International Meeting on Marine Renewable Energy

Perspectives of marine renewable energies in the Canary Islands

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Canary Islands Institute of Technology

Las Palmas de Gran Canaria, April 5th 2019

SOCLIMPACT

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Renewable Energy Department

CANARY ISLANDS INSTITUTE OF TECHNOLOGY

MISSION

Support the Regional Government in implementing sustainable energy policies, and contribute to position ITC as a centre of reference in European Islands, in applied research in the fields of Renewable Energy Sources (RES).

OBJECTIVES

- Contribute to increase energy efficiency, and develop solutions to overcome existing technical barriers to maximization of RES penetration in island electrical systems
- Promote the Canary Islands as an experimental platforms for demonstration of RES and complementary technologies
- Support efforts for transferring clean energy technologies to less developed countries, especially of the Western African Coast

ENERGY FRAMEWORK IN THE CANARY ISLANDS

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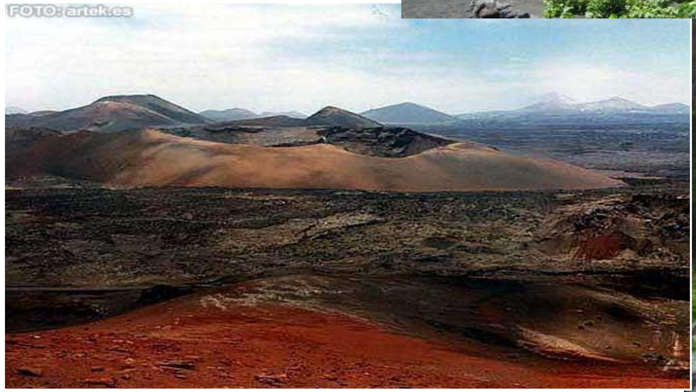
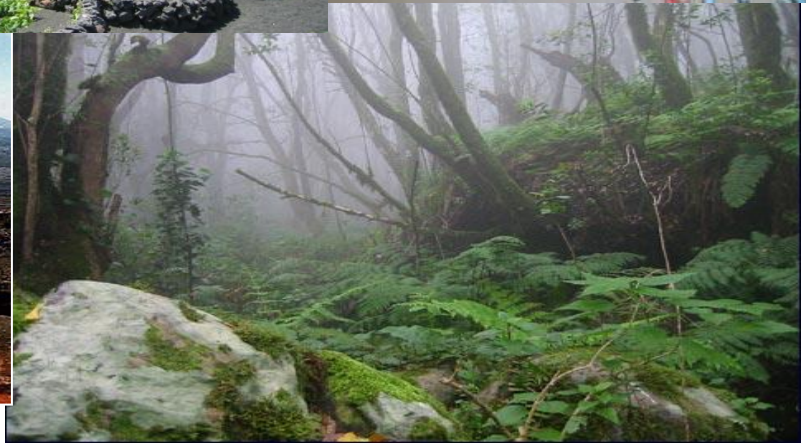
- Canary Islands Energy System
  - Fossil fuels
  - Electrical system
- Potential for RES
- Existing barriers to RES
  - Territorial constraints
  - Air-safety regulation
  - Bathymetry
  - Grid stability
  - Economic issues
- Strategy for maximizing RES
  - Stability analysis of island grids
  - Forecasting
  - Demand Management
  - Energy storage





ENERGY SYSTEM

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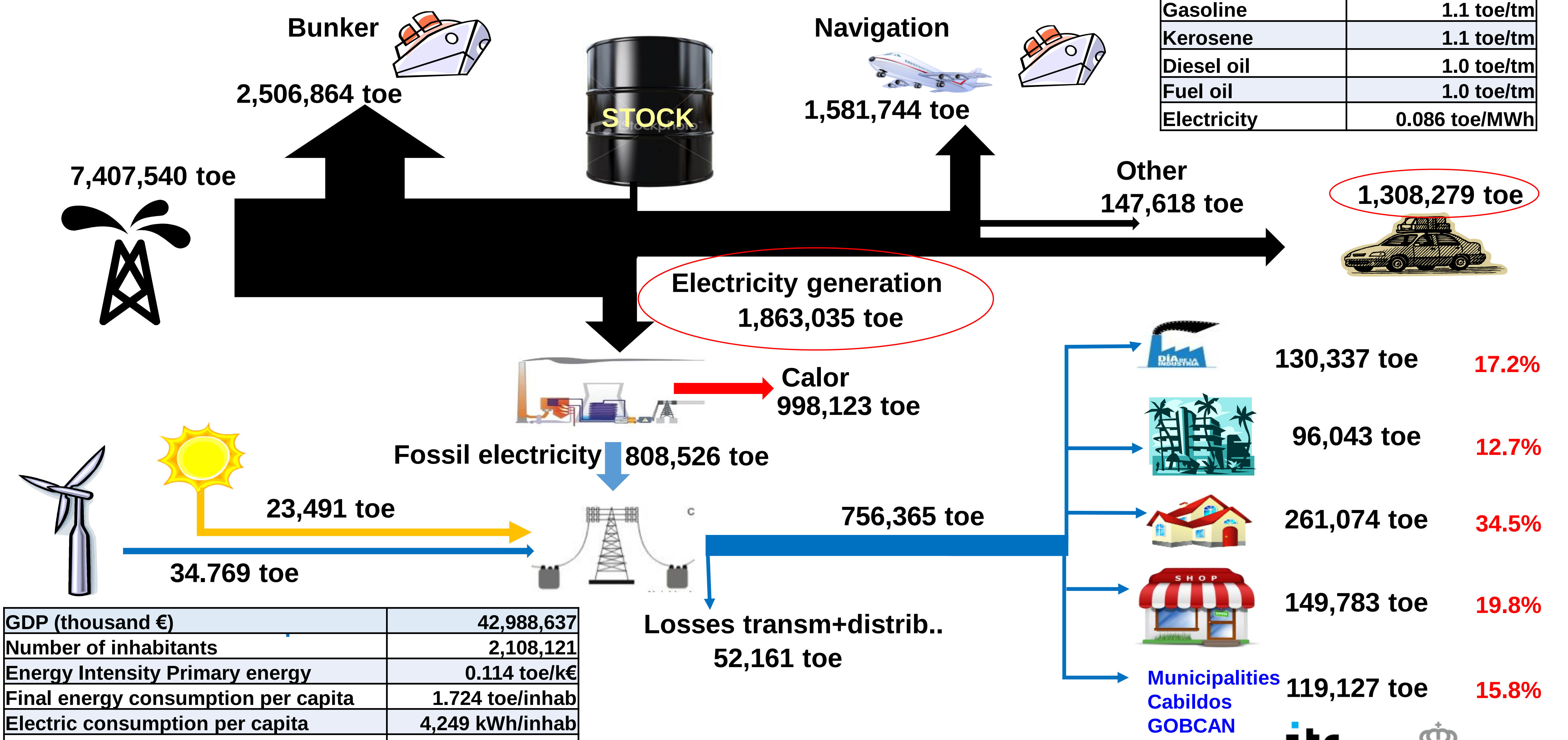
BALANCE ENERGÉTICO DE CANARIAS 2017

Conversion factor	
Crude oil	1.0 toe/tm
Gasoline	1.1 toe/tm
Kerosene	1.1 toe/tm
Diesel oil	1.0 toe/tm
Fuel oil	1.0 toe/tm
Electricity	0.086 toe/MWh



GDP (thousand €)	42,988,637
Number of inhabitants	2,108,121
Energy Intensity Primary energy	0.114 toe/k€
Final energy consumption per capita	1.724 toe/inhab
Electric consumption per capita	4,249 kWh/inhab
Energy intensity (electric)	0.21 kWh/€
Average cost of lectric generation	0.138 €/kWh

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CANARY ISLANDS ENERGY SYSTEM 2017

- In the current energy mix, imported oil accounts for 98.27% of total primary energy in the archipelago, and 92.79 % in electric power generation

- Power generation is more expensive in islands given the small size of the power plants, and high cost of fuel (continental power stations benefit from higher economies of scale, and cheaper nuclear, hydro and natural gas generation)

- The same electricity price in the Canary Islands as in mainland Spain, through a tariff cross-subsidy (that contributes to the national tariff deficit)

- Average yearly generation cost in the Canary Islands was 0.22 €/kWh in he 2014. In 2017 0.13 €/kWh.

- Wind and PV have gone past the grid-parity. Wind cost 0.04 – 0.06 €/kWh, and cost of PV below 0.1 €/kWh.

Yearly generation cost (€/kWh)		
	2014	2017
OIL PRICE	99 $/Bb	51 $/Bb
El Hierro	0.26	0.55
La Gomera	0.22	0.21
La Palma	0.19	0.19
Lanzarote - Fuerteventura	0.20	0.13
Tenerife	0.18	0.13
Gran Canaria	0.19	0.12

Any energy supplied from RES has a positive impact as a means of reducing the “Excess-cost” of the Canary Island electric system, and its contribution to the National “Tariff Deficit”

INSTALLED POWER AND ELECTRICITY 2017

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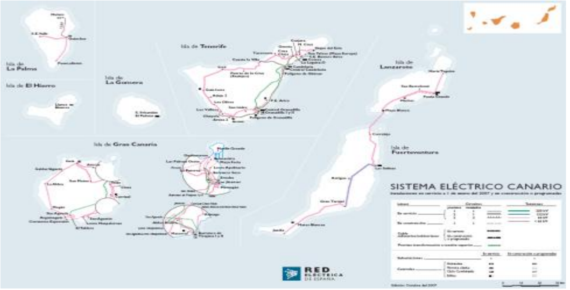
TOTAL	
Power	3,119.7 MW
Energy	9,401 GWh

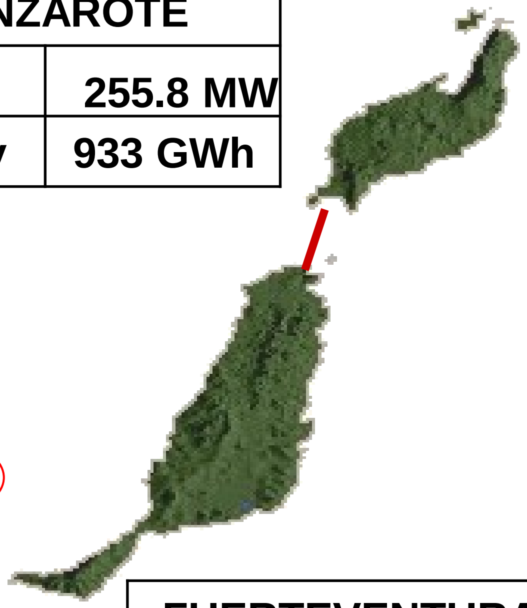


EERR 7.21 % (677.45 GWh)

LA PALMA	
Power	117.7 MW
Energy	279 GWh

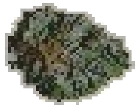
TENERIFE	
Power	1,289.9 MW
Energy	3,697 GWh

LANZAROTE	
Power	255.8 MW
Energy	933 GWh

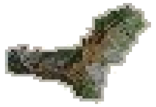


GRAN CANARIA	
Power	1,183.3 MW
Energy	3,650 GWh

LA GOMERA	
Power	21.6 MW
Energy	77.1 GWh



EL HIERRO	
Power	37.8 MW
Energy	45 GWh

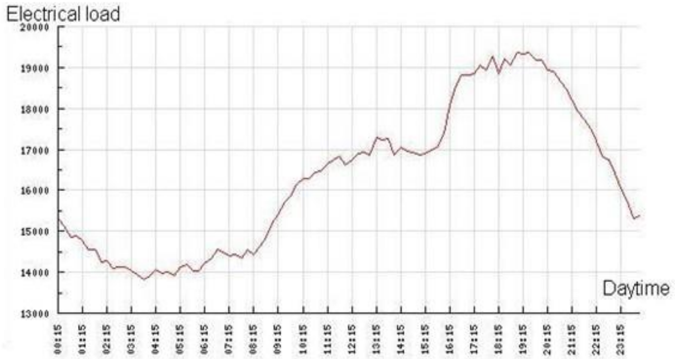


FUERTEVENTURA	
Power	213.6 MW
Energy	721 GWh

CHARACTERISTICS OF ELECTRICITY DEMAND

- No significant seasonal changes
- Large differences between the low valley and evening peak-demand hours
- No constant energy demands, due to low specific weight of the industry

		POWER (MW)			
	Demand (GWh)	Installed	Peak	Valley	Max/Min
Gran Canaria	3.649.971	1.183,3	553,0	318,0	1,74
Tenerife	3.696.507	1.289,9	560,0	308,0	1,82
Lanzarote	933.158	255,8	141,0	78,0	1,81
Fuerteventura	720.965	213,6	122,0	68,0	1,79
La Palma	278.700	117,8	45,8	23,5	1,95
La Gomera	77.125	21,6	12,2	8,5	1,44
El Hierro	45.037	37,8	8,0	4,5	1,78
Canarias	**9.401.462**	**3.119,7**			



