Electricidade da Madeira

EEM’s strategy to maximize the integration of renewables in the electrical grid of Madeira island

Hybrid system: reversible hydro, BESS, synchronous condenser and renewables

(Madeira Island - isolated grid)

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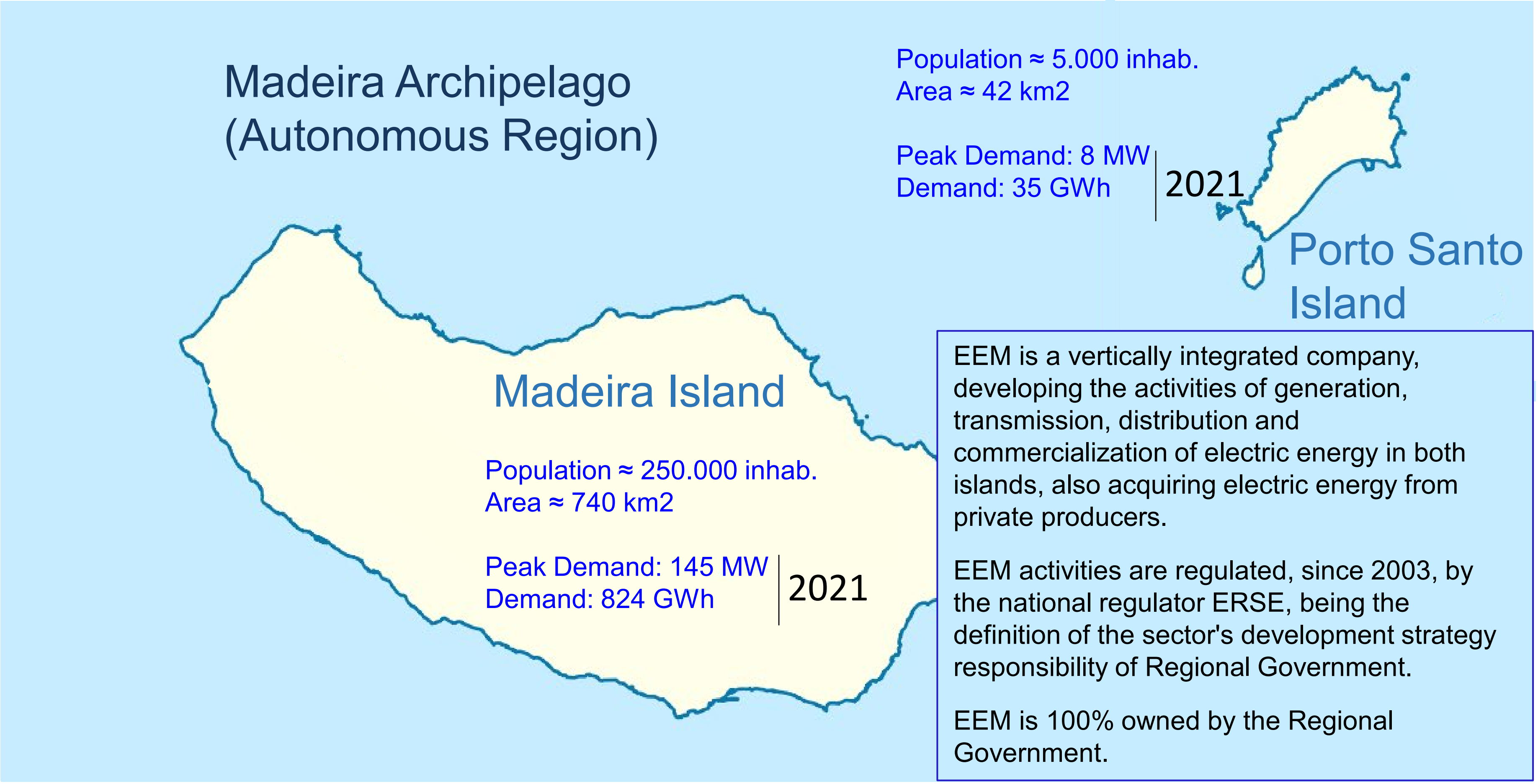
Location, size and some key electrical indicators



EEM is a vertically integrated company, developing the activities of generation, transmission, distribution and commercialization of electric energy in both islands, also acquiring electric energy from private producers.

EEM activities are regulated, since 2003, by the national regulator ERSE, being the definition of the sector's development strategy responsibility of Regional Government.

EEM is 100% owned by the Regional Government.

Main constraints, sustainability challenges and targets

Electricidade da Madeira

Main constraints of Madeira electrical system

- Small and isolated electrical system: It is not possible to export the excess of renewable generation, nor benefit from the grid stability associated with larger systems.
- High intermittent renewable sources (Wind and PV) in a short territory: creates difficulties in their usage and may endanger the safe operation of the electrical system.
- Small energy accumulation capacity in hydroelectric plants: Essentially run-of-river systems.
- Need to have a minimum number of thermal generators running for operating safety purposes.
- Occurrence of curtailment, mainly wind energy, especially at night, with abundant water resources.

