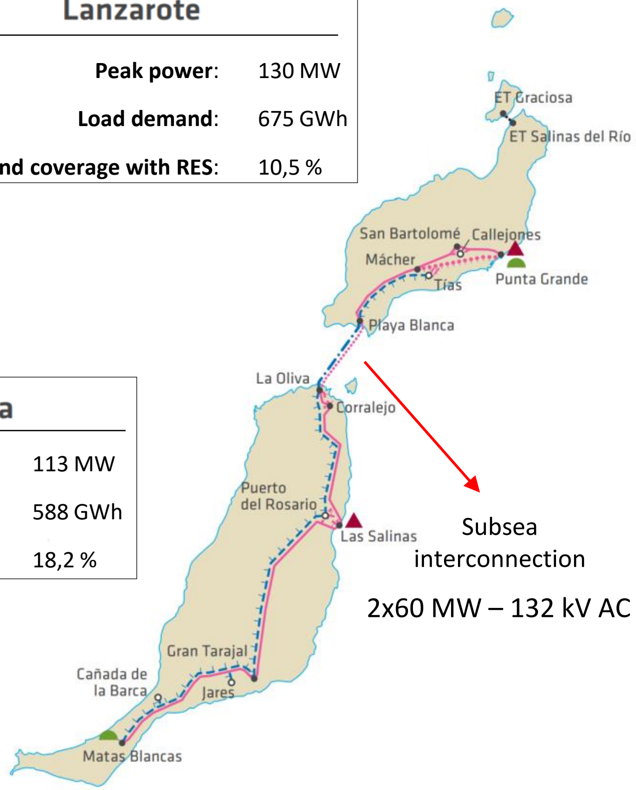
2x50 MW – 66 kV AC

Lanzarote

Peak power:	130 MW
Load demand:	675 GWh
Load demand coverage with RES:	10,5 %

Fuerteventura

Peak power:	113 MW
Load demand:	588 GWh
Load demand coverage with RES:	18,2 %



Subsea interconnection

2x60 MW – 132 kV AC

El Hierro

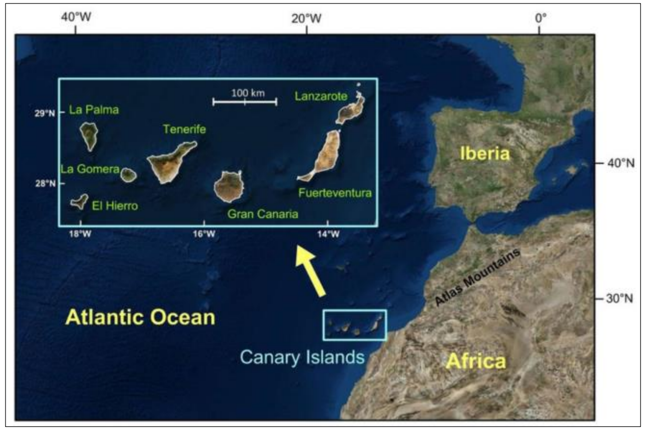
Peak power:	8,6 MW
Load demand:	48 GWh
Load demand coverage with RES:	56,1 %

La Gomera

Peak power:	11,9 MW
Load demand:	68 GWh
Load demand coverage with RES:	0,2 %

Gran Canaria

Peak power:	529 MW
Load demand:	3.204 GWh
Load demand coverage with RES:	20,6 %



Current situation

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High reliance in fossil fuels

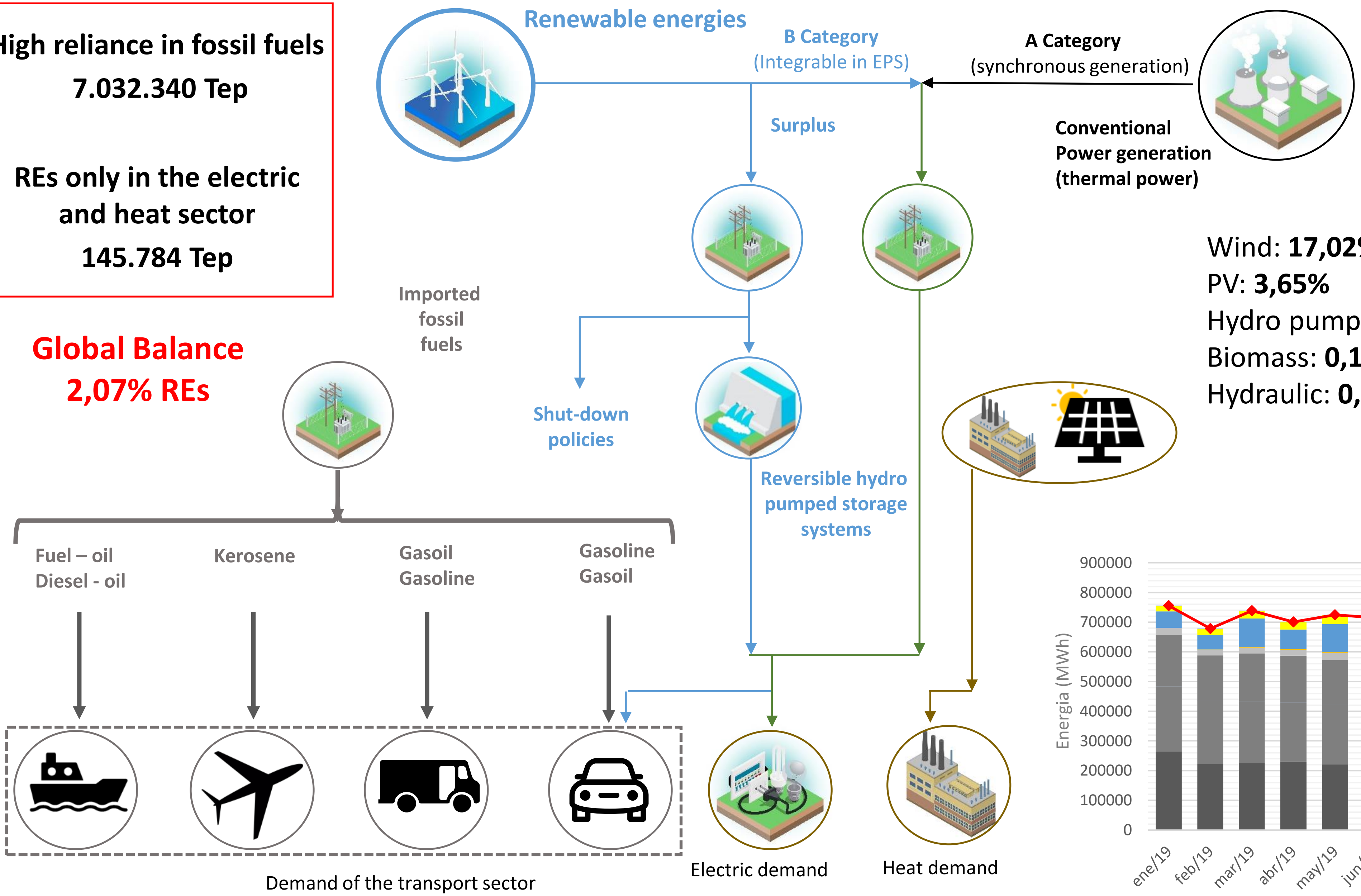
7.032.340 Tep

REs only in the electric and heat sector

145.784 Tep

Global Balance

2,07% REs



Wind: **17,02%**
PV: **3,65%**
Hydro pump: **0,29%**
Biomass: **0,10%**
Hydraulic: **0,04%**