Diesel only
- La Gomera
- El Hierro
- La Palma

Steam units:
- Gran Canaria
- Tenerife

Combined cycles
- Gran Canaria 463,2 MW
- Tenerife 456,8 MW

RES POTENTIAL

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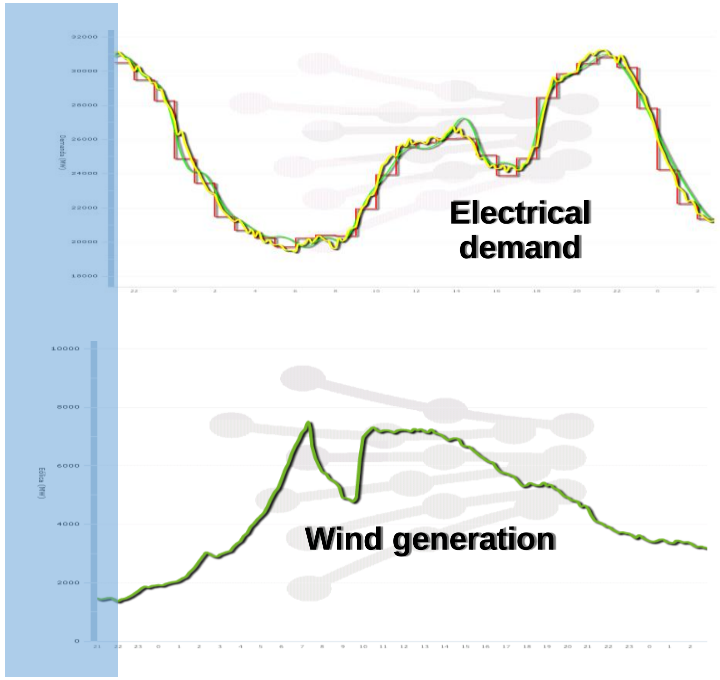
RENEWABLE ENERGY SOURCES - RES

Maximizing the penetration of RES in the Islands electrical systems is one of the main objectives of the energy policy of the Regional Government of the Canary Islands, conditioned by the need to reduce the current dependence on foreign energy and reducing CO_2 emissions.

Solar Energy Potential

Sun hours > 3,000 h/yr

Radiatión 6 kWh/(m^2 –day)



Wind Potential

Mean average wind speed: 6 - 8 m/s

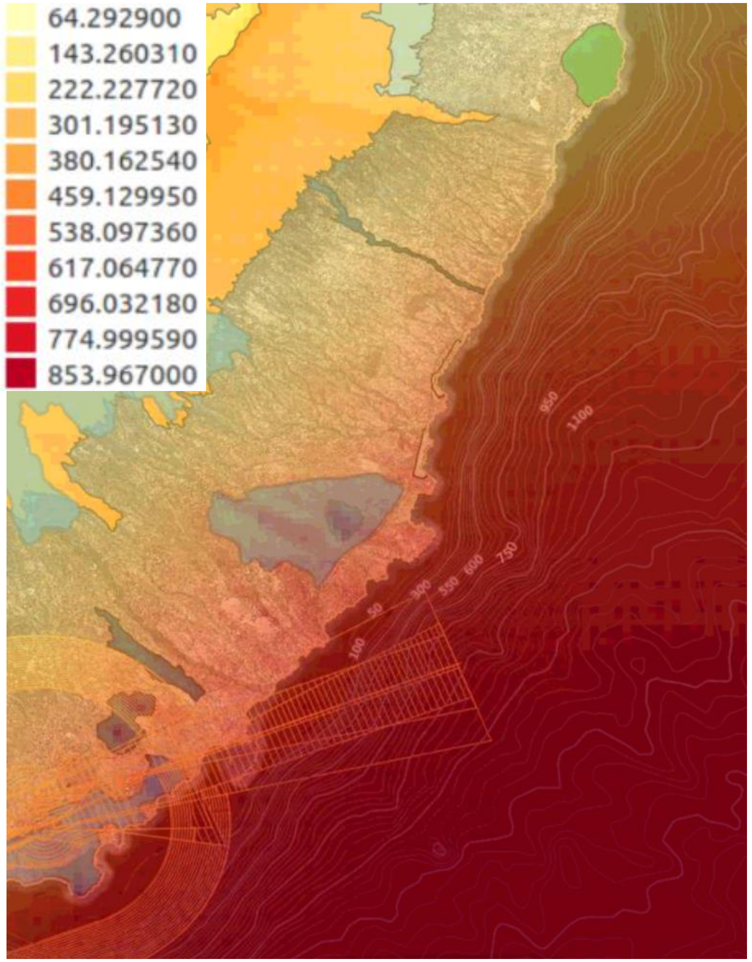
Operation : 3,000 – 4,500 eq. hrs

WIND RESOURCE ASSESSMENTS

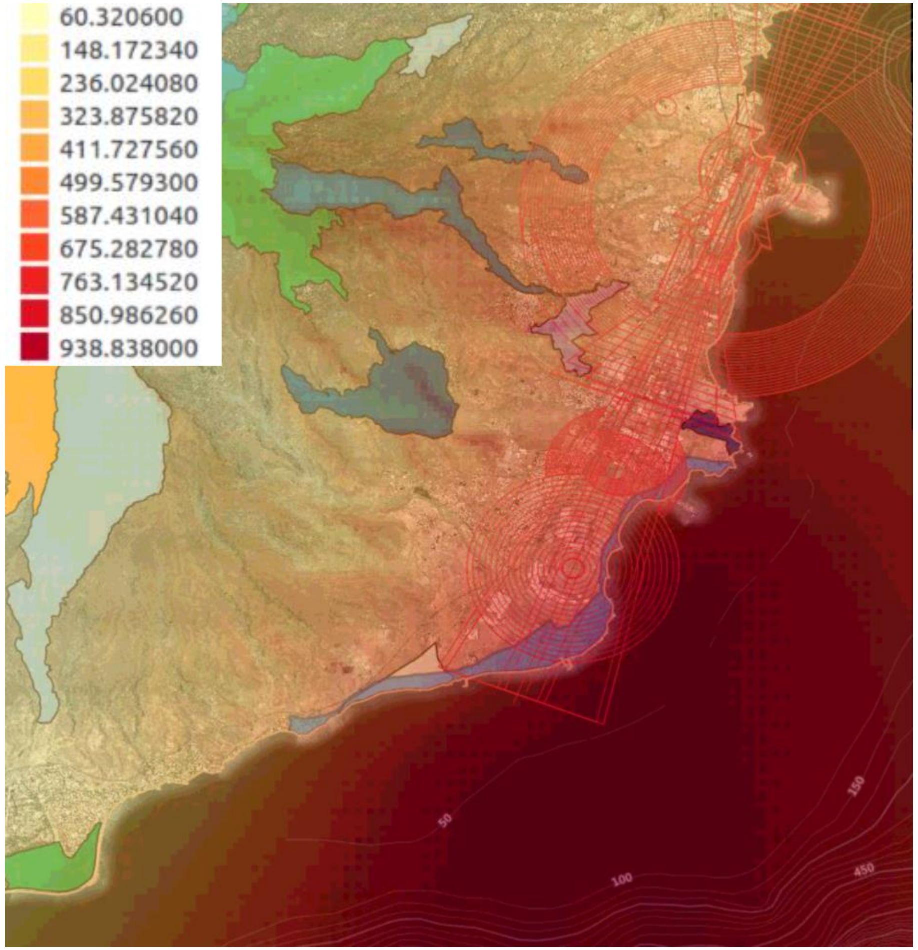
Wind power densities

Off-shore wind potential greater than in on-shore wind farms. Wind power densities higher than 700 W/m² off-shore could be reached, while mean value of 500 W/m² in on-shore conditions.

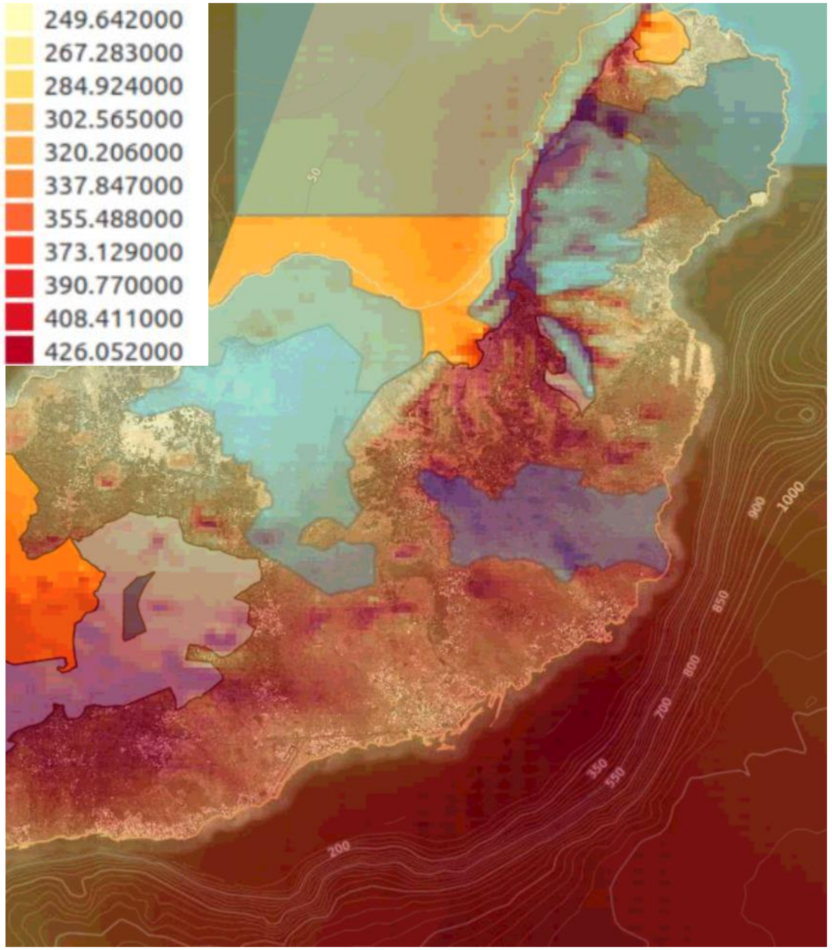
Southeast of Tenerife



Southeast of Gran Canaria



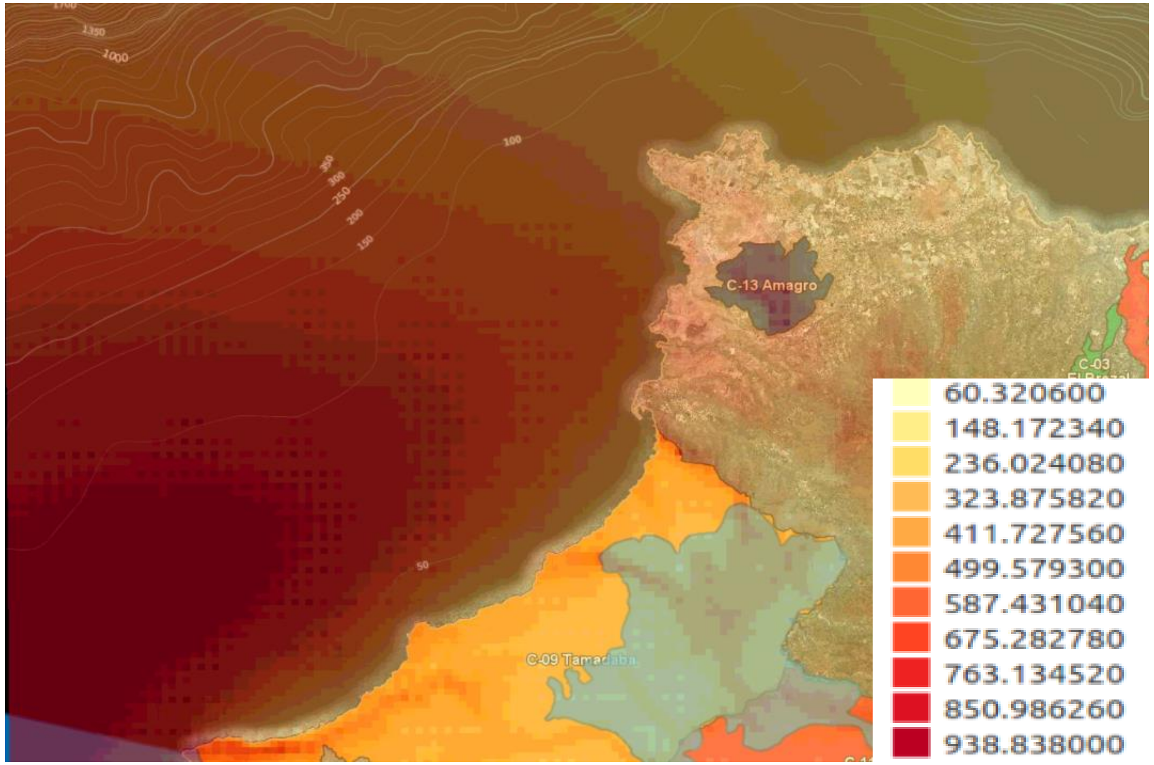
South of Lanzarote



Estimation of offshore wind power generation

In regions of high interest such as the Southeast of Gran Canaria, the production can de 70% higher than the mean power production for the Canary Islands on-shore wind farms (2,900 equivalent hours according in 2016 statistics).