Main constraints are technical constraints, not economic, as the unitary cost for renewables (wind and PV) is below the cost of fossil fuels and CO_2 cost.

Sustainability: Main challenges

- Climate change adaptation
- CO2 emissions reduction

ARM (Autonomous Region of Madeira) target: 2022-2024

- 50% electricity from renewable sources
- CO_2 emissions reduced by 20% compared to 2005

EEM's strategy to maximize the integration of renewables in the grid of Madeira island

System/grid services in isolated electric systems

Capabilities to assure the electric system safety operation:

- A-Inertia capability
- B-Frequency regulation capability:
  - B1-Primary regulation
  - B2-Secondary regulation
- C-Voltage regulation capability
- Short-circuit capacity

Traditional mix system generation	System services			
Technology	A-Inertia	B1_Frequency primary regulation	B1_Frequency secondary regulation	C-Voltage regulation
Thermal Generation (Gas, Fuel/Diesel engines)	X	X	X	X
Hydro	x	-	x	X
Wind	x	-	-	x
PV	-	-	-	x
Waste incineration	x	-	-	x
Result	X✓	X✓	X✓	X✓
Result without thermal generation	x	-	x	X✓

Mix system generation, without thermal	System services			
Technology	A-Inertia	B1_Frequency primary regulation	B1_Frequency secondary regulation	C-Voltage regulation
Synchronous condenser with inertia	X			X
Battery Power Plant	-	X	X	X
Hydro reversible (Storage, pumping and operation as a synchronous condenser)	x	-	X	X
Wind	x	-	-	x
PV	-	-	-	x
Waste incineration	x	-	-	x
Result without thermal generation	X✓	X✓	X✓	X✓

EEM's strategy to maximize the integration of renewables in the grid of Madeira island

Madeira Island Strategy Guidelines to Reduce Fossil Fuels

Electricidade da Madeira

Provide the electrical system with technologies that allow the regulation of the main network parameters (inertia, voltage regulation, frequency regulation and short-circuit power), tendentially without thermal power, through:

1. Adequacy of characteristics of RES generators to withstand more severe regimes by adapting the Grid Code **(New Grid Code to Madeira region was approved by Regional Government in September/2019)**

2. Refurbishment of main hydroelectric power plants adding a new operation mode: **synchronous cond**: Cases of Socorridos (24 MW) and Calheta II (7 MW) hydro power plants**: Base scenario: Minimum of 4 thermal generators;**

3. New reversible hydroelectric systems, with important storage capacity and regulation capabilities, including variable frequency pumping and synchronous cond. operation **(eg Calheta III, since 2021)**

4. New battery energy storage systems to remove thermal generators from the grid, allowing primary/secondary frequency regulation and the increase of renewable energy use:
   - ✓ **15 MW / 15 MWh – Madeira Island (Under construction. Expected to be in operation until august 2022): Minimum of 2 thermal generators**

5. New synchronous condenser designed to substantially increase electrical system inertia (2023) and a second BESS of 15 MW / 15 MWh – Madeira Island (Expected to be in operation until 2024)**: 0 thermal generators**

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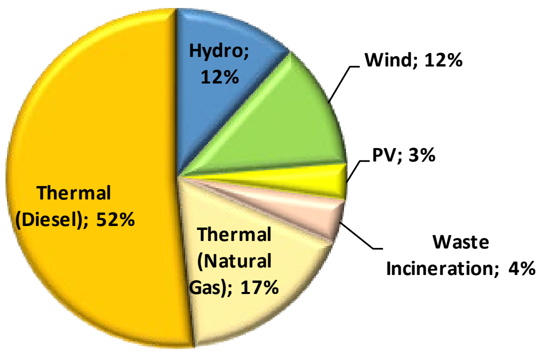
Recent / medium term planning - Madeira Island

- Reinforcement of 25 MW of wind power associated with the Calheta III project (18 MW already installed in 2021 and 7 MW to install in 2022).

- Increase of photovoltaic power up to about 60 MW (2023-2024).