REs in the energy mix

Year 2022 (until October)
21,7%

Year 2021
19,5%

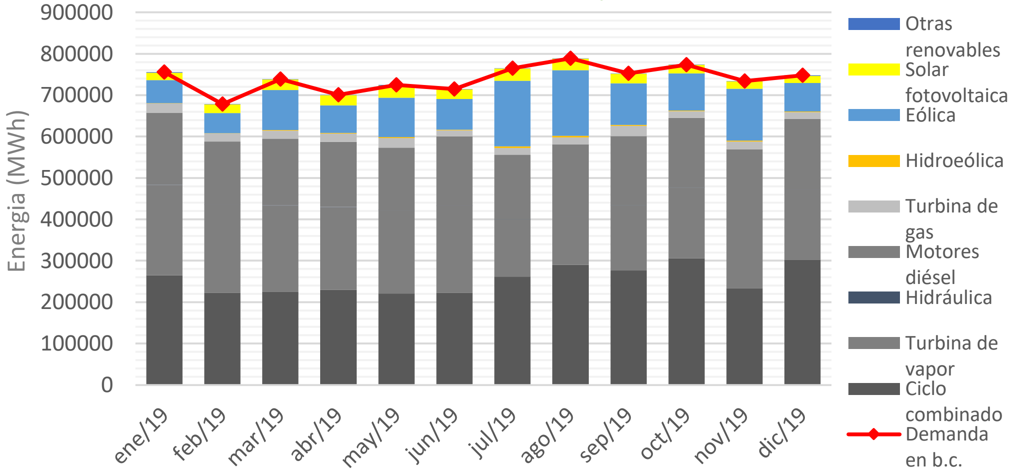
Year 2020
17,0%

Year 2019
16,4%

Year 2018
10,0%

Year 2017
7,6%

+14,1%
6 years



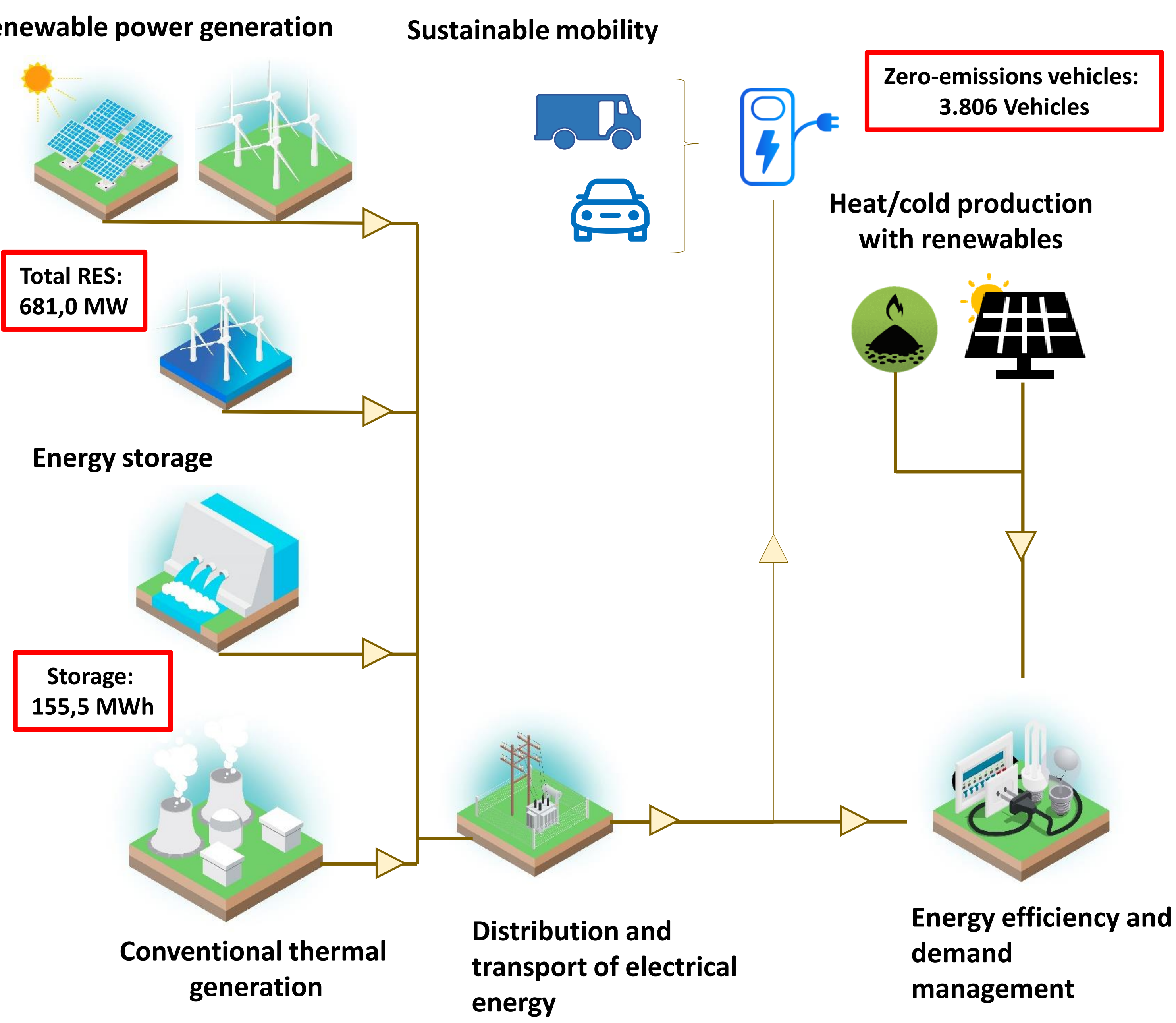
Initial situation (2020)

Fuel demand	3.531 kTm	Electrical power demand	8.355 GWh	Thermal energy demand	158 KTep	Number of vehicles	1.745.742

Renewable power generation	Power
Onshore wind	463,4 MW
Offshore wind	5,2 MW
PV	182,3 MW
PV Off-shore	0,0 MW
PV self-consumption	24,4 MW
Biomass	3,7 MW
Wave energy	0,0 MW
High enthalpy geothermal	0,0 MW
Solar thermal	0,0 MW
Small scale hydro	2,0 MW

Storage	Energy
Consumer storage	- MWh
Grid storage	5,5 MWh
Large scale storage	150 MWh

Conventional thermal generation	Power
Conventional Thermal	2.357 MW
Hydrogen engines/turbines	0 MW



Mobility	Ratio
Promoting public transport	0,81Veh./citizen.
Electric vehicle	3.806
Slow charging stations	156
Fast charging stations	75
Rapid charging stations	81
Hydrogen vehicles	7
Hydrogen stations	0
Other zero emissions alternatives	0
Maritime transport e-solutions	0 GWh
Maritime transport hydrogen	0 tH2

Heat sector	Ratio
Solar thermal	125.019 m^2
Low enthalpy geothermal	32 MW
Biomass	- toe/year
Cogeneration	89,98 MW

Communities and buildings	Ratio
Energy efficiency	-
Demand management	No

General structure of PTECan

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Plan de Transición Energética de Canarias

1 – PV self-consumption strategy

2 – Energy storage strategy

3 – Electric Vehicle strategy

4 - Geothermal energy strategy

5 – Marine Energy strategy

6-Manageable Energy strategy

7 – Green hydrogen strategy

8 – Demand Side Management and Smart-Grid

1040 *DECRETO 9/2021, de 18 de febrero, por el que se encomienda a la Consejería de Transición Ecológica, Lucha contra el Cambio Climático y Planificación Territorial la elaboración de un plan de transición energética para la Comunidad Autónoma de Canarias.*