North of Gran Canaria



Indicative values of the existing wind resource (100 meters)

Coastal Position	Approx. depth	Distance to coast	Mean wind speed	Productio (hr.eq)	Wind power density
Gáldar G.Canaria	170 m	3 km	7.4 m/s	3,110 hours	430 W/m^2
Arucas G. Canaria	165 m	4 km	5.0m/s	1,230 hours	160 W/m^2
Sta. Lucía G.Canaria	60 m	6 km	11.5 m/s	5,300 hours	1,190 W/m^2
Buenavista Tenerife	240 m	3 km	8.3 m/s	3,250 hours	580 W/m^2
Famara Lanzarote	118 m	3 km	6.5 m/s	2,005 hours	305 W/m^2

Wind power densities estimated at 100 m height. MASS model (50 m * 50 m spatial resolution and long-term conditions).

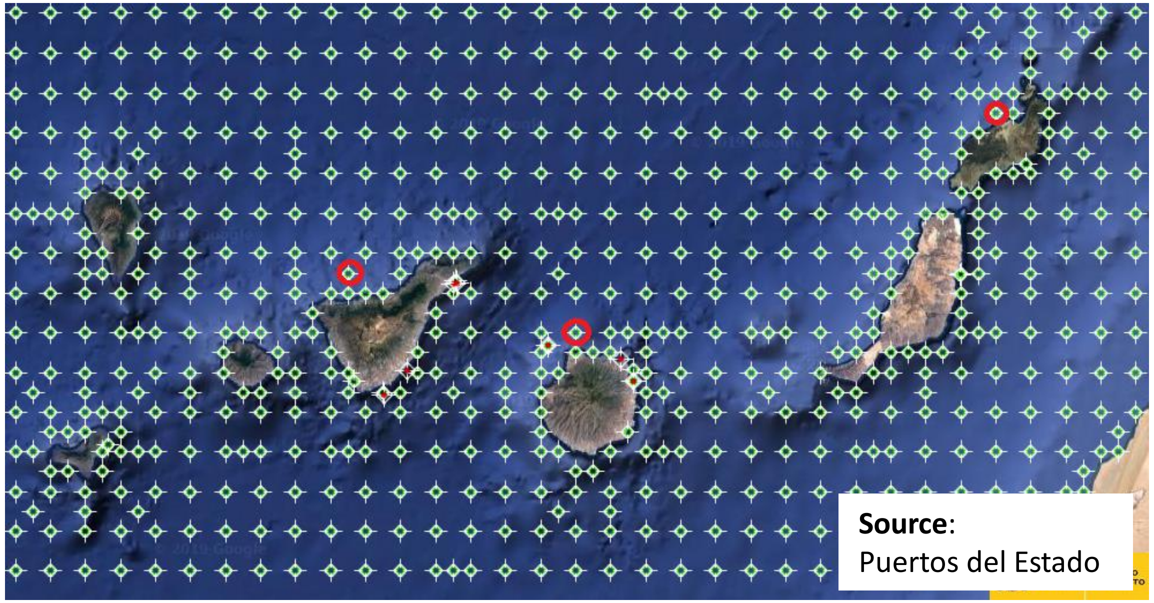
WAVE RESOURCE ASSESSMENTS

Wave resource:
Best positions located in the North of Gran Canaria, Tenerife, Lanzarote and Fuerteventura.

Maximum height → 2– 4 meters

Maximum period → 10 – 20 seconds

Best Positions – SIMAR [Canary Islands]



Source:
Puertos del Estado

Month	North Gran Canaria					North Tenerife					North Lanzarote				
	Max. Hs	Tp	Dir	Day	Hour	Max. Hs	Tp	Dir	Day	Hour	Max. Hs	Tp	Dir	Day	Hour
January	4.41	19.51	0	18	19	4.68	19.51	347	18	18	5.25	19.51	344	18	16
February	4.74	13.32	1	8	8	4.68	12.11	2	8	8	4.81	17.74	279	28	10
March	3.65	17.74	348	12	0	4.3	17.74	335	11	23	5.1	14.66	289	1	10
April	3.82	16.12	4	10	7	4.04	17.74	334	4	15	4.37	14.66	348	10	4
May	2.6	9.1	14	14	7	2.69	13.32	9	13	23	3.13	10.01	6	14	7
June	1.72	7.52	17	2	5	1.67	14.66	322	8	21	2.08	6.83	6	2	1
July	1.77	6.83	21	16	9	1.75	13.32	348	29	16	2.19	8.27	13	21	8
August	1.98	9.1	15	11	21	1.82	8.27	20	12	12	2.44	9.1	6	11	12
September	1.78	11.01	358	5	20	1.85	12.11	350	5	16	1.96	11.01	350	5	20
October	3.69	13.32	13	29	8	3.72	13.32	15	29	7	4.07	13.32	359	29	5
November	3.69	19.51	325	18	5	5.65	19.51	315	18	1	5.58	19.51	306	18	6
December	2.68	14.66	348	15	6	3.32	14.66	333	14	22	3.84	14.66	334	14	23

EXISTING BARRIERS TO RES

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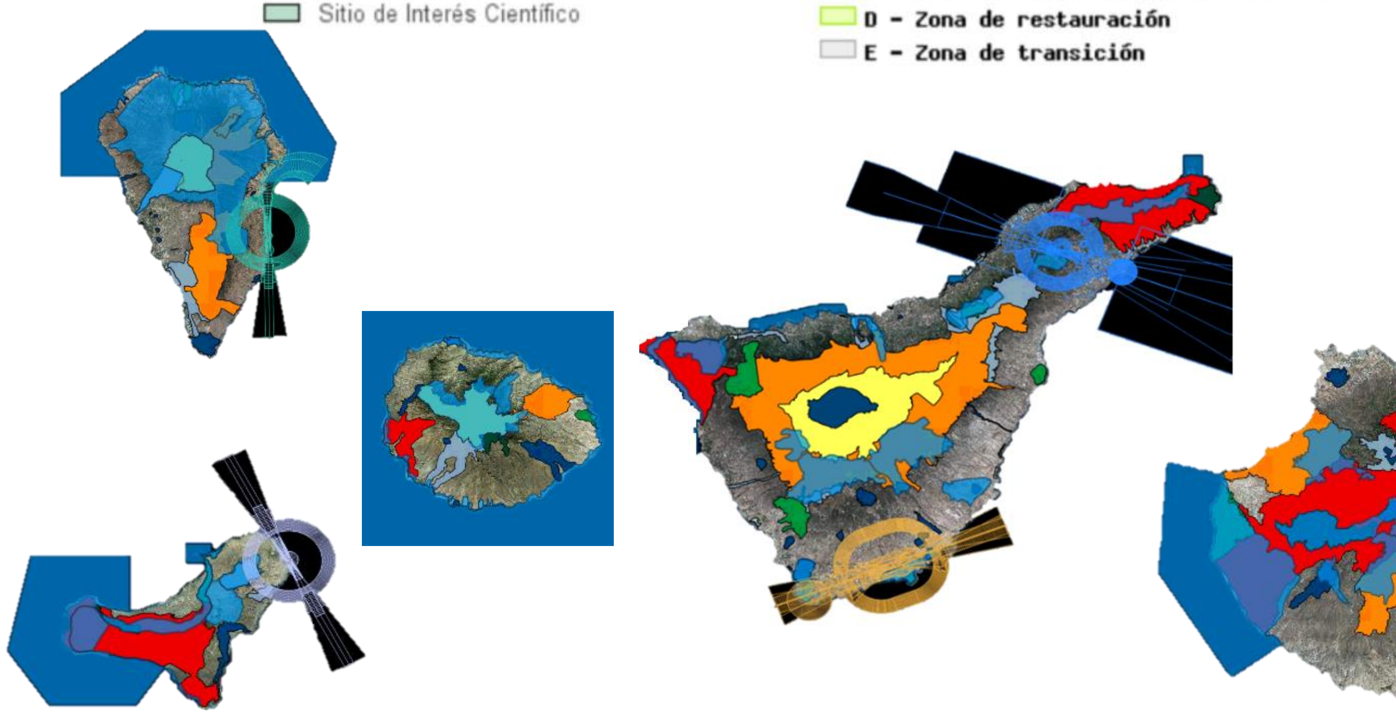
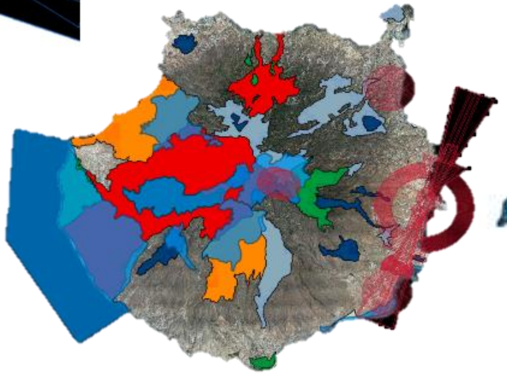
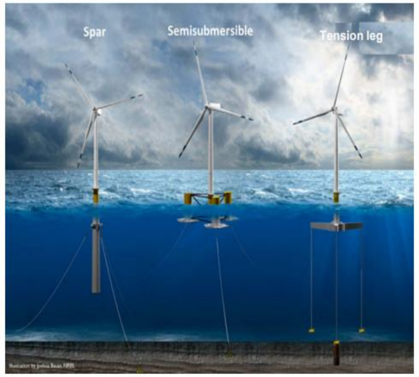
SPATIAL CONSTRAINTS CAN LIMIT THE DECARBONISATION OF THE ENERGY SYSTEM

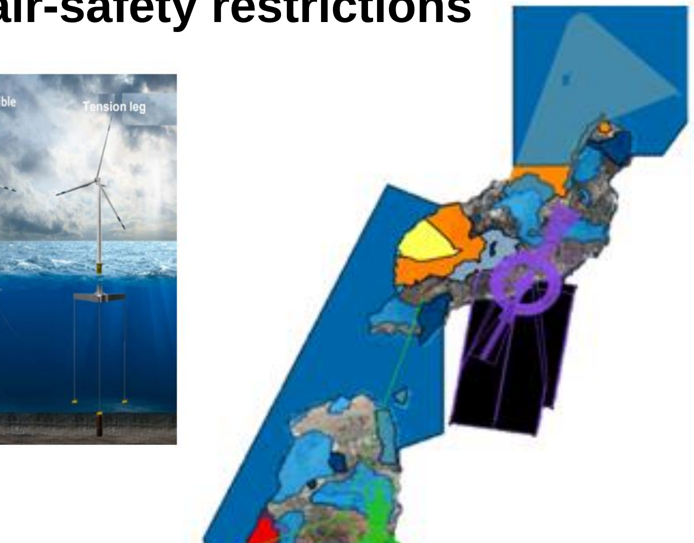




Territorial protection and-air safety restriction

- **70% of the territory is currently protected**
- **Heavily protected areas due to birds**
- **Best wind resource in proximity to airports exposed to air-safety restrictions**