Production Mix - 2018 - Madeira



2022
Expected renewable electricity rate with Calheta III project and associated wind component:

2024
Expected renewables electricity rate with the reinforcement of the photovoltaic component:

Renewables: 31% → **40%** → **50%**

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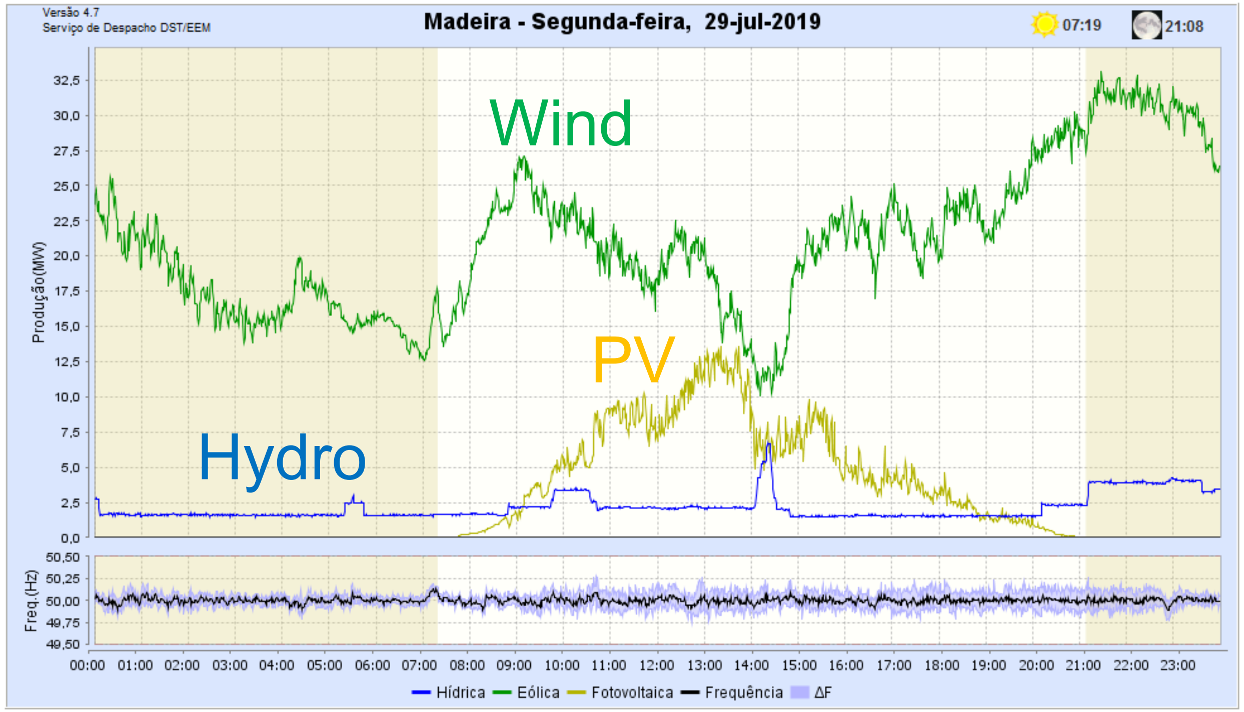
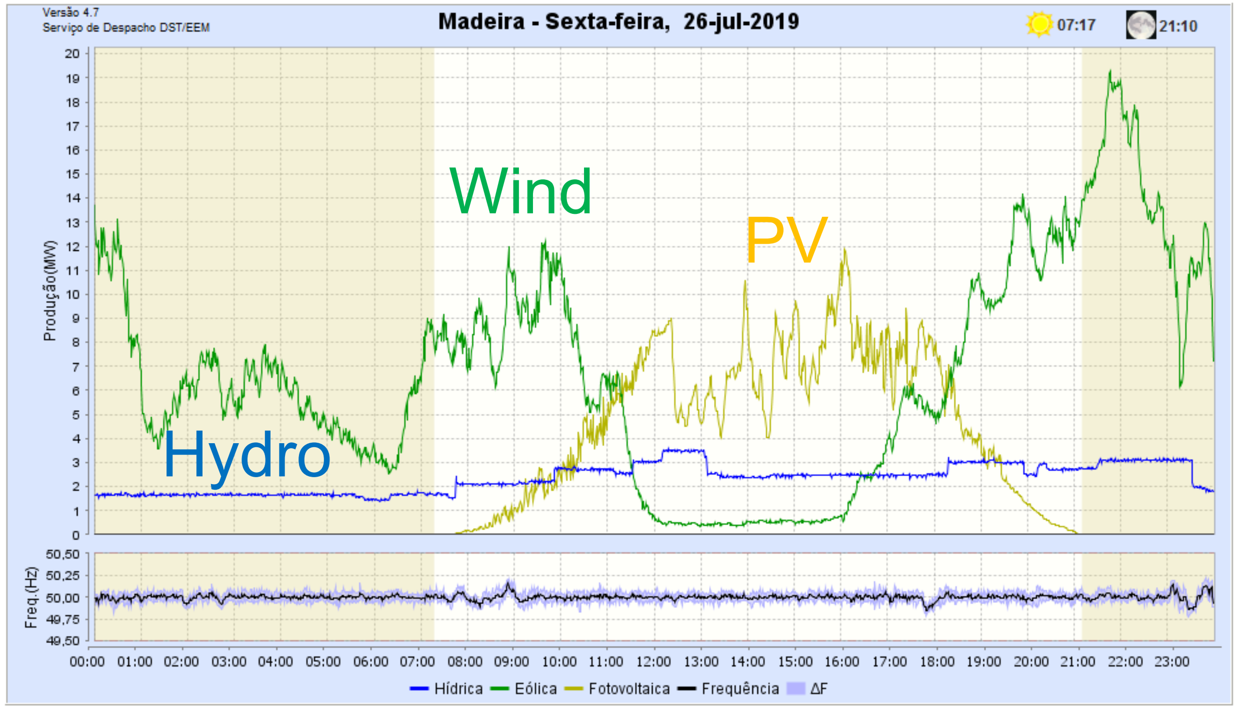
Examples of real mix renewable diagrams