PROYECTOS DE LEY

EN TRÁMITE
10L/PL-0018 De Cambio Climático y Transición Energética de Canarias. Página 1

OBJECTIVE
Decarbonisation of the Canarian energy system

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ENERGY DEMAND
Time evolution according to:
- ☒ Gross Domestic Product
- ☒ Population
- ☒ Price of fuels
- ☒ Right Emission Prices
- ☒ Climate Change IPCC

ECONOMIC DIMENSION
- Self-consumption
- Decarbonisation of the economy
- Blue economy: promotion of marine renewable energy
- Low carbon economy: promotion of RES and the electrification of heat demand and mobility
- Circular economy: energy recovery from waste

Alternative 0
Trend

Alternative 1
100% RES
0 % CO_2
2040
2030 2040

Alternative 2
100% RES
0 % CO_2
2040
2030 2040

DIMENSION SOCIAL
- Exploit new sources of green employment
- Fair Energy Transition
- Fight against energy poverty
- Promotion of energy communities
- Energy democratization

DIAGNOSIS
- SWOT
- Specific objectives

ACTION PLAN
- Insularized
- Anualized

ECONOMIC ANALYSIS
- Financing
- Positive externalities

ENVIRONMENTAL DIMENSION:
- Conservation of landscape wealth
- Reduction of environmental pollution
- Mitigation of climate change
- Biodiversity Conservation

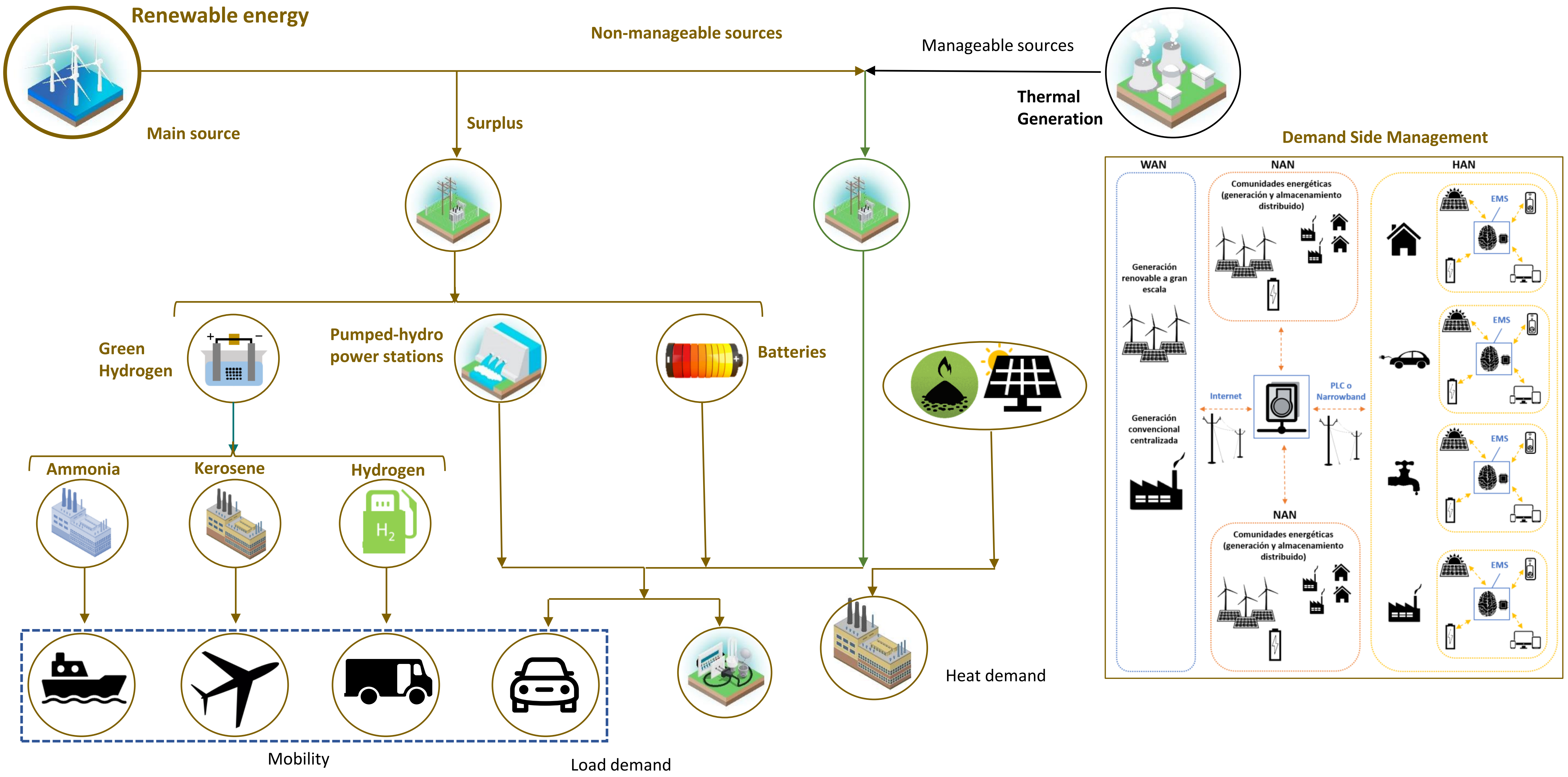
→ **Strategic Environmental Assessment**