Source:
IDE Canarias y AESA

SCARCITY OF LAND AVAILABILITY FOR WIND FARMS

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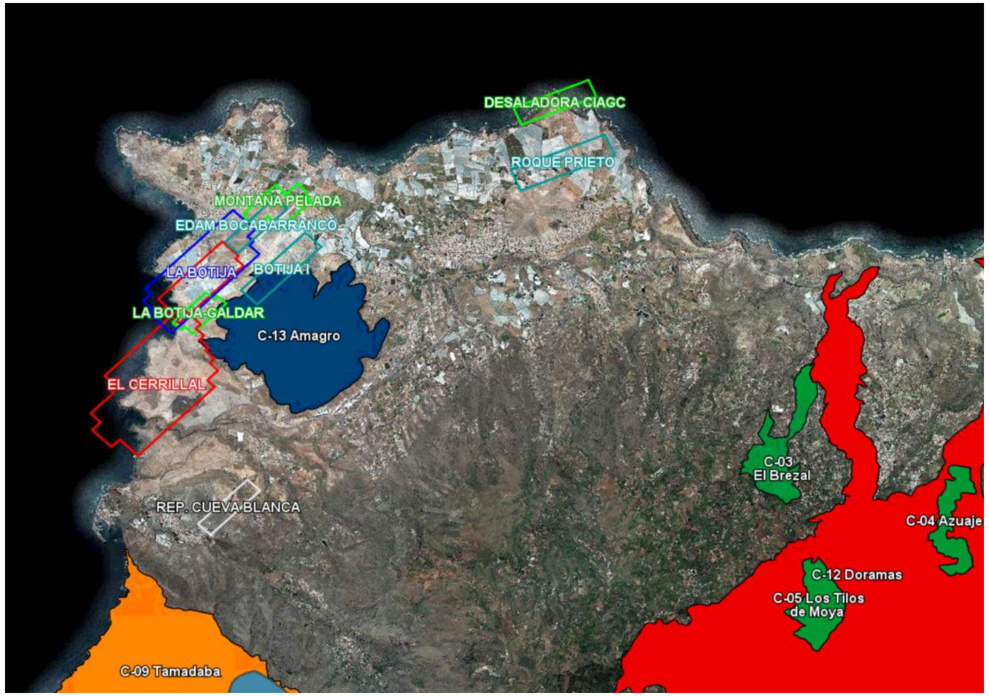
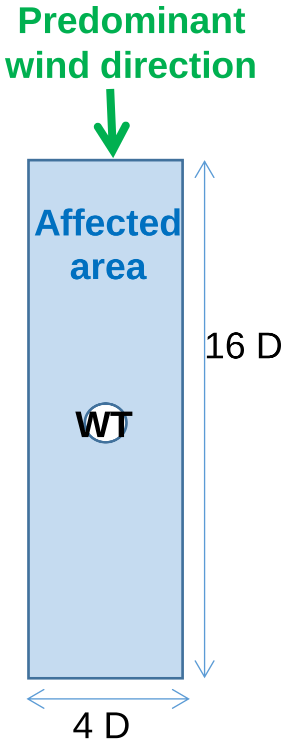
Areas already affected by wind farms and proximity to populated areas:

- In the most suitable areas, there is a high concentration of wind farms. Technical limitation according to Decree 6/2015.
- Affected area = 16 * 4 rotor-diameters
- A wind turbine of 4.5 MW, with rotor diameter of 145 m, affects 134,6 hectares

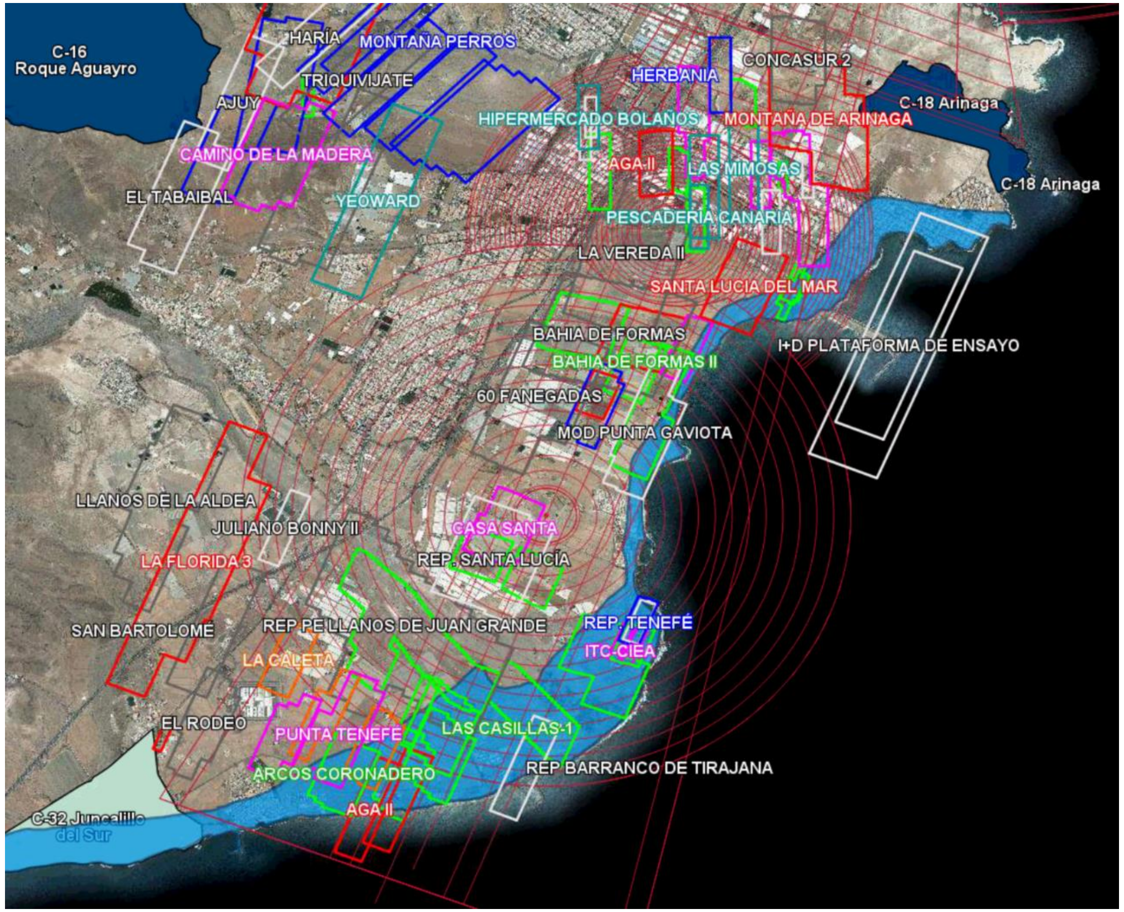




Current windfarms affected areas (North-West Gran Canaria)

- In addition, minimum required distances to populated areas (400 meters for powers greater than 900 kW according to Decree 6/2015).

Current windfarms affected areas (Southeast Gran Canaria)



AIR-SAFETY REGULATIONS

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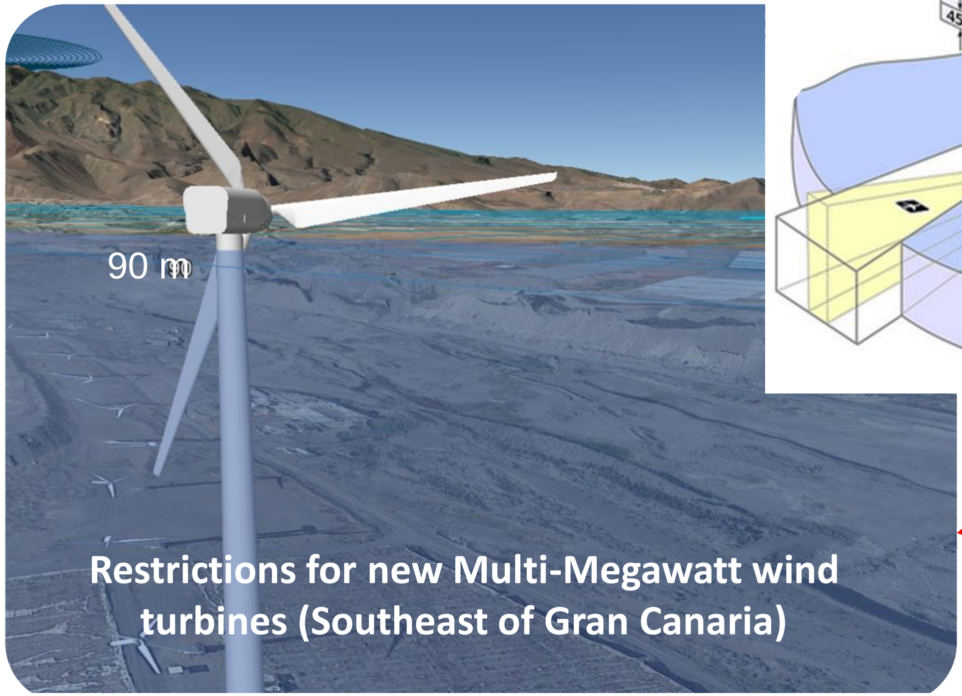
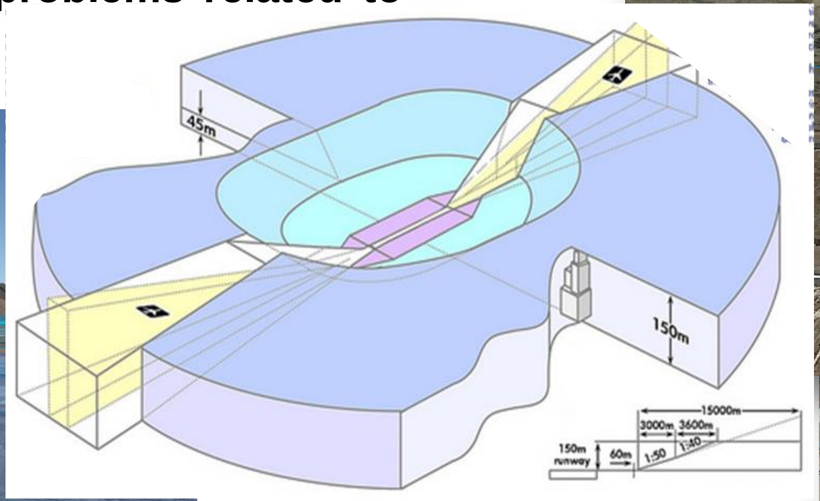
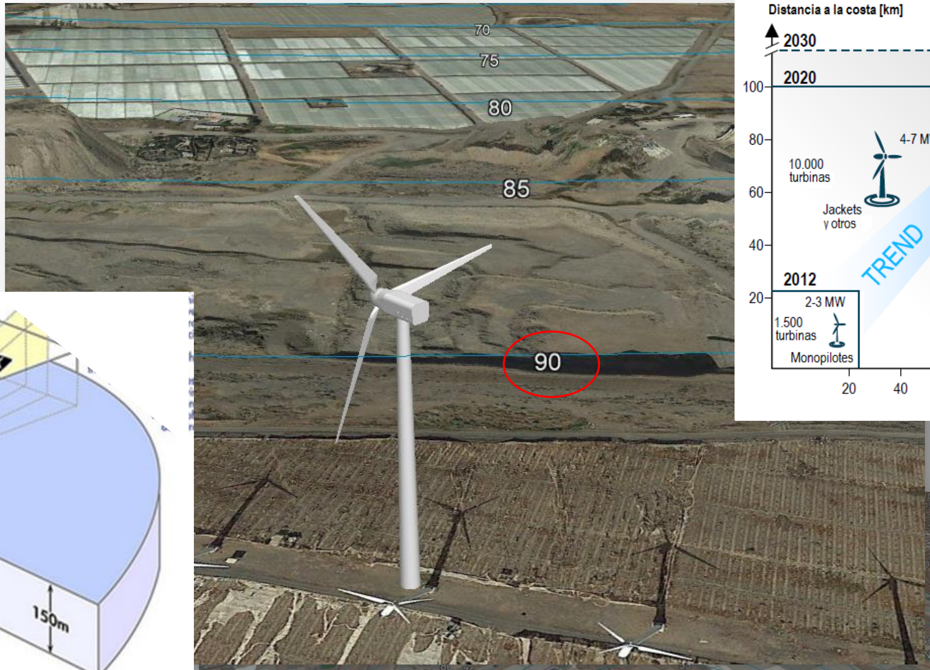
Multi-Megawatt wind turbines:

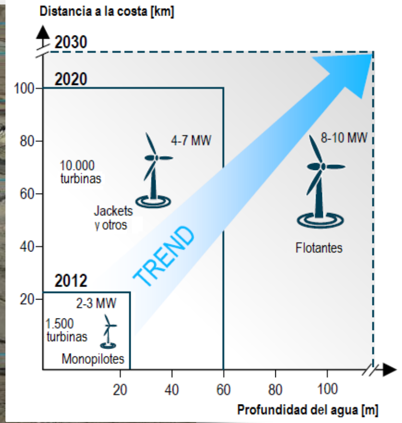
- **Wind turbines with powers below 1 MW begin to be obsolete. Trend of unit-power increases to 5 - 10 MW.**
- **These wind turbines have higher hub heights and rotor diameters, which carriages problems related to the air-safety regulations.**

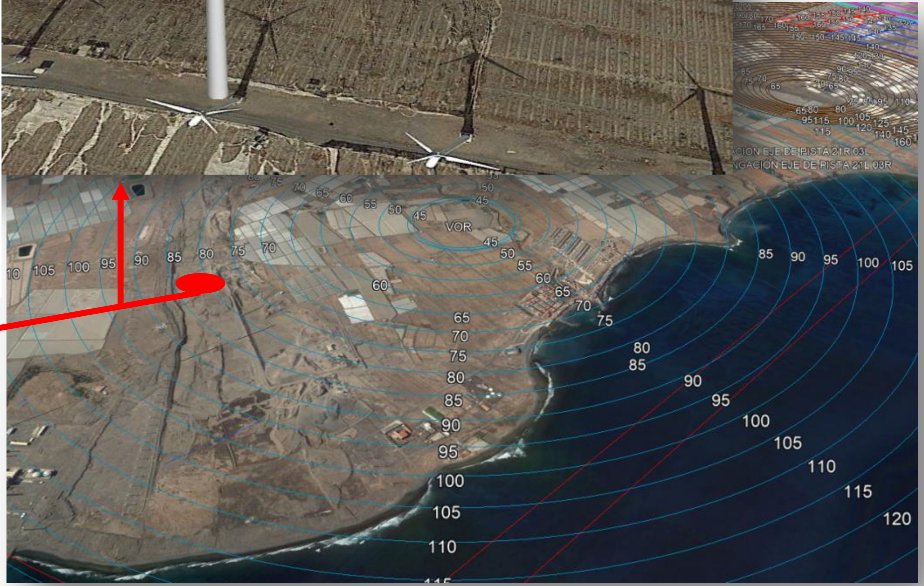


Restrictions for new Multi-Megawatt wind turbines (Southeast of Gran Canaria)