July 2019 (Wind, PV and Hydro)

Installed Power: Wind: 45 MW; PV: 15 MW



Ponta: 126.91MW às 11:52 **Vazio:** 74.3 MW às 03:19



Ponta: 131.2MW às 12:11 **Vazio:** 76.17 MW às 03:28

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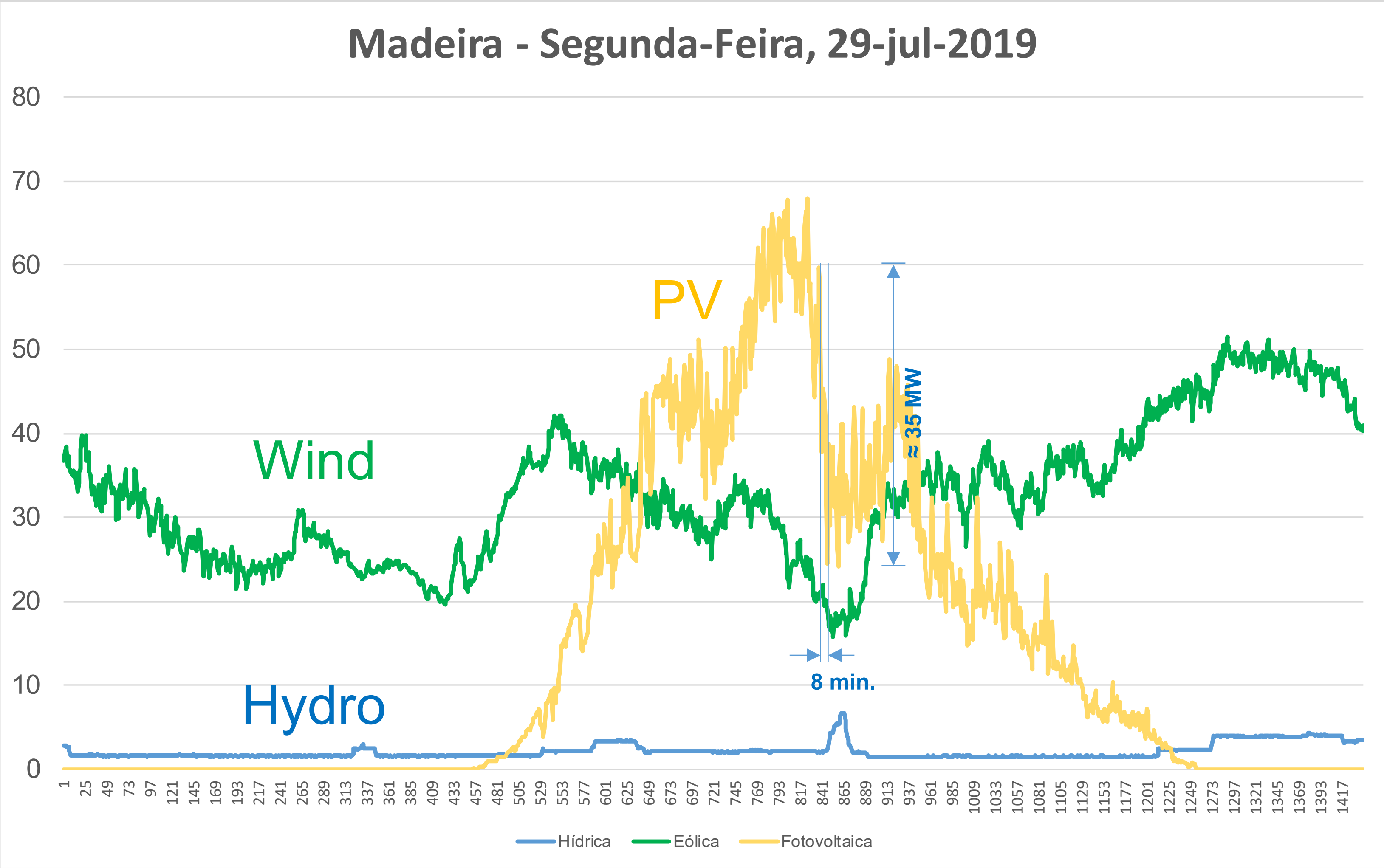
Short/Medium term perspective

Electricidade da Madeira



Existing power:

- Wind: 45 MW
- PV: 15 MW

New power:

50% Ren. ⇨

- **Wind: 25 MW**
- **PV: 60 MW**

Extrapolation:

- Wind: **70**/45 MW
- PV: **75**/15 MW

Great challenge to manage the electrical system!