ANNUAL OBJECTIVES

INVESTMENT

ZONIFICATION

Basic scheme of the proposed energy system



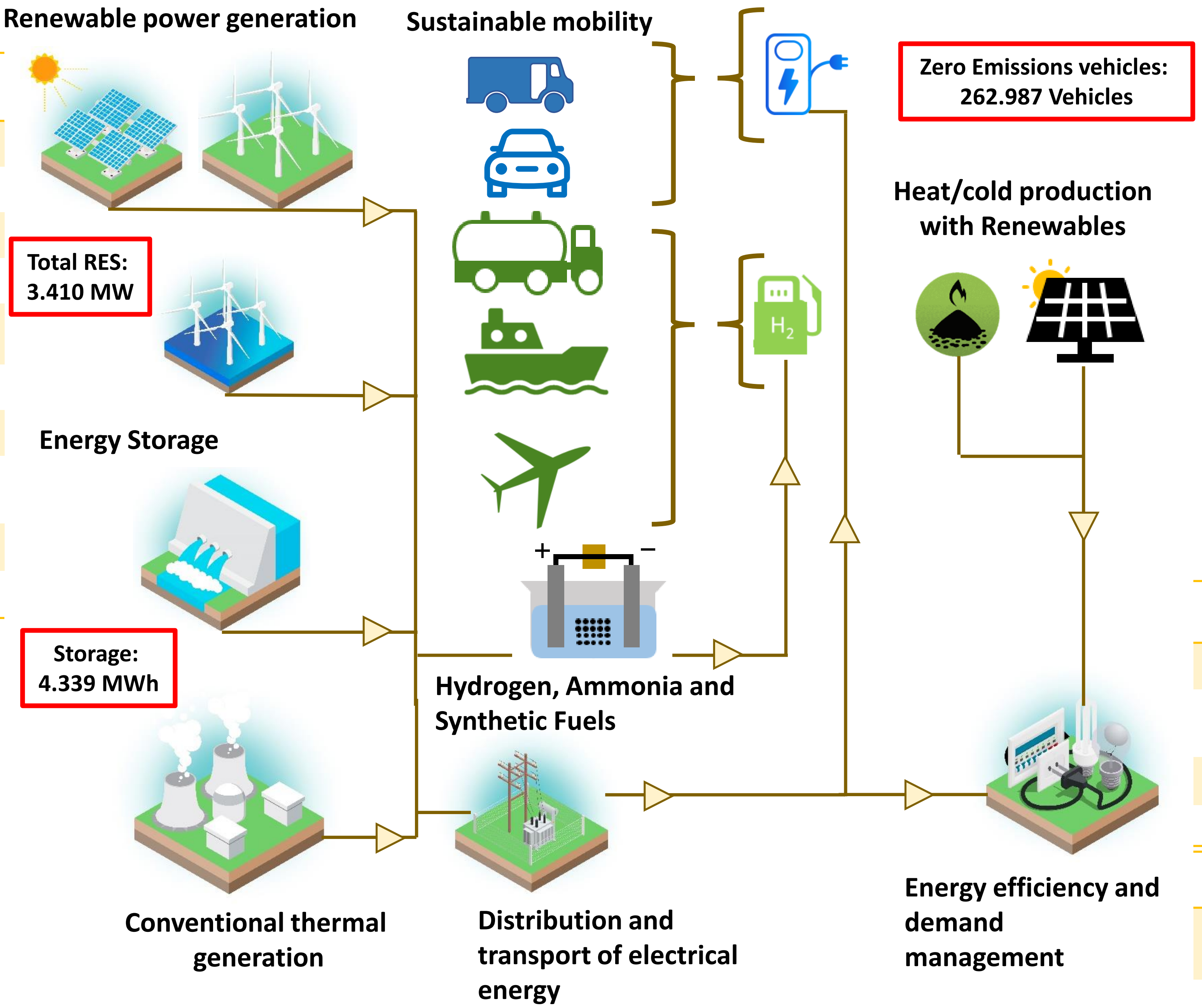
Objective 2030

Fuel demand	5.426 kTm	Electr. power demand	8.692 GWh	Thermal energy demand	130 kTep	Number of vehicles	1.669.825

Renewable power generation	Power
Onshore wind	1.706 MW
Offshore wind	330 MW
PV	759 MW
Floating PV	31 MW
PV self-consumption	524 MW
Biomass	18 MW
Wave energy	4 MW
High enthalpy geothermal	30 MW
Solar thermal	6 MW
Small scale hydro	2 MW

Storage	Energy
Consumer storage	827 MWh
Grid storage	162 MWh
Large scale storage	3.350 MWh

Conventional power generation	Power
Conventional thermal	1.440 MW
Hydrogen turbines/engines	45 MW



Mobility	Ratio
Promoting public transport	0,717 Veh./citiz.
Electric vehicle	225.424 .
Slow charging stations	249.765
Fast charging stations	5.692
Rapid charging stations	1.700
Hydrogen vehicles	7.183
Hydrogen stations	17
Other zero emissions alternatives	13.847 veh.
Maritime electrical transport	168 GWh
Maritime hydrogen transport	6.834 tH_2

Heat sector	Ratio
Solar thermal	456.272 m^2
Low enthalpy geothermal energy	59 MW
Biomass	15.423 Toe/year
Cogeneration	8 MW

Communities and buildings	Ratio
Energy efficiency	38% increase from year 2005
Demand management	VE

Global objectives of PTECan

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Improving energy efficiency

27%

Greenhouse Gas Emissions compared to 1990

+2,6%

-37%

Greenhouse gases emissions compared to 2010 (ref. PNIEC)

Renewable energy in electricity generation

62%

Renewable on the end use of energy

29%

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Economic indicators

Total investment (2021 – 2030)	6.248 M€
Total investment (2021 – 2040)	39.170 M€
Savings in operating cost for energy systems of the Canary Islands	937 M€/año

Comparison 2019 - 2030

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	Wind On-shore	PV	PV Self-Consumption	Total SP	Wind Off-shore	PV Off-shore	Wave converter	Total Off-shore
2019	419,5 MW	181,7 MW	12,4 MW	194,1 MW	5,5 MW	0 MW	0 MW	5,5 MW
2022 October Current situation	576,8 MW	205,4 MW	56,3 MW	261,7 MW				
2030	1.706,5 MW	758,7 MW	524,3 MW	1.283 MW	330,0 MW	30,8 MW	4,0 MW	364,8 MW

	Pumped-Hydro	Thermal generation	Hydrogen turbines	Geothermal	Small scale hydro	Biomass	Solar thermal
2019	150 MWh	2.357 MW	0 MW	0 MW	2 MW	3,70 MW	0 MW
2030	3.350 MWh	1.440 MW	45 MW	30 MW	2,6 MW	18,2 MW	5,6 MW

	Zero Emission vehicles	Charging stations (chargers)	Hydrogen stations	Biomass	Solar thermal	Low Enthalpy Geothermal
2019	2.578	312	0		123.719 m^2	32 MWt
2030	262.987	257.157	17	15.423 t/year	456.272 m^2	59 MWt

Technical aspects

- Avoid recharging vehicles for long periods of time. Hydrogen is stored in tanks, refuelling the vehicle in similar times to diesel vehicles.

Electric busses:
600 kWh

Daily service
300 km/día

Charging time

Charge: 50 kW
Time: 12 hours

H2 Alternative

Charge: 350 bar
Time: 9 minutes

- **Priority niche: Vehicles over 3.500 kg.**
- **Average consumption**: 6 kg/100 km.
- **Autonomy**: 400 – 600 km.
- **Supply pressure**: 350 bar.
- **Charging time: Less than 9 minutes.**
- **Engine:** Electric coupled to fuel cell.
- **Tank capacity**: 30 – 45 kgH2.

Standard Features

Economic aspects

- **Cost parity.** It determines the price at which hydrogen should be sold so that users pay the same as with the current fuel (diesel for this class of vehicles).

It depends on the type of vehicle (daily fuel consumption) and the price of the fuel it replaces.

Final use of hydrogen closest to economic profitability.

Keep in mind that the change of vehicle has a cost as a direct consequence of the technology.

Cost parity between hydrogen and diesel according to the price of diesel					
Vehicle	Reference	Reference	Reference	Reference	Reference
Taxi	0,5 €/l	0,8 €/l	0,95 €/l	1,20 €/l	1,50 €/l
Bús (Clase B)	3,65 €/kgH_2	3,08 €/kgH_2	3,65 €/kgH_2	4,62 €/kgH_2	5,77 €/kgH_2
Bús (Clase A)	3,57 €/kgH_2	5,71 €/kgH_2	6,79 €/kgH_2	8,57 €/kgH_2	10,71 €/kgH_2
Truck	3,13 €/kgH_2	5,00 €/kgH_2	5,94 €/kgH_2	7,50 €/kgH_2	9,38 €/kgH_2
Vehicle	3,39 €/kgH_2	5,42 €/kgH_2	6,44 €/kgH_2	8,13 €/kgH_2	10,17 €/kgH_2