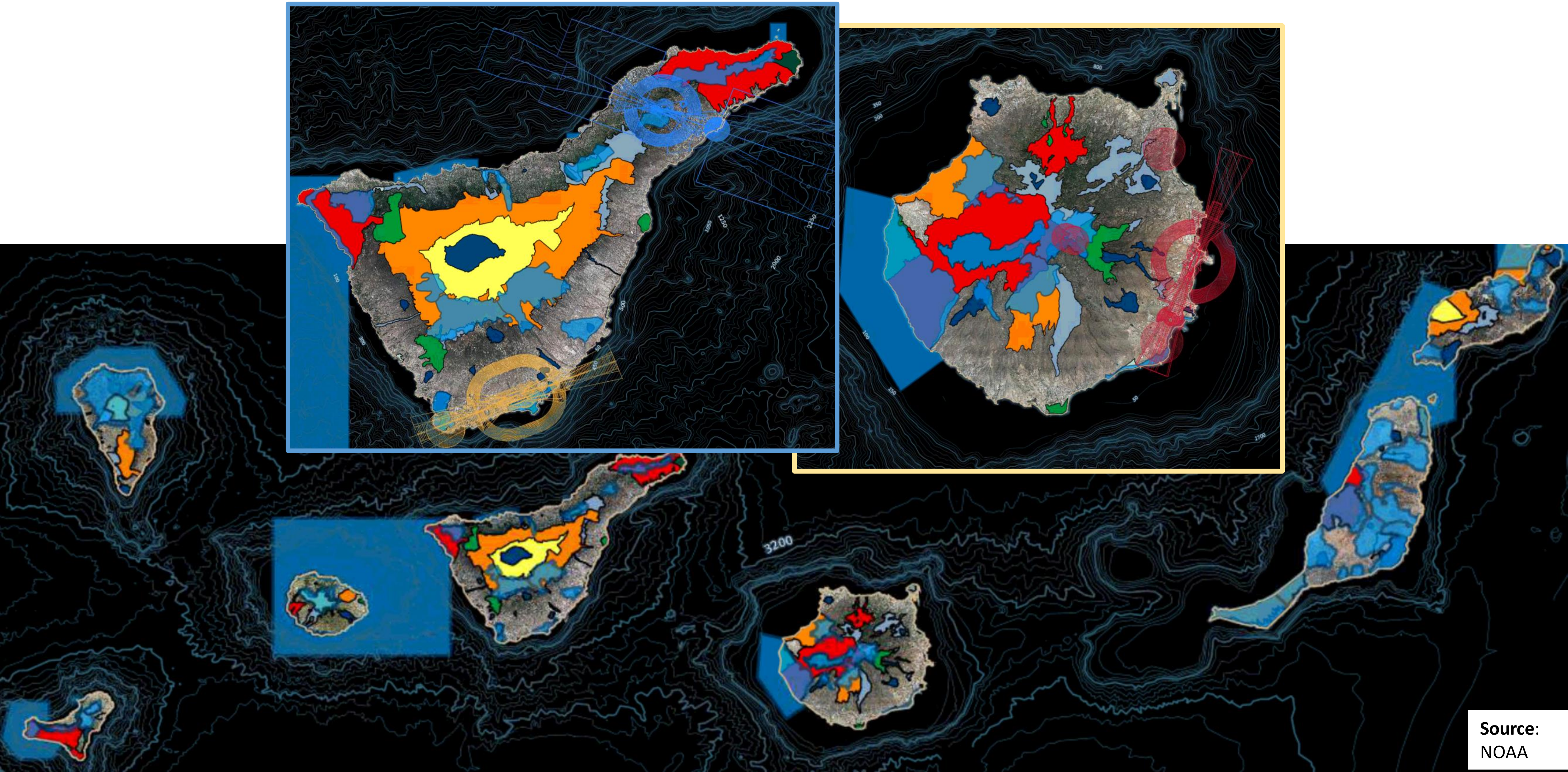




The low-level airspace around an airport's runway needed for aircraft to climb or descend, must be protected from obstacles.

Wind turbines are obstacles and should, as a rule, not be permitted to penetrate the "obstacle surface".

BATHYMETRY

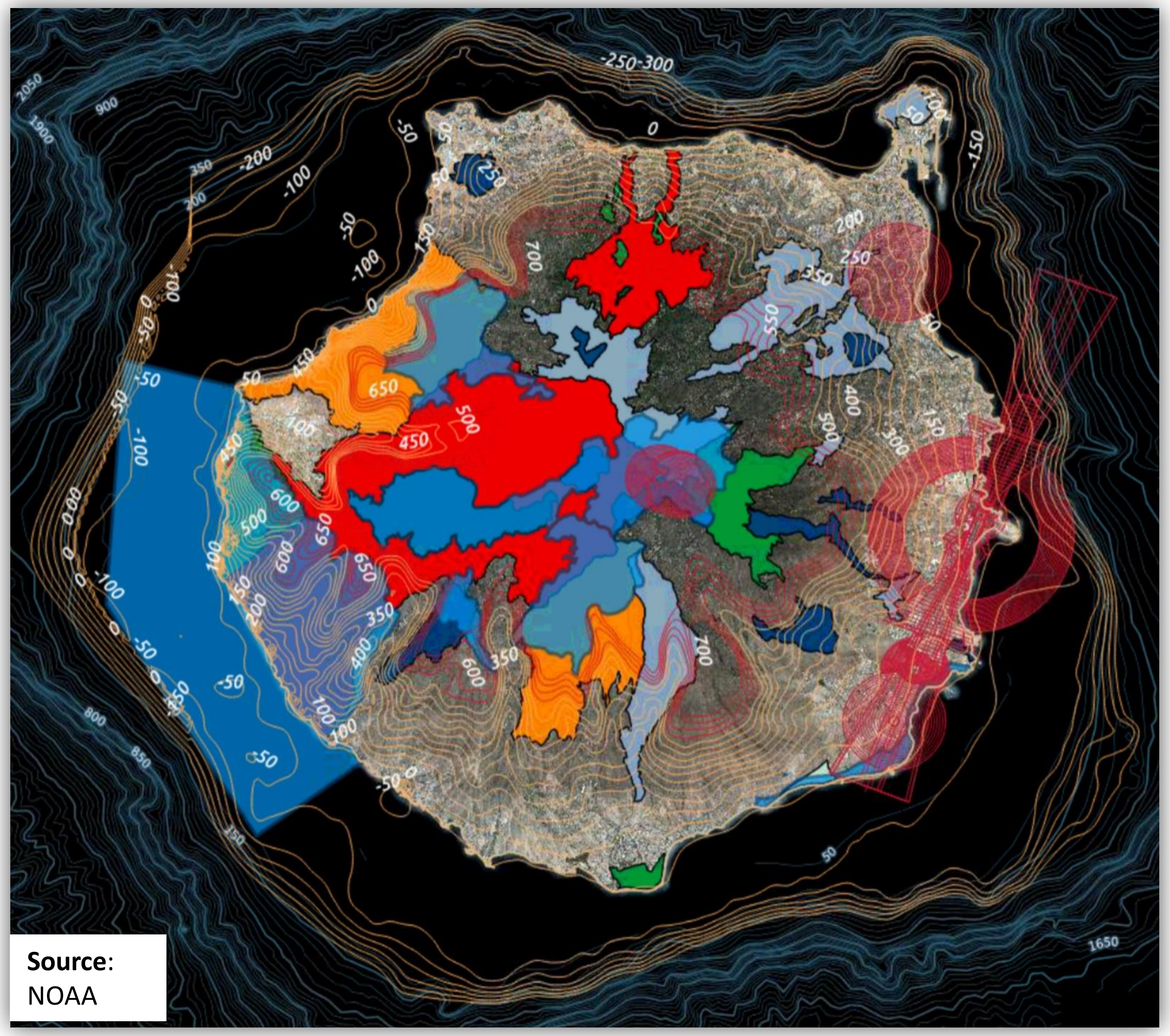


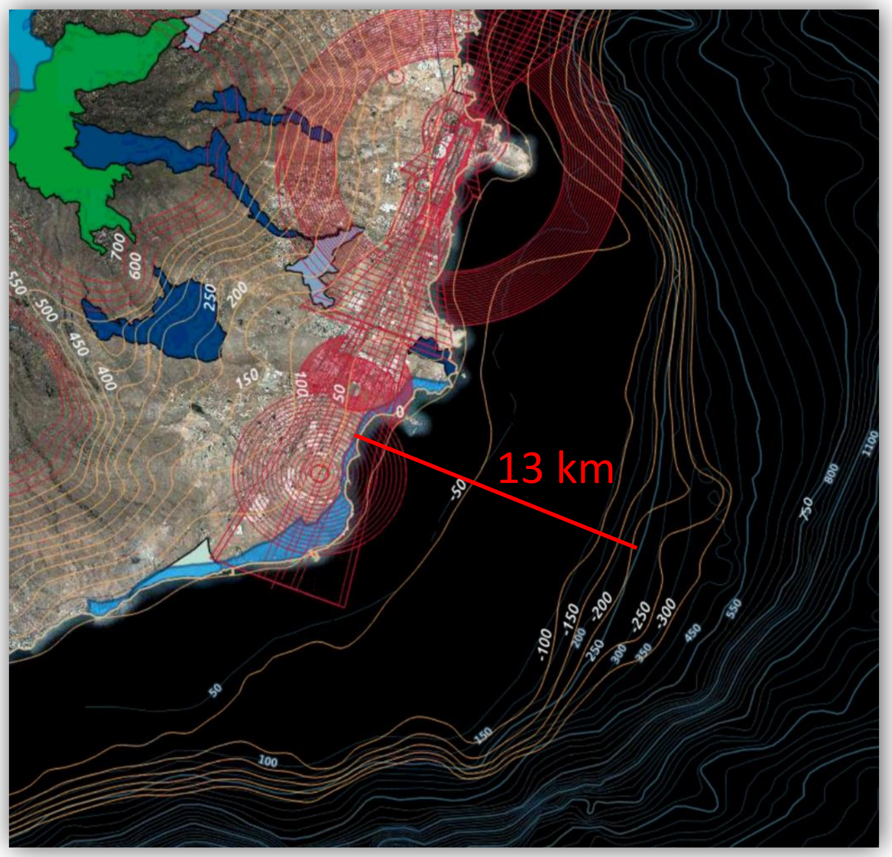
Source:
NOAA

BATHYMETRY GRAN CANARIA

Bathymetry

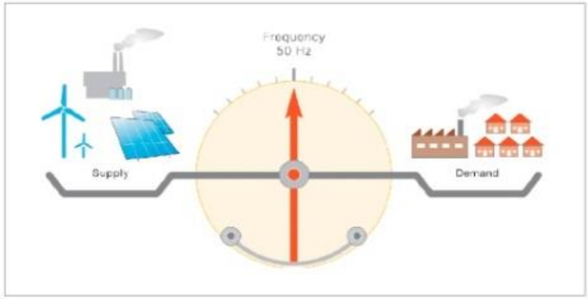
- Islands with greater potential: Gran Canaria, Lanzarote, Fuerteventura and Tenerife.
- Southeast of Gran Canaria: 200 km^2 with depths less than 300 m and away from the coast a distance of 2 - 13 km.





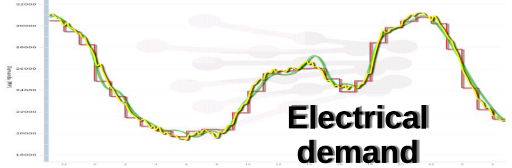
TECHNICAL BARRIERS TO RES

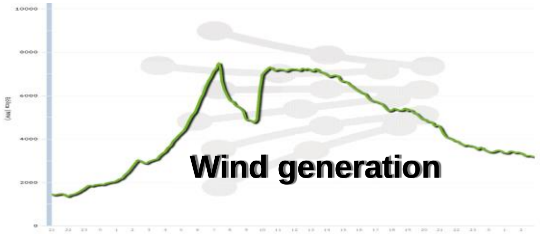
Small non-interconnected island electric systems are more sensitive to RES variations, a critical issue affecting grid stability.