EEM's strategy to maximize the integration of renewables in the grid of Madeira island

Renewables Mix / Renewable Curtailment / Storage Capacity

Electricidade da Madeira

Planning an optimized electrical system with a strong penetration of renewable electricity, requires the analysis of different variables, like:

- Renewable electricity target (50%-60%-70%,…)
- Power mix of intermittent renewables
- Unitary average cost (kWh) for renewable electricity generation
- Rates of curtailment
- Forecast of variable unitary cost (kWh) of electricity from fossil fuels (natural gas, fuel oil, oil + cost of CO_2/kWh)
- Unitary cost of storage with different technologies
- EV contribution for electric system management (Smart charge & V2G): Near future?
- Other uses of energy curtailment (hydrogen)
- The quality of intermittent renewables forecast

A possible approach is to calculate the LCOE (Levelized cost of energy), for the entire generation system, considering different scenarios of renewables mix and other assumptions mentioned above, and choose those with lower LCOE value.

Calheta III project – The biggest hydro project in Madeira island

Electricidade da Madeira

Calheta III Project: reversible hydroelectric system

- It is a structuring project for maximizing the use of renewable energy
- Calheta III is an expansion of the previous Calheta hydroelectric system (Madeira island)
- Investment ≈ 75 M€
- 45 M€ financed by Cohesion Fund, Integrated on the Priority Axis “Supporting the Transition to a Low Carbon Economy in All Sectors” by POSEUR (Operational Program for Sustainability and Efficiency in Resource Use)
- Four operation modes: Generation; Pumping; Synchronous condenser; Pumping + Synchronous cond.
- Allow 55% increase in wind power installed (25 MW), and the reduction of renewable curtailment