Gasoil: 0,5 €/l

Hydrogen: 3,6 €/kgH2

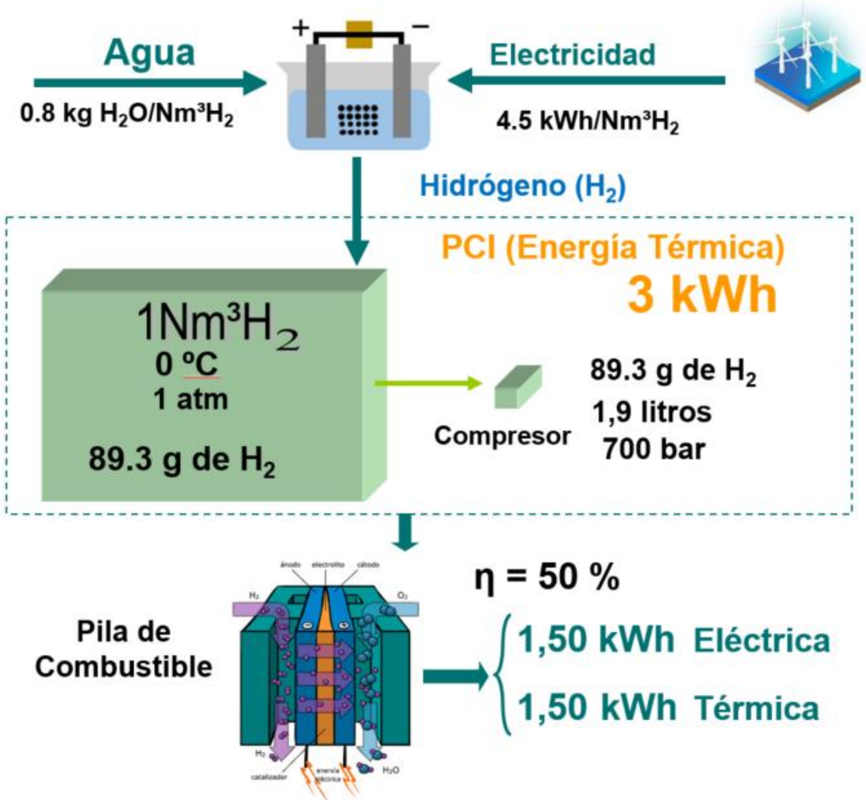
Gasoil: 0,95 €/l

Hydrogen: 6,8 €/kgH2

Re-electrification to support weak and isolated grids

Technical aspects

- In general, the re-electrification of hydrogen is not advisable since the overall efficiency is 33%.



$$\frac{1{,}5\ \text{kWh}}{4{,}5\ \text{kWh}} = 33\%$$

- However, it is an interesting option **to bring renewable energy closer to locations where wind or photovoltaic cannot be installed**, and is also manageable.

Protected and isolated areas

Economic aspects

- **Cost parity.** Determines the price at which hydrogen should be sold if it replaces electricity purchased from the grid or propane (when Combined Heat & Power is used).

Parity analysis		
Inputs	**Case 1**	**Case 2**
Power of the fuel cell	400 kW	800 kW
Annual load demand	3.338 MWh	6.244 MWh
Annual heat demand	3.338 MWh	6.244 MWh
Quantity of hydrogen	190 tH_2/año	320 tH_2/año
LCV of propone	12,88 kWh/kg	

This option is close to economic profitability but the low price of electricity compared to the cost of production distorts the market.

Cost parity in re-electrification options (Other cases)				
Inputs	**Option 1**	**Option 2**	**Option 3**	**Option 4**
Price of electricity	0,07 €/kWh	0,09 €/kWh	0,12 €/kWh	0,15 €/kWh
Price of propane	1,07 €/kg	1,10 €/kg	1,15 €/kg	1,20 €/kg
Parity only electricity	1,37 €/kgH_2	1,76 €/kgH_2	2,34 €/kgH_2	2,93 €/kgH_2
Parity only CHP	2,99 €/kgH_2	3,42 €/kgH_2	4,08 €/kgH_2	4,75 €/kgH_2

Electricity: 0,12 €/kWh → **Hydrogen: 2,3 €/kgH2**

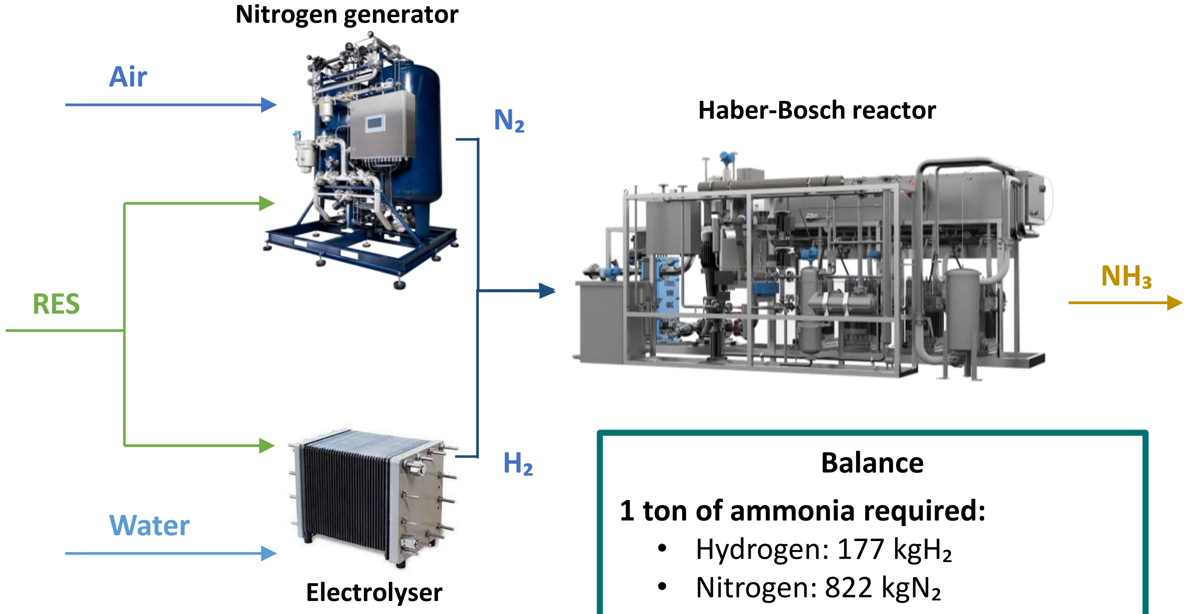
CHP: **0,12 €/kWh** **1,15 €/kg** → **Hydrogen: 4,1 €/kgH2**

Ammonia as a fuel for maritime navigation

Technical aspects

- Ammonia can be produced by the reaction of hydrogen with nitrogen (HABER-BOSCH process).
- In maritime transport sector, optimization of space is vitally important:

  - ✓ Hydrogen at liquid phase → -253 ºC.
  - ✓ Ammonia at liquid phase → -33 ºC ó 9 bar & t_{amb}.



Balance

1 ton of ammonia required:

- Hydrogen: 177 kgH_2
- Nitrogen: 822 kgN_2
- Electricity: **11 MWh/tNH_3**

Economic aspects

- **Cost parity.** Determine the price at which ammonia should be sold to replace fuel and diesel. In addition, we have also estimated the price at which hydrogen should be also sold to achieve the cost objective of ammonia.

Cost parity in ammonia use options in the maritime sector				
Price of fuel	0,3 €/kg	0,5 €/kg	0,6 €/kg	0,7 €/kg
Price of diesel	0,5 €/kg	0,7 €/kg	0,8 €/kg	0,9 €/kg
Ammonia Price to avoid fuel	0,12 €/$kgNH_3$	0,21 €/$kgNH_3$	0,25 €/$kgNH_3$	0,29 €/$kgNH_3$
Ammonia Price to avoid diesel	0,19 €/$kgNH_3$	0,27 €/$kgNH_3$	0,31 €/$kgNH_3$	0,35 €/$kgNH_3$
Hydrogen price for the production of NH3 to replace fuel	0,43 €/kgH_2	0,72 €/kgH_2	0,87 €/kgH_2	1,01 €/kgH_2
Hydrogen price for the production of NH3 to replace diesel	0,68 €/kgH_2	0,95 €/kgH_2	1,09 €/kgH_2	1,22 €/kgH_2

The results show that the business model is still far from economic profitability, but this is an alternative that makes the decarbonisation of the maritime sector possible.