Grid stability: balancing the electrical island systems

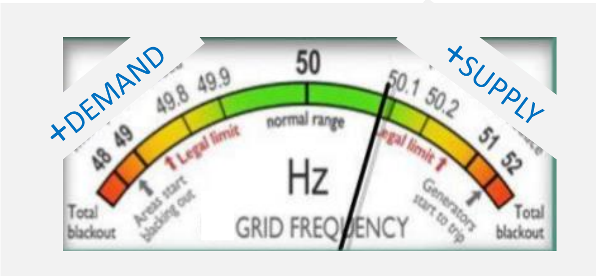
- The islands power systems have to be at equilibrium at every moment, which requires that power generation be regulated to guarantee that it always equals instantaneous electricity demand





- Since the variable generation curve profiles of RES doesn't match the electrical demand curve of the island, curtailment of RES generation is needed to avoid excess electricity

- Power regulation of RES translates into curtailment and less operating hours of wind systems, which negatively impact the initially foreseen return on investment of these investment projects



COST CONSIDERATIONS OF THE INTEGRATION OF MARINE RES

- RES systems, although with cero marginal cost (no variable cost associated to fuel consumption), have the drawback of requiring high initial investment

- Depreciation of capital becomes the major cost of power generation. A fix cost, which means that disregarding their capacity factor, the full cost of depreciation has to be supported

- High investment cost of marine RES systems means a risk is assumed by the private investors. Especially relevant in scenarios of high RES, if production where to be curtailed in support of grid balancing

FINANCIAL BARRIERS

Access to private funding will contribute to overcome barriers associated to the high initial investment cost of RES projects.

- High financing costs are especially significant to the competitive position of RES, since it requires higher initial investments than fossil
- Access to financial resources, at a reasonable cost (interest) is therefore required
- Financial institutions perceive marine RES technology as risky, so that they may lend money at higher rates

NEED OF A STABLE RETRIBUTION FRAMEWORK

- Bankability of RES island projects needs a suitable retribution framework
- Initial high investment requires a stable price framework for RES to guarantee that the investment can be recovered in a reasonable time period (reducing risk and uncertainty)

ESTRATEGY FOR MAXIMIZING RES

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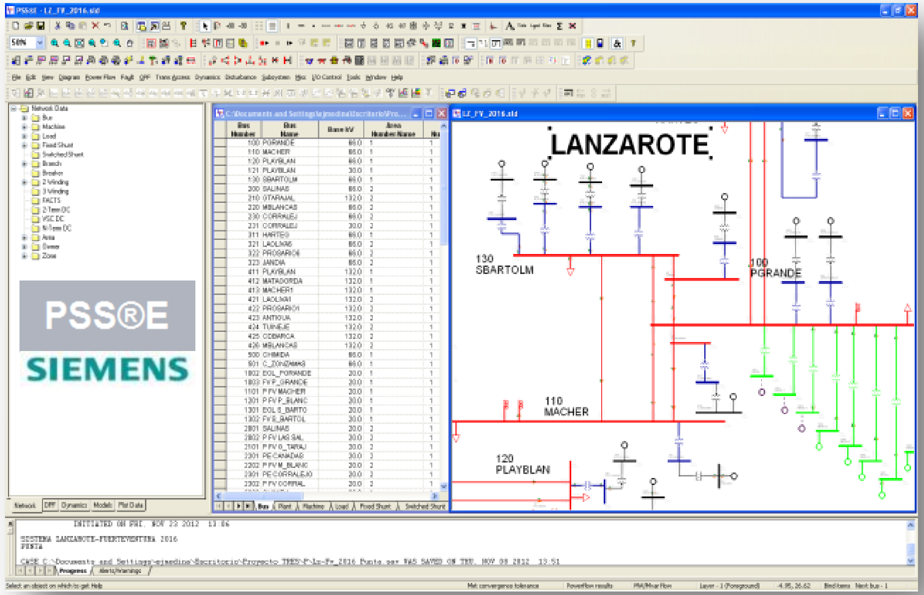
GRID ANALYSIS

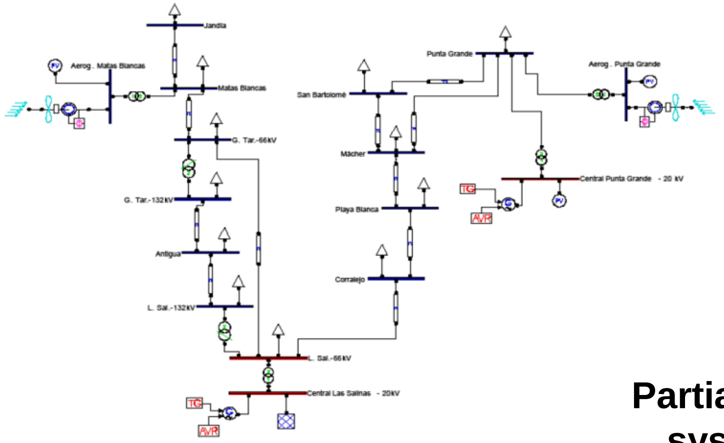
Analysis of islands transmission-distribution grids capacity to handle RES

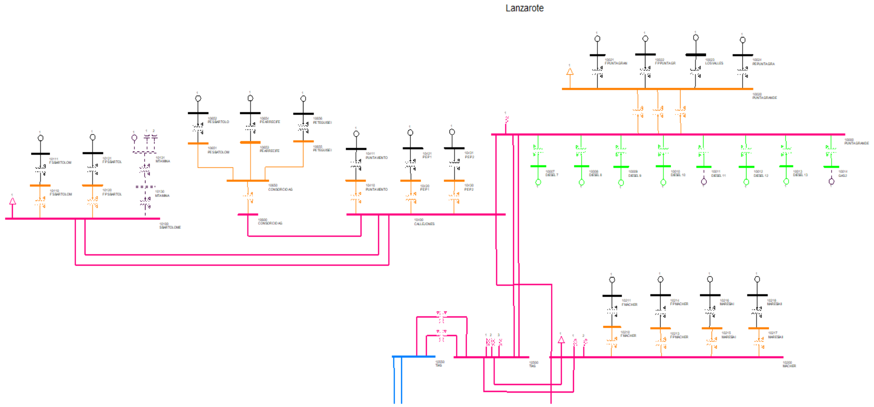
- Elaboration of mathematical models to simulate the dynamic behaviour of electrical island systems, to the constraints that limit the penetration RES.
- Determine maximum admissible levels of penetration of variable and intermittent RES in small and weak island electrical grids



Modelling on PSS®E v32.

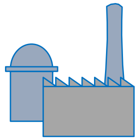
Modelling on PSAT



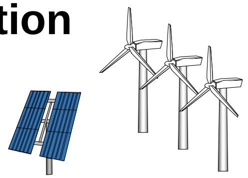


Partial view of a line (single line diagram) in the electrical system of Lanzarote-Fuerteventura in 2025 in PSS®E

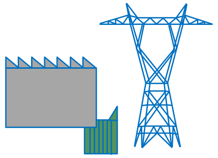
Conventional generation
- Diesel Genset
- Gas turbines
- Steam groups



Renewable generation
- Wind
- Photovoltaic

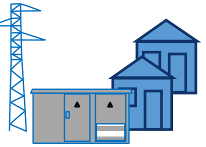


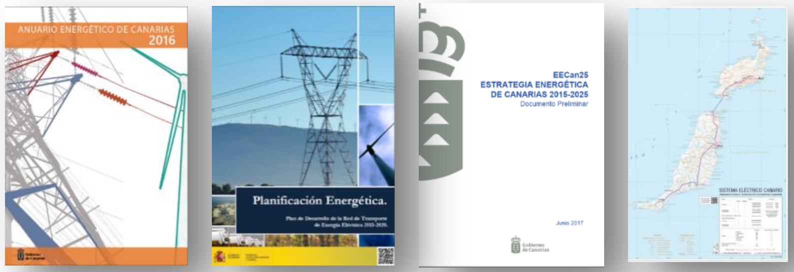
Transmission lines
- Lines (66 kV, 132 kV)
- Substations



Load demand and distribution lines

Modelling as aggregate demands corresponding to substations.



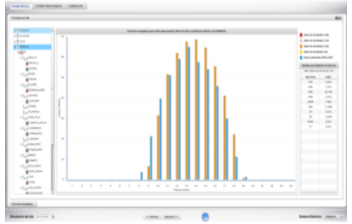


ENERGY FORECASTING

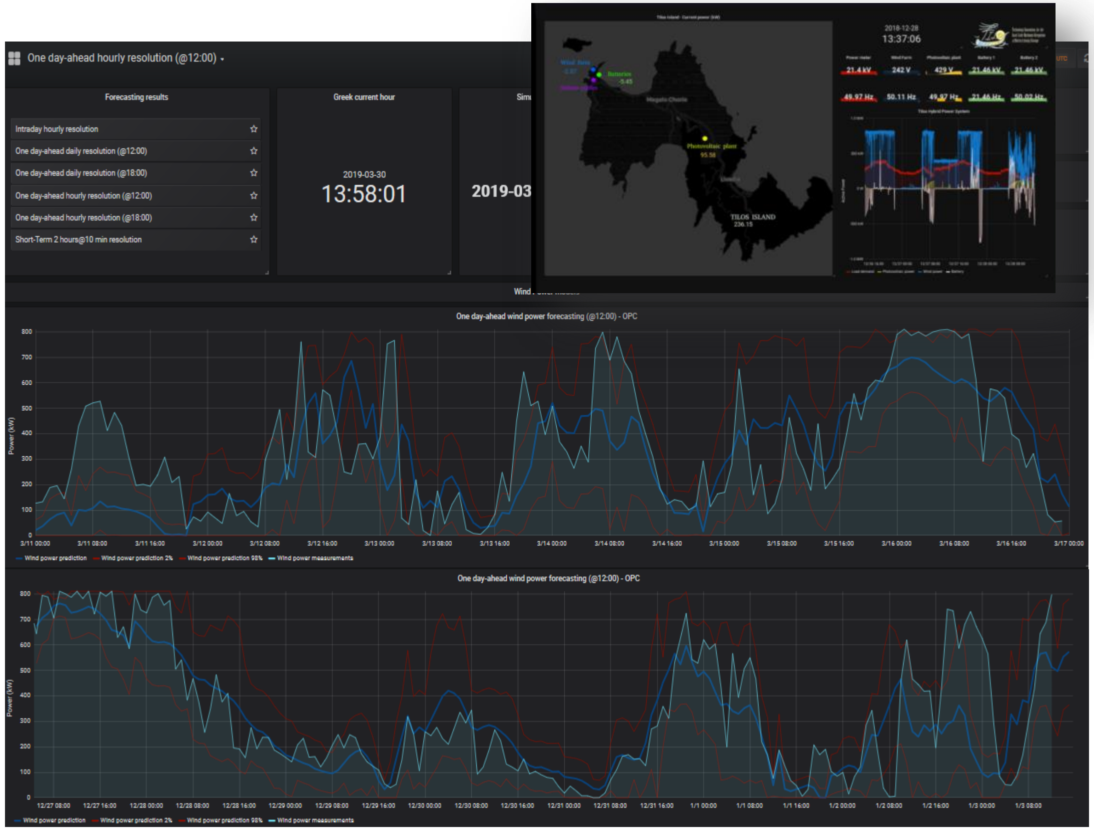
Reliable wind and solar forecasting is possible through the development of climate models. An important tool for electrical generation scheduling that would make a maximum use of available RES

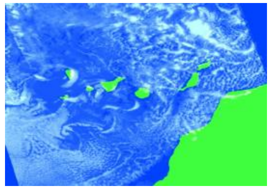
Main characteristics:

- Models:
  - One day-ahead (24h@1h)
  - Intraday (12h@1h)
  - Intraday (6h@1h)
  - Short-Term (2h@10min)
  - Now-casting (10-30min@1min)
- Techniques:
  - Weather Research Forecast.
  - Machine Learning (SVR, RF)
- Configurable resolutions according to system requirements.
- Forecasting platform:
  - Automatic execution
  - Communication system



Real data of the platform deployed in Tilos [Greece]





Forecasting model	MAE	SMAPE	R^2	BS
Wind power forecasting models				
One day-ahead [Resolución horaria]	123301	12.33%	84.3%	0.188
One day-ahead [Total diario]	1514592	9.69%	82.4%	-
Intraday day-ahead [Resolución horaria]	85995	13.38%	79.7%	0.195
6h@1h short-term	62437	12.67%	76.6%	0.221
2h@10min short-term	79587	8.83%	78.9%	0.151
10min@1min short-term	53133	6.32%	83.54%	0.092

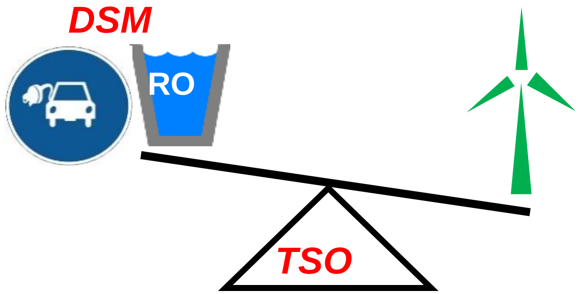
NWP (Numerical Weather Prediction): Modells WRF and post processing with artificial intelligence techniques.