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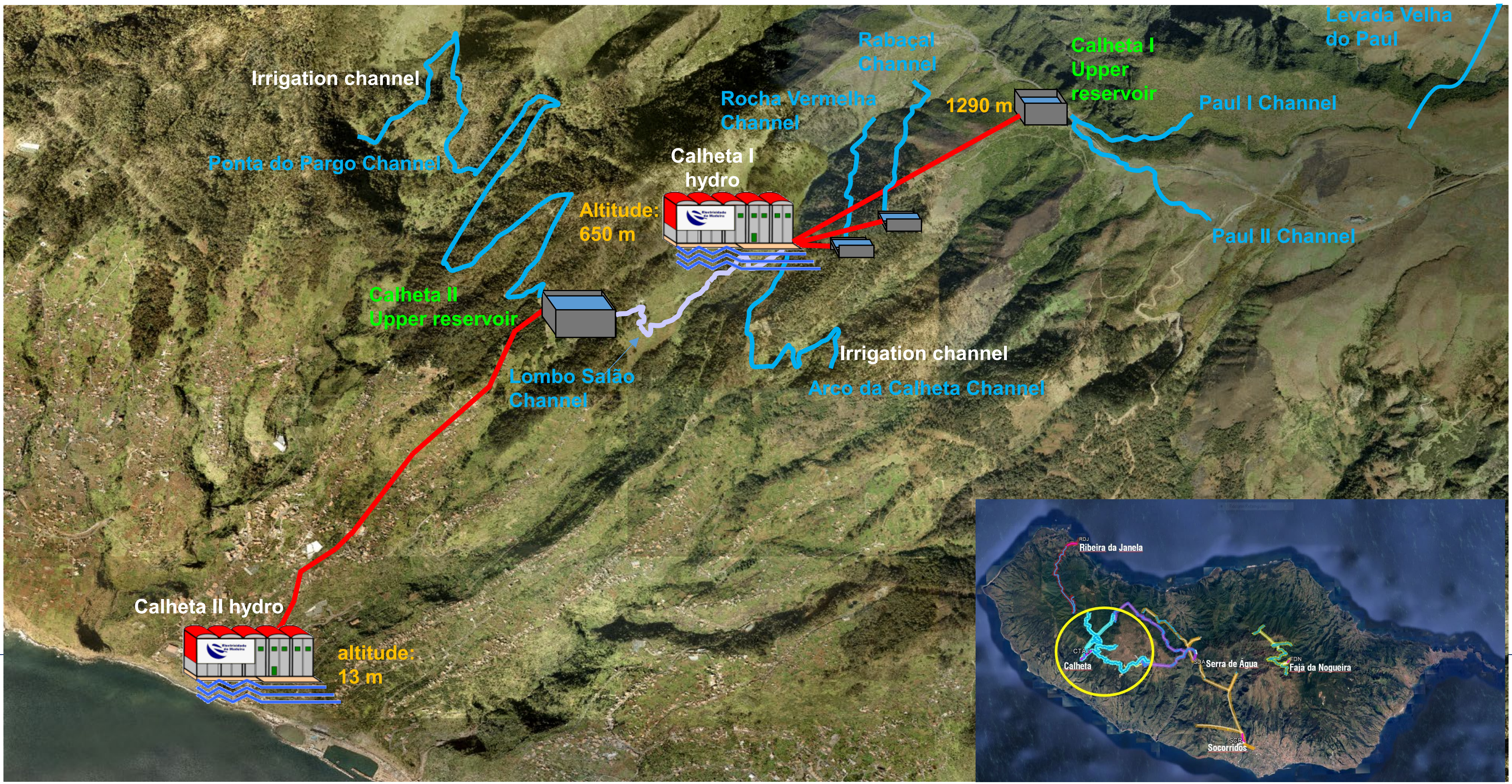
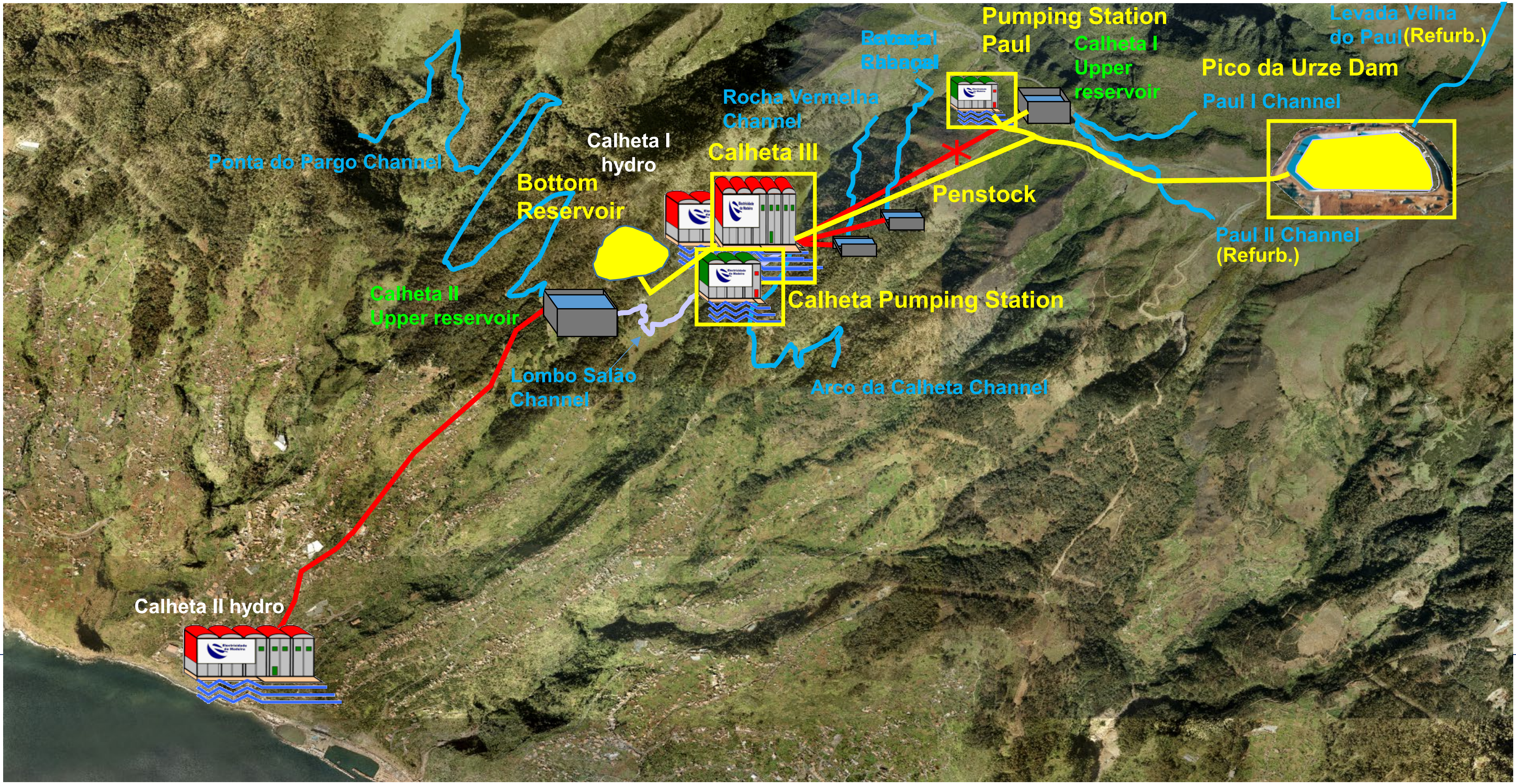
Old hydroelectric power system of Calheta