Diesel: 0,8 €/kg ← → **Hydrogen: 0,95 €/kgH2**

Fuel: 0,5 €/kg ← → **Hydrogen: 0,72 €/kgH2**

Canary Islands hydrogen strategy

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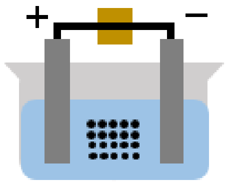
Price at which customers would be willing to pay for hydrogen, taking as a reference the energy source it replaces

Road heavy transport (>3.500 kg)	3,6 – 6,8 €/kgH_2
Re-electrification	2,3 – 4,1 €/kgH_2
Large-scale Energy storage	1,1 – 2,8 €/kgH_2
Maritime transport	0,7 – 1,0 €/kgH_2
Air transport	0,5 – 0,8 €/kgH_2

Production cost



Cost of hydrogen production in the Canary Islands

6,5 – 7,2 €/kgH_2

Highly dependent on the cost of electricity supply

Requires the use of RES as cheap as possible

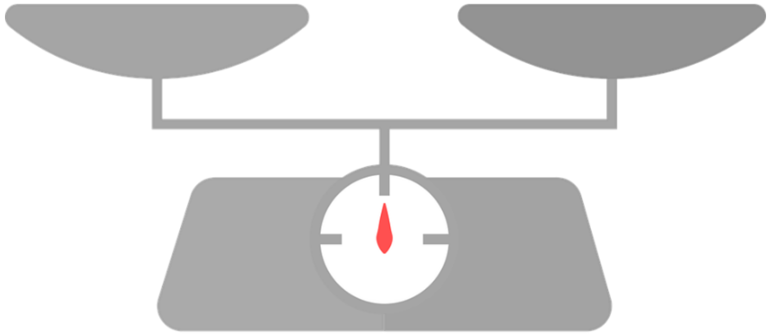
(Curtailments)

Operate electrolyser at full capacity

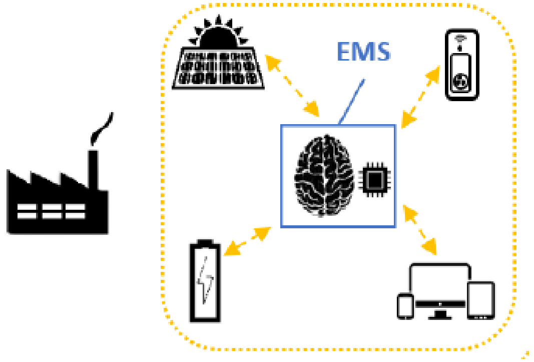
The cost of the technology implies that, from an economic point of view, electrolysers must operate as long as possible.

Oversize electrolysers

To produce hydrogen only in peak hours of wind and photovoltaic production



The electrification of transport can be another strategic solution to increase the integration of RES in the energy mix of the Canary Islands.

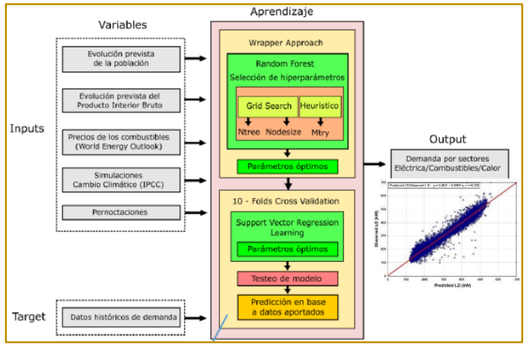


Diagnosis of the potential of the Canary Islands. Methodology

Estimation of the **hydrogen demand**

Estimation of the **hydrogen capacity production**

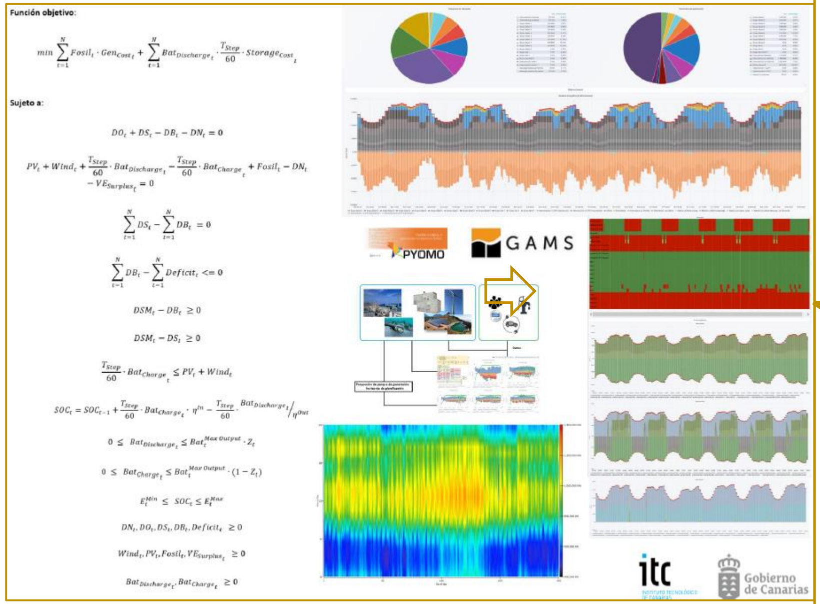
1

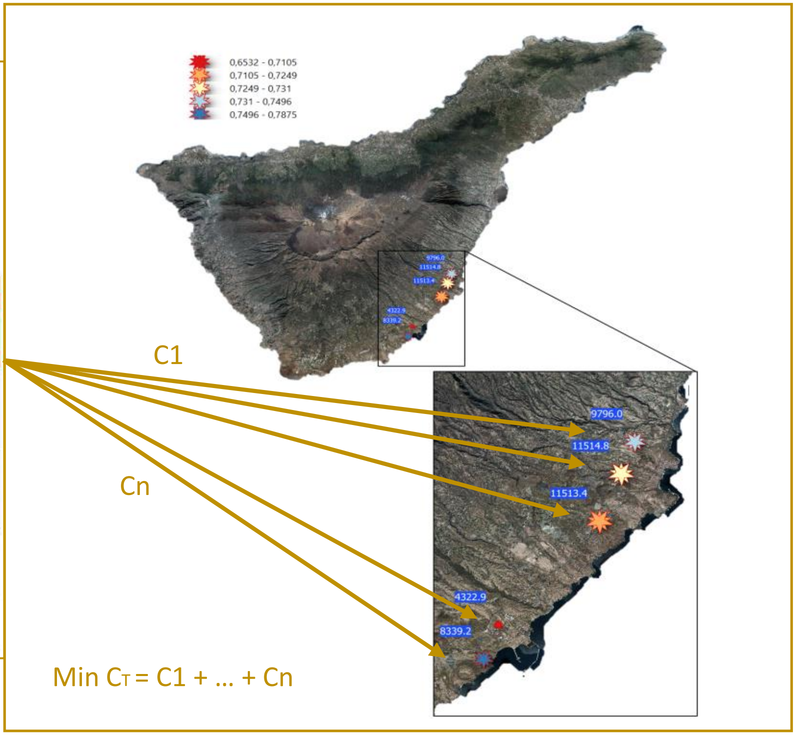


- Estimation of demand by market niches:
  - Heavy road transport sector (>3.500 kg).
  - Maritime transport sector (between islands).
  - Air transport (between islands).
  - Re-electrification: 15% Tourist/Industrial load demand.
  - Large-scale storage: LZ and FV.
- Input data: Socioeconomic information and historical data of demand.
- Multivariate Linear Regression Method: Random Forest.