MSG Antenna
5 min Time Resolution
1,2 km Spatial Resolution

DEMAND SIDE MANAGEMENT (DSM)
Balancing the island electric grid

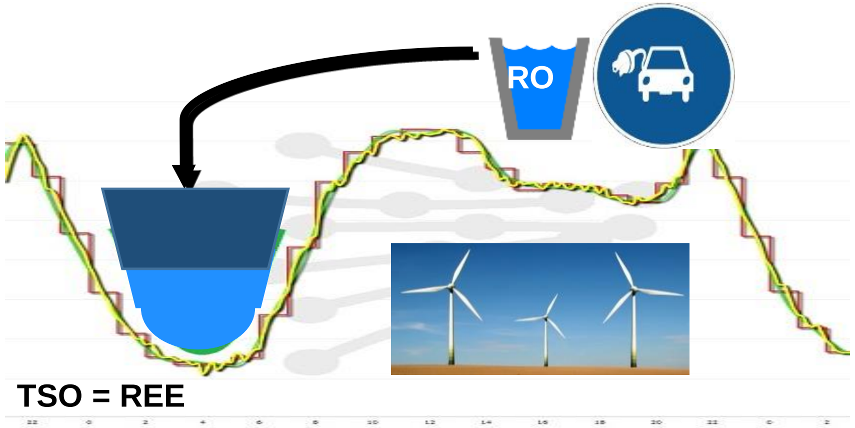
In the island electric context, value of DSM comes from the ability of manageable deferrable loads to respond to RES variability, and support stable island grid operation.

- **DSM, as a tool of the TSO (REE), an essential element in the strategy for peak-shaving and for balancing the intermittent RES. Key issues in the strategy towards maximizing RES.**



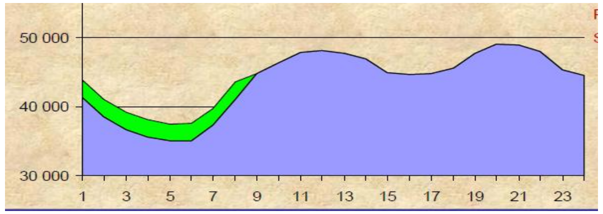
- **DSM optimizes energy assets, lowering the CAPEX and OPEX of the global island electrical system (reduces the need for installed power capacity).**

- **Through DSM and Demand Response (DR) the Transmission System Operator (TSO) adjust load power consumption to variable RES power generation, and dispatchable non-critical loads are put to full operation capacity at valley hours of the electric demand curve.**



DEMAND MANAGEMENT

Peak shaving: load shedding and time shifting of non-critical deferrable loads, reduces the need for curtailment of non-dispatchable RES.



ELECTRIC MOBILITY

More than 30% of oil consumed in the internal market goes to the road transport sector.

Electric vehicle are manageable loads with potential to become an instrument to promote greater RES penetration.

OTHER MANAGEABLE LOADS

- **The residential sector represents 30 % of electricity demand in the islands**

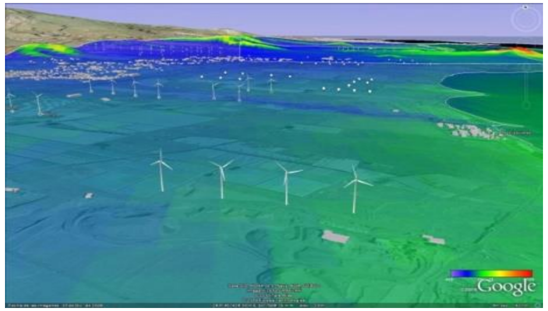
- **Domestic Hot Water in the residential sector represents 30-40 % of electricity demand.**

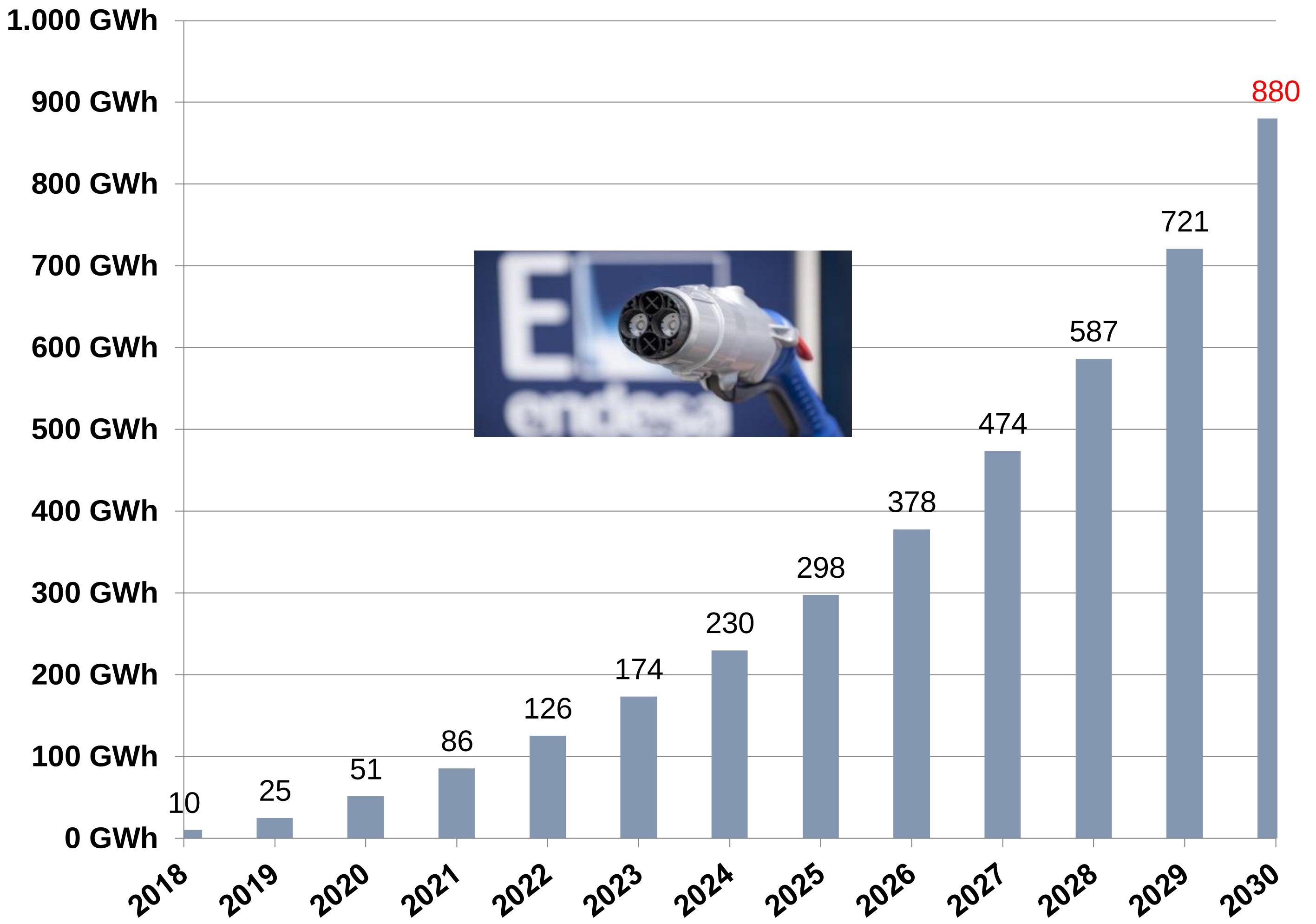
20% of electricity goes to water desalination and water distribution.

Sea-water	430,000 m³/d	167 plants
Brackish-water	150,000 m³/d	146 plants

ELECTRICITY DEMAND OF EVs BY 2030

GWh	2030
Lanzarote	60.45
Fuerteven.	48.32
G.Canaria	340.84
Tenerife	377.85
La Gomera	8.95
La Palma	38.06
El Hierro	5.51
TOTAL	**879.99**

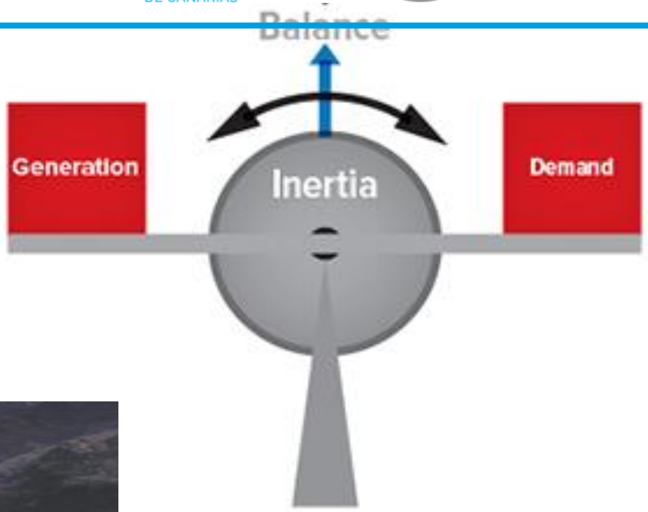




In 2030 it will be necessary to provide electricity to 300,000 EVs. Aprox. 880 GWh.

ENERGY STORAGE

Energy storage capacity is essential to maximize RES penetration in small and weak electrical grids.

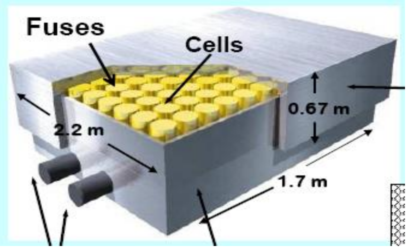


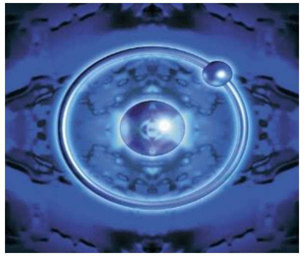
- Solutions to store surplus RES in peak hours to feed into the grid in peak demand.
- Energy carriers for the use of RES in transport.

- Reverse Pumped–Hydro
- Compressed air
- Flywheels

- Batteries
- Ultracapacitors

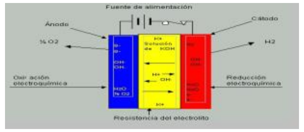
- Hydrogen
- Thermo-chemical cycles





HYDROGEN ENERGY BALANCE

Electrolizer



WATER

0.8 kg H_2O/Nm^3H_2

ELECTRICITY

4.5 kWh/Nm^3H_2

HYDROGEN (H_2)