New hydroelectric power system of Calheta: Calheta III

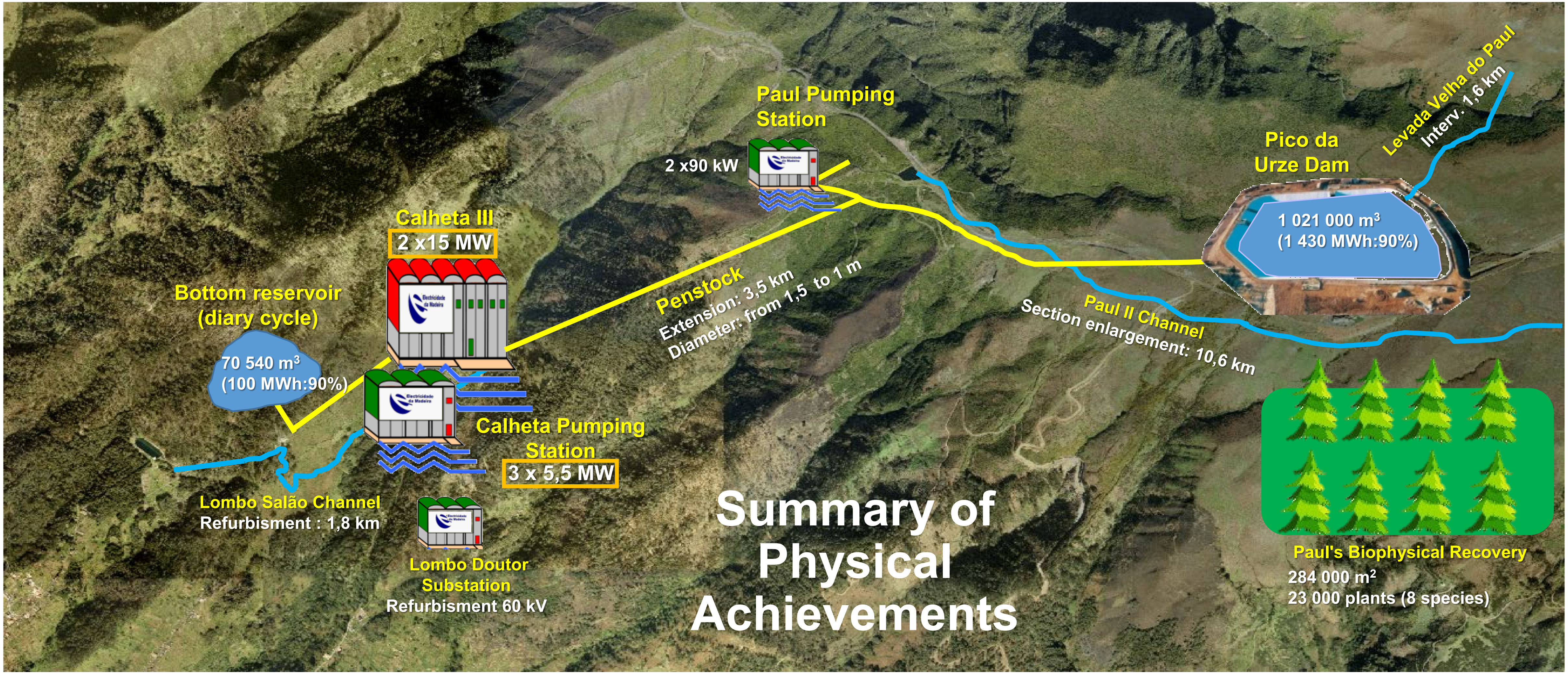
Calheta Hydroelectric System Expansion



New hydroelectric power system of Calheta (III)

Calheta Hydroelectric System Expansion

Electricidade da Madeira



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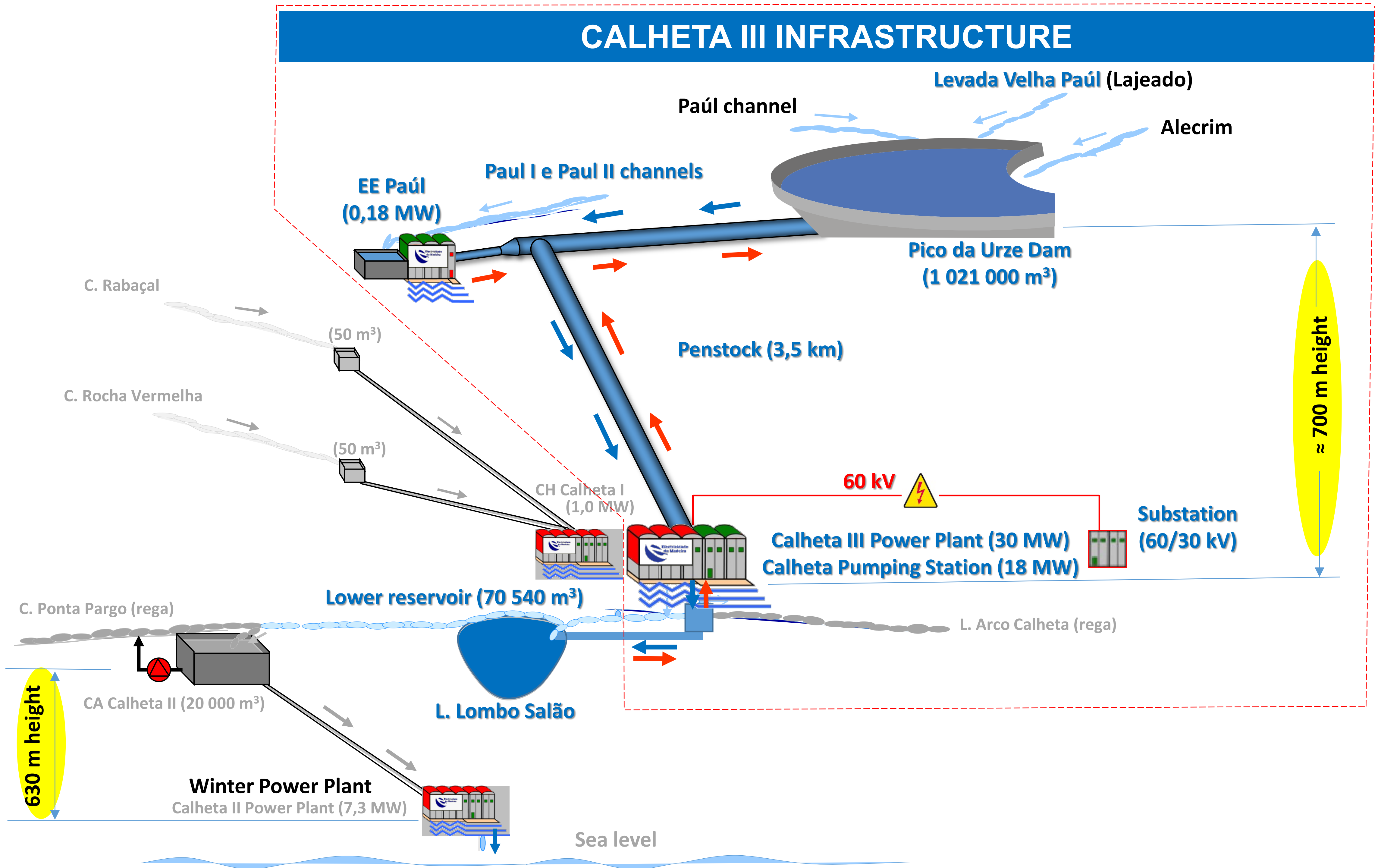