2

- **Multinode MILP** optimization model.
  - One node for each electrical substation with Category B renewable power.
- Simulates the behaviour of electrolysers in each location.
- For each substation **it simulates different sizes of electrolysers, choosing the configuration that satisfy the H2 demand at the minimum cost.**





Hydrogen requirements to decarbonise the Canary Islands

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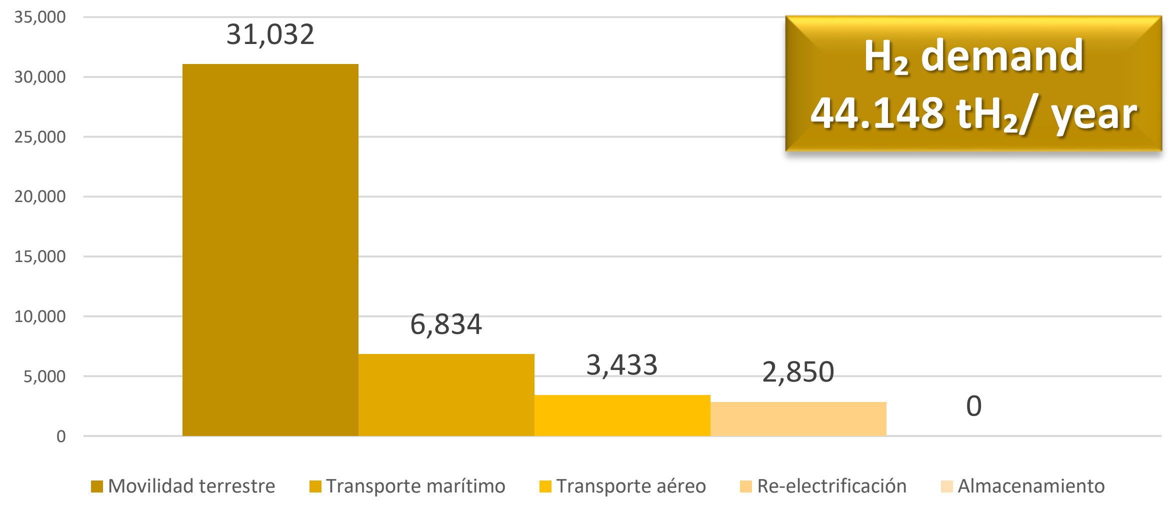
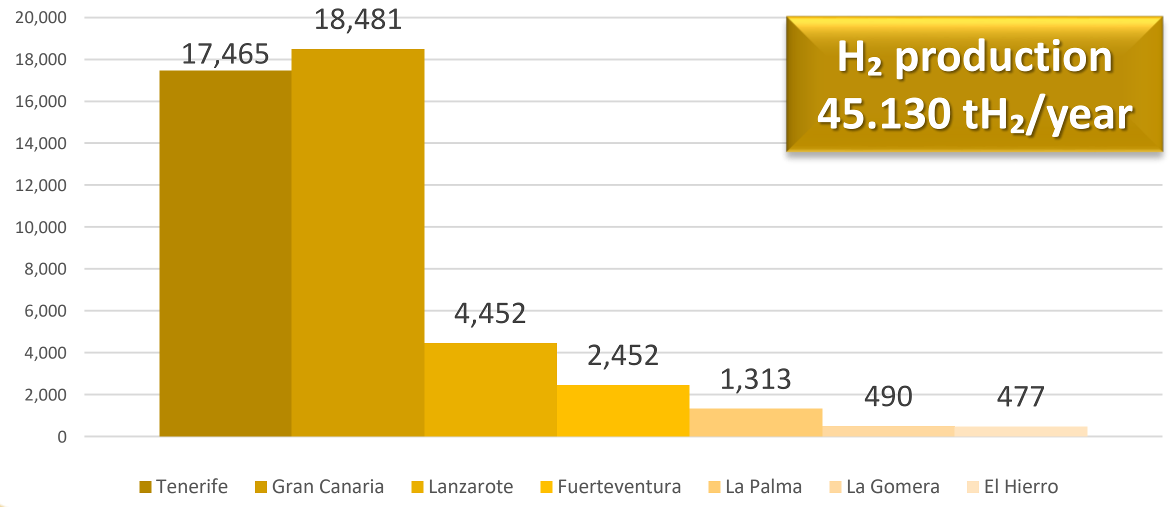
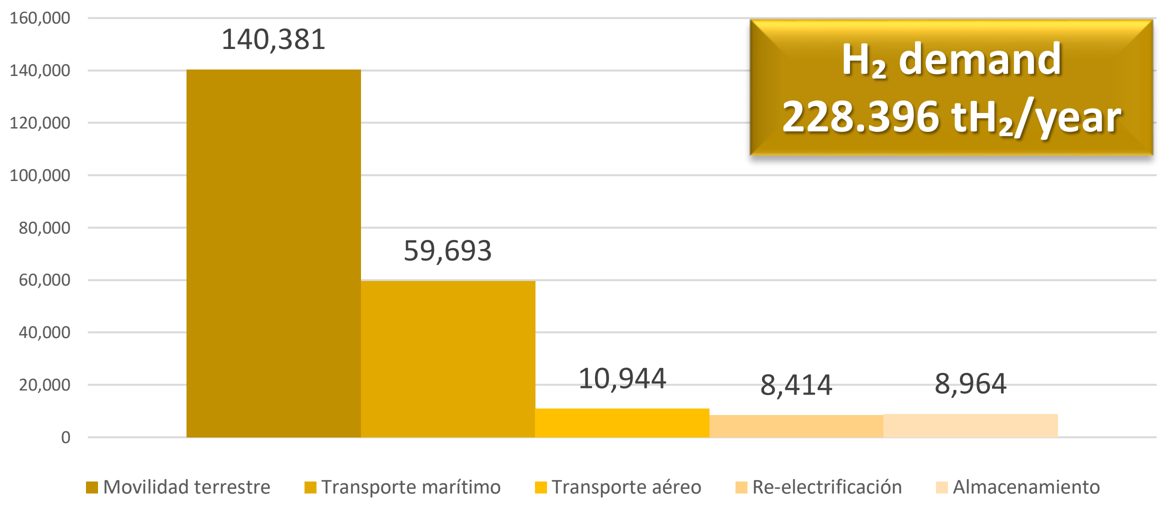
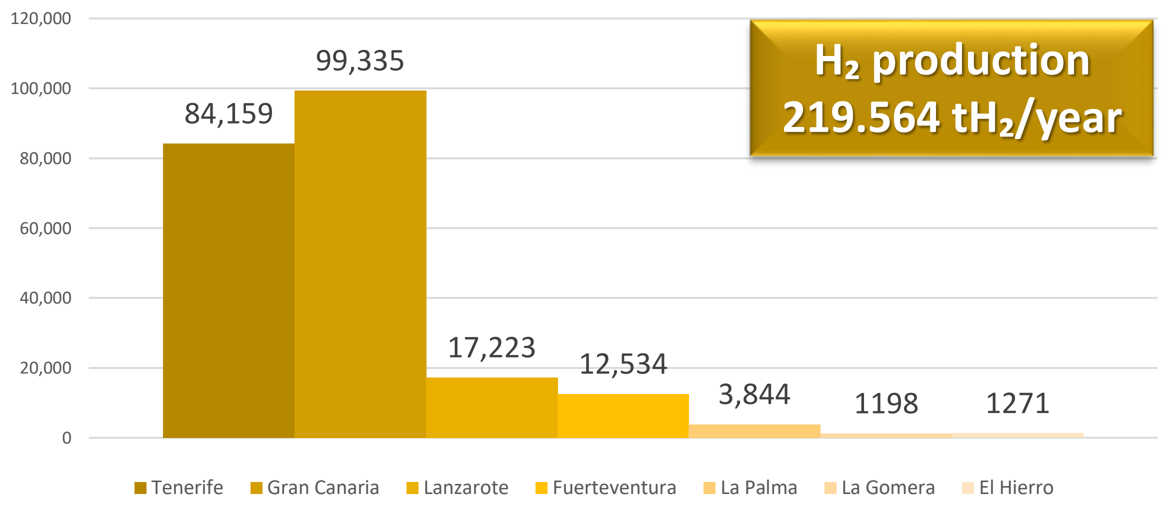
2030