Heating power
3 kWh/Nm^3H_2

$1Nm^3H_2$
0 ºC
1 atm

89.3 g de H_2

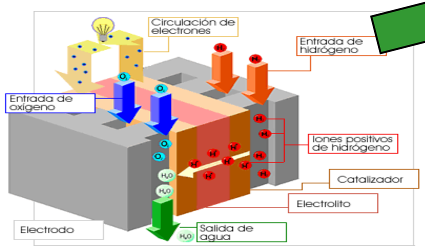
Compressor

89,3 g of H_2
25 bar

η = 50 %

1.5 kWh Electricity
1.5 kWh Heat

Fuel cells

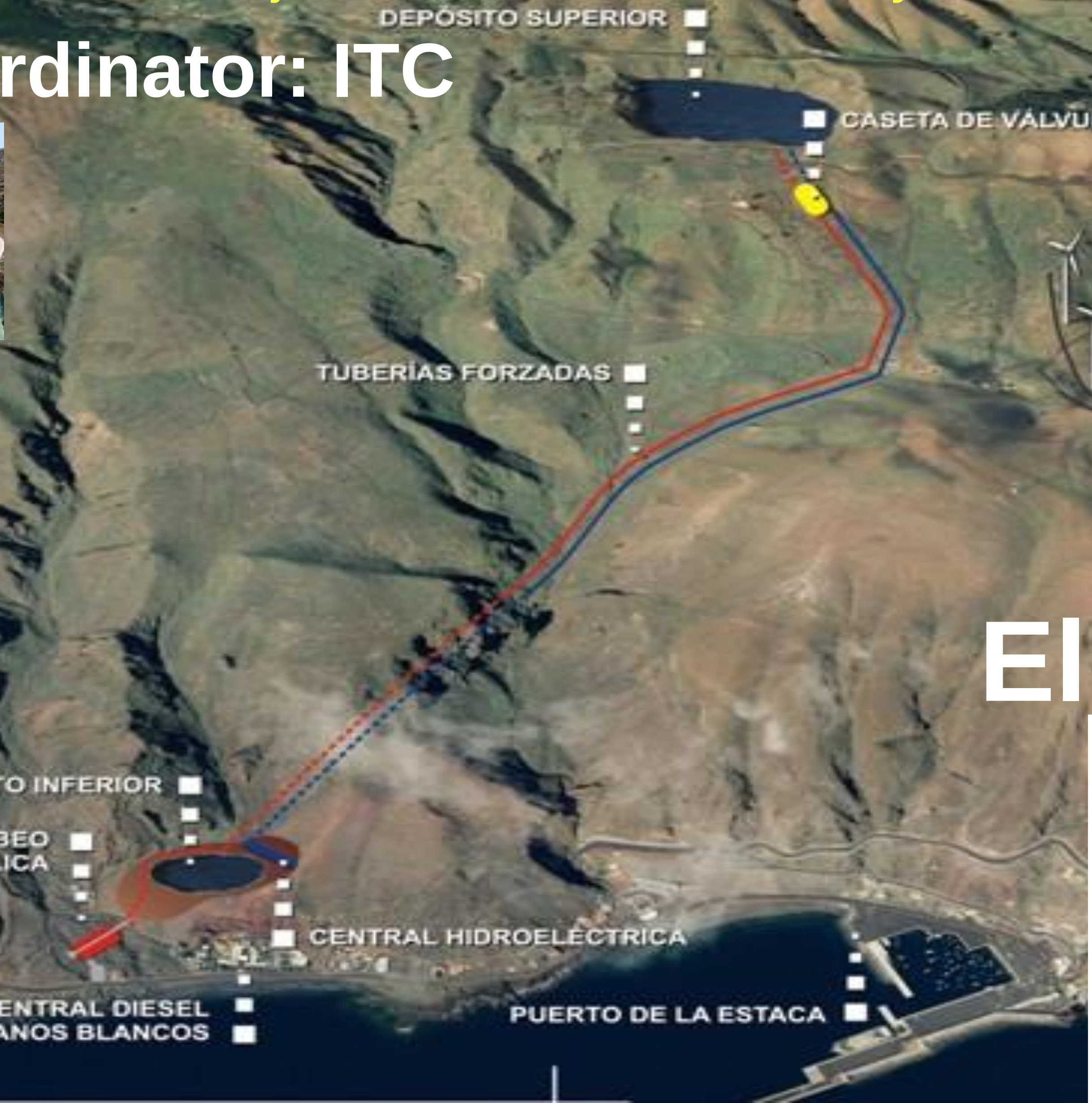


Wind-Pumped-Hydro power station – 5th FP

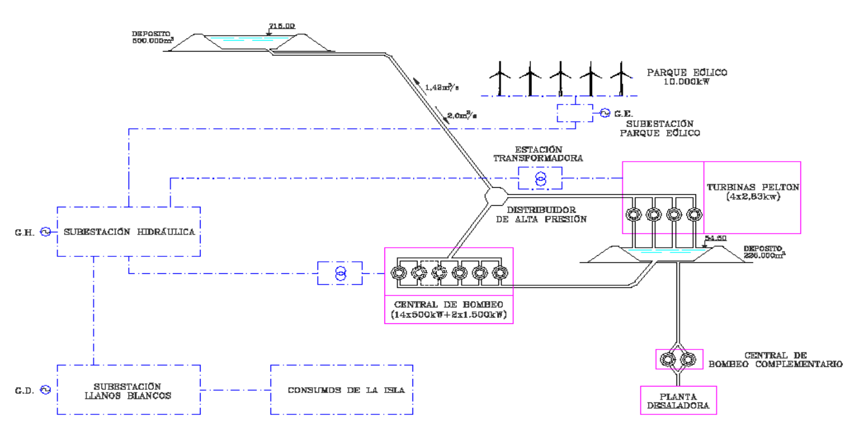
EUROPEAN COMMISSION, DG TREN Contract Nº: NNE5-2001-00950

"Implementation of 100% RES Project for El Hierro Island -Canary Islands

Project Coordinator: ITC

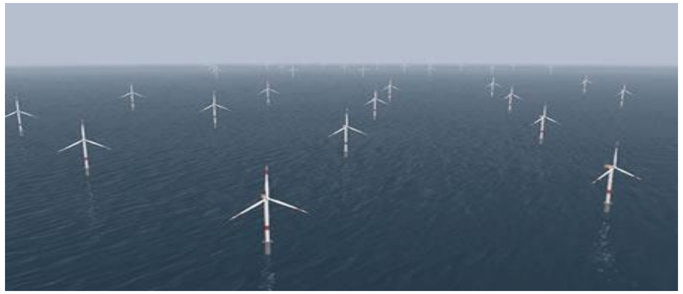


El Hierro island



GRAN CANARIA REVERSE PUMPED-HYDRO SYSTEM

itc INSTITUTO TECNOLÓGICO DE CANARIAS — Gobierno de Canarias



- **The reverse hydro-pumping power station Chira-Soria is being built.**
- **Operation foreseen for 2025**
- **This power plant will contribute to mitigate the impact of the integration of large amounts of marine power in the Gran Canaria grid.**

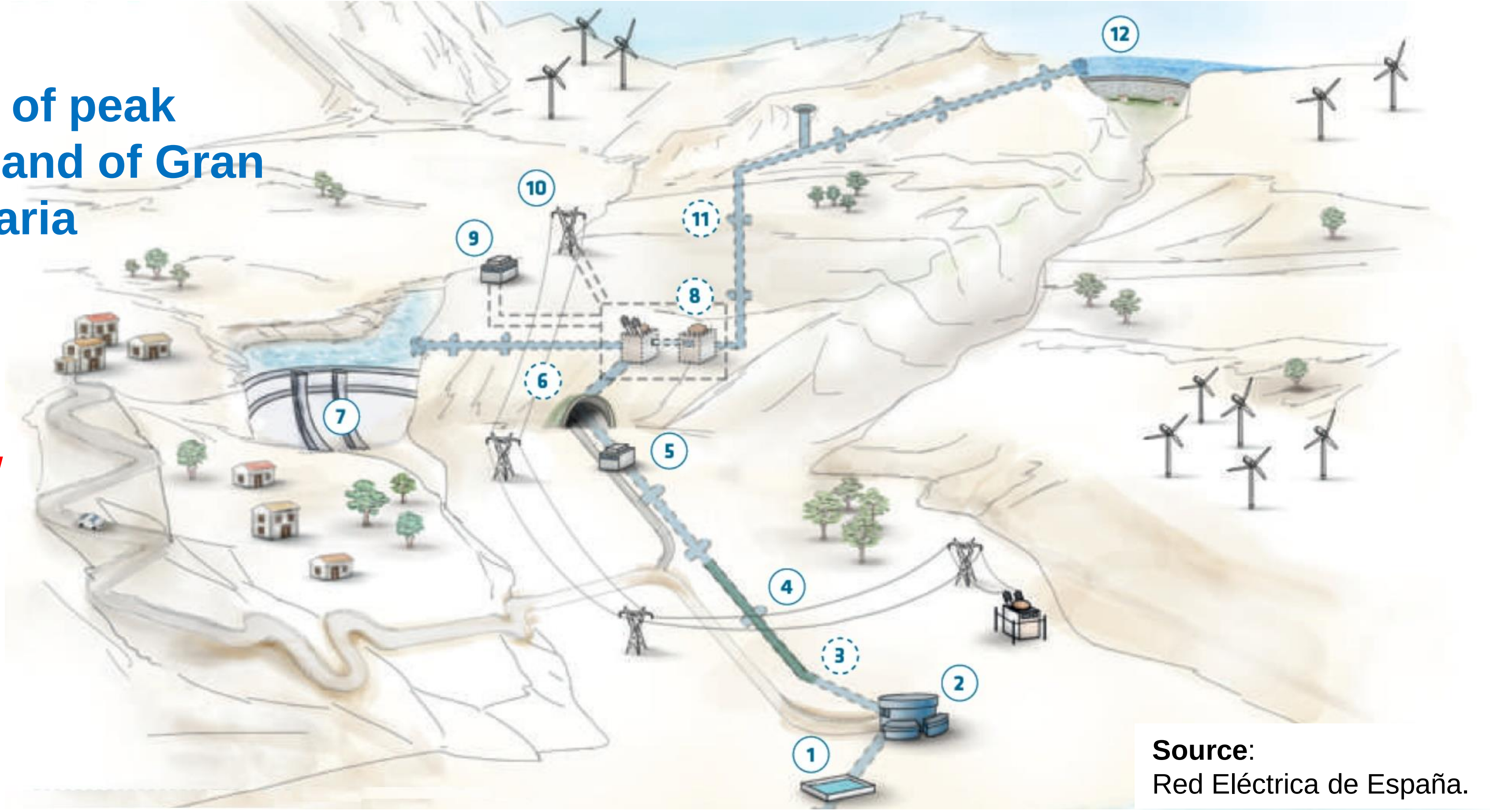
36% of peak demand of Gran Canaria

6 reversible turbines

- **Pump = 6 * 36.7 MW = 220 MW**
- **Turbine = 6 * 33.3 MW = 200 MW**

Penstock = 19.5 km. 5 m diameter
Connecting cables = 18 km

Investment 320 M€



Source:
Red Eléctrica de España.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No776661

SOCLIMPACT project

HORIZON 2020

EU BLUE ECONOMY IN FACTS

Maritime Transport

90% of external trade
40% of internal trade
9.000 ships

Ports

Commerc. ports=1,200
Cargo=3.5 bill ton/y
Passagers=350 M/y

Shipbuilding

Shipyards=300
Companies=9,000
Turnover=12,000M€

Fisheries

Fishermen=400,000
Vessels=90,000
Catches=6 Mton/yr

Aquaculture

20% of fisheries production
1.3 Mton
3,900 M€
85,000 jobs

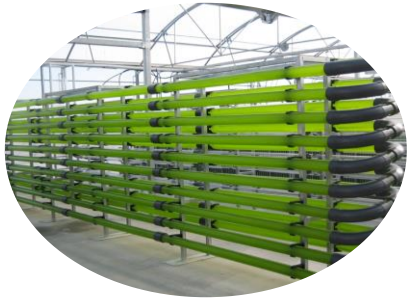
Coastal & Maritime Tourism

Revenue=75 bill€
Marinas=4,000
Leisure boats=6 M
Cruise ships=150
Passengers=3M/yr

Ocean Energy

Off-shore windfarms
3,589 turbines
12,631 MW capacity
150,000 jobs

Blue Biotech

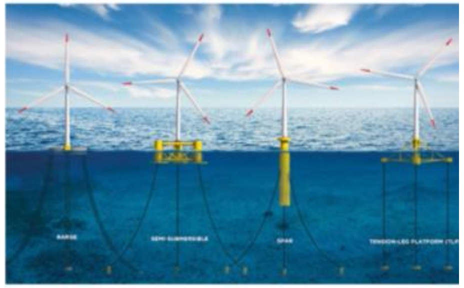


8% of biotech
13% of cosmetics
32% of nutraceutics

SOCLIMPACT

MARINE ENERGY AND CLIMATE CHANGE

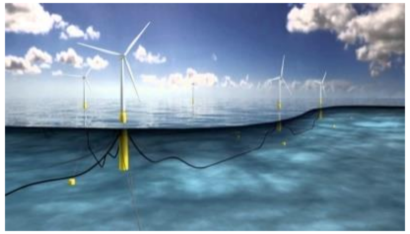
A major concern related to these capital intensive marine energy systems, is assuring an economic useful life beyond their PAYBACK periods; an issue that has to be addressed when faced with the growing risk of extreme weather events induced by climate change, with potential to destroy off-shore power generation systems.



- Assessing these climate change impacts and proposing solutions for mitigating them, will contribute to the reduction of risk, making investment in marine energy projects more attractive to private investors.

SOCLIMPACT project

- Identifies and assesses hazard factors, associated risks and impacts of climate change
- Addresses strategies to adapt marine RES to extreme weather events and minimize negative impacts of climate change
- Will propose cost-effective actions to reduce vulnerability and strengthen the resilience of the marine RES systems and its associated electrical infrastructure



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CONCLUSIONS

- Scarcity of land, air-safety restriction, and environmental issues, limit the on-shore installation of multi-megawatt wind turbines
- Wind resource off-shore up to 70% higher than the average on-shore
- Island system operators faces a growing challenge of bringing balance to electricity supply and demand, in a context of rapid growth of non-dispatchable RES power generation
- In addition to grid stability studies, the implementation of specially trained forecasting models to estimate offshore power is essential.
- A strategic element to be considered is the possibility of disposing of Demand Side Management of grid connected deferrable electrical loads, to increase/decrease overall electric power demand of the island, as a function of available RES power generation.
- Hybridization with energy storage should be understood as an alternative to provide adjustment services and stable production programs.
- For a business case to be made for energy storage systems as an instrument used by the TSO for grid balancing and maximizing RES in islands, part of the benefits from higher RES should go to reward energy storage, to off-set their high investment cost).
- Among the main barriers for the commercial exploitation of the different marine RES technologies, is the need to advance in the cost reduction curve (in terms of the Levelized Cost of Energy – LCoE) over their operating lifetime, and on the improvement of their reliability.

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