2040





Summary of results for the Canary Islands

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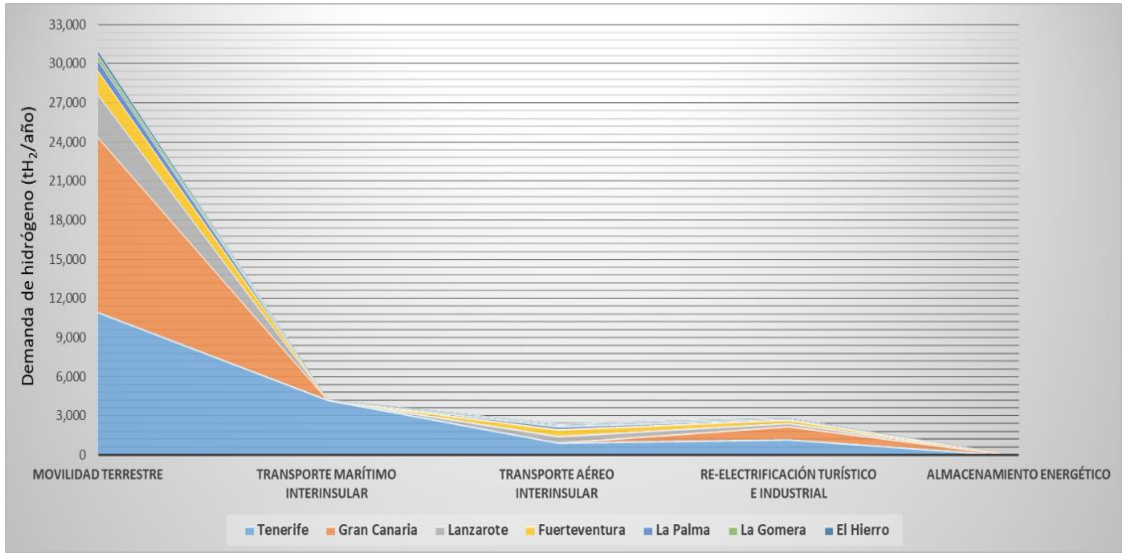
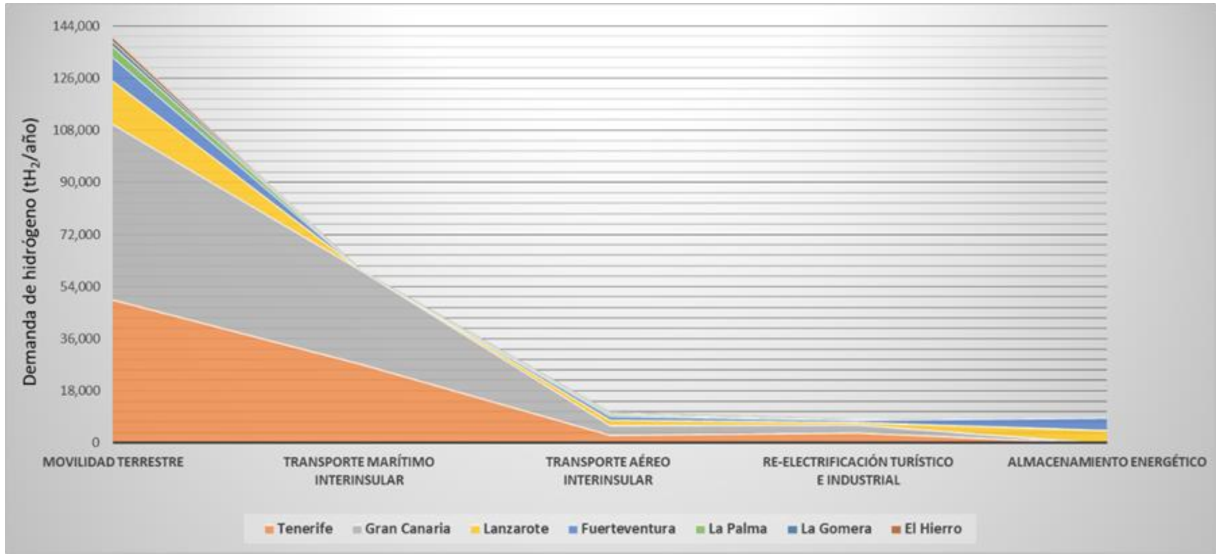
Hydrogen demand by sectors and islands by 2030



Hydrogen demand by sectors and islands by 2040



Hydrogen production by islands by 2030

Sistemas de producción de hidrógeno para satisfacer la demanda de hidrógeno en el año 2030

Isla	Electrolizador (MW)	Prod. eólica total (MWh)	Prod. FV total (MWh)	Prod.EERR destinada a H_2 (MWh)	H_2 producido (kgH_2/h)	H_2 producido anual (tH_2/año)	Prod. máxima (kgH_2/h)	Factor de capacidad (%)	Pot. media electrol. (kW)
Tenerife	170	1.597.099	969.955	1.155.888	1.994	17.465	2.569	78,0%	131.950
Gran Canaria	170	2.546.938	1.016.991	1.223.076	2.110	18.481	2.569	82,1%	139.620
Lanzarote	40	739.873	196.000	294.660	508	4.452	604	84,1%	33.637
Fuerteventura	25	144.474	295.436	62.266	131	2.452	378	74,1%	18.525
La Palma	13	176.340	29.807	86.869	150	1.313	196	76,3%	9.917
La Gomera	5	47.477	8.291	32.457	56	490	76	74,1%	3.705
El Hierro	4	62.180	6.964	31.570	54	477	60	90,1%	3.604
Canarias	**427**	**5.314.381**	**2.523.443**	**2.886.786**	**5.002**	**45.130**	**6.452**	**79,8%**	**340.958**

Hydrogen production by islands to 2040

Sistemas de producción de hidrógeno para satisfacer la demanda de hidrógeno en el año 2040

Isla	Electrolizador (MW)	Prod. eólica total (MWh)	Prod. FV total (MWh)	Prod.EERR destinada a H_2 (MWh)	H_2 producido (kgH_2/h)	H_2 producido anual (tH_2/año)	Prod. máxima (kgH_2/h)	Factor de capacidad (%)	Pot. media electrol. (kW)
Tenerife	840	3.807.842	2.354.377	5.569.865	9.607	84.159	12.692	75,7%	635.829
Gran Canaria	970	5.935.158	1.095.053	6.574.170	11.340	99.335	14.732	77,0%	750.476
Lanzarote	166	1.057.702	196.000	1.139.879	1.966	17.223	2.508	78,4%	130.123
Fuerteventura	133	1.138.399	348.781	829.527	1.431	12.534	2.010	71,2%	94.695
La Palma	38	230.394	41.414	254.422	439	3.844	577	76,0%	29.044
La Gomera	15	66.468	16.582	79.285	137	1.198	227	60,3%	9.051
El Hierro	15	74.616	15.669	84.098	145	1.271	227	64,0%	9.601
Canarias	**2.177**	**12.310.579**	**4.067.877**	**14.531.245**	**25.064**	**219.564**	**32.973**	**76,2%**	**1.658.819**

Canary Islands Institute of Technology

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