CALHETA III INFRASTRUCTURE
Levada Velha Paúl (Lajeado)
Paúl channel
Alecrim
Paul I e Paul II channels
EE Paúl
(0,18 MW)
Pico da Urze Dam
(1 021 000 m³)
C. Rabaçal
(50 m³)
Penstock (3,5 km)
C. Rocha Vermelha
(50 m³)
≈ 700 m height
60 kV
CH Calheta I
(1,0 MW)
Substation
(60/30 kV)
Calheta III Power Plant (30 MW)
Calheta Pumping Station (18 MW)
Lower reservoir (70 540 m³)
C. Ponta Pargo (rega)
L. Arco Calheta (rega)
CA Calheta II (20 000 m³)
L. Lombo Salão
630 m height
Winter Power Plant
Calheta II Power Plant (7,3 MW)
Sea level

New hydroelectric power system of Calheta

Calheta Hydroelectric System Expansion

Electricidade da Madeira

Calheta III Dam

Calheta III Hydropower Station

Penstock

Calheta III Hydropower Station

Lower Reservoir

EEM's strategy to maximize the integration of renewables in the grid of Madeira island

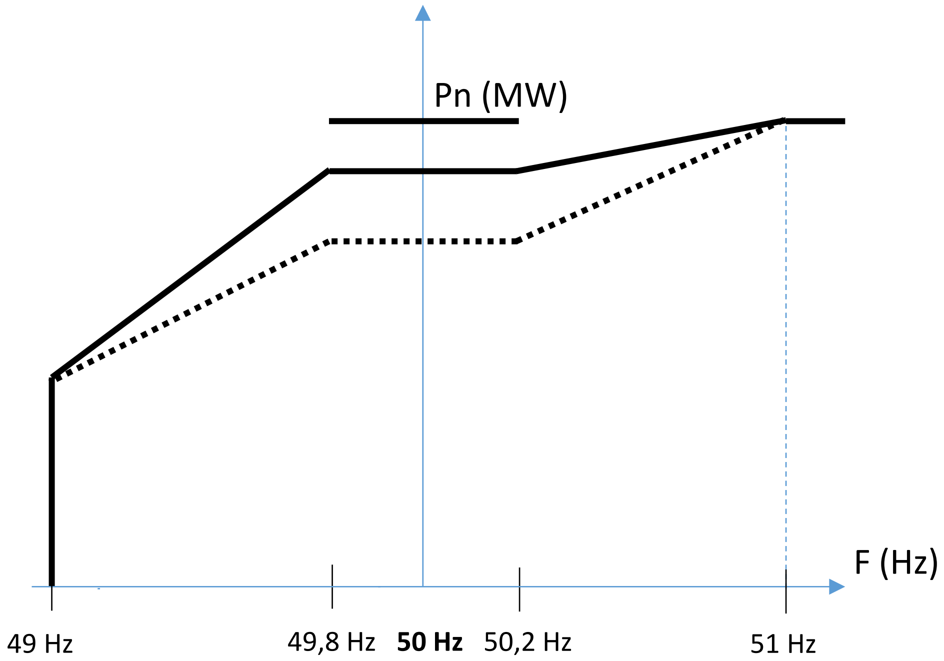
Main contributions of Calheta III project for the electrical system regulation

1-Operation as Synchronous Condenser

- Provides synchronous inertia
- Improve voltage control

2-Variable Frequency Pumping

- Allows to adjust the pumping power according to the needs
- Helps to reduce frequency drift in case of disturbance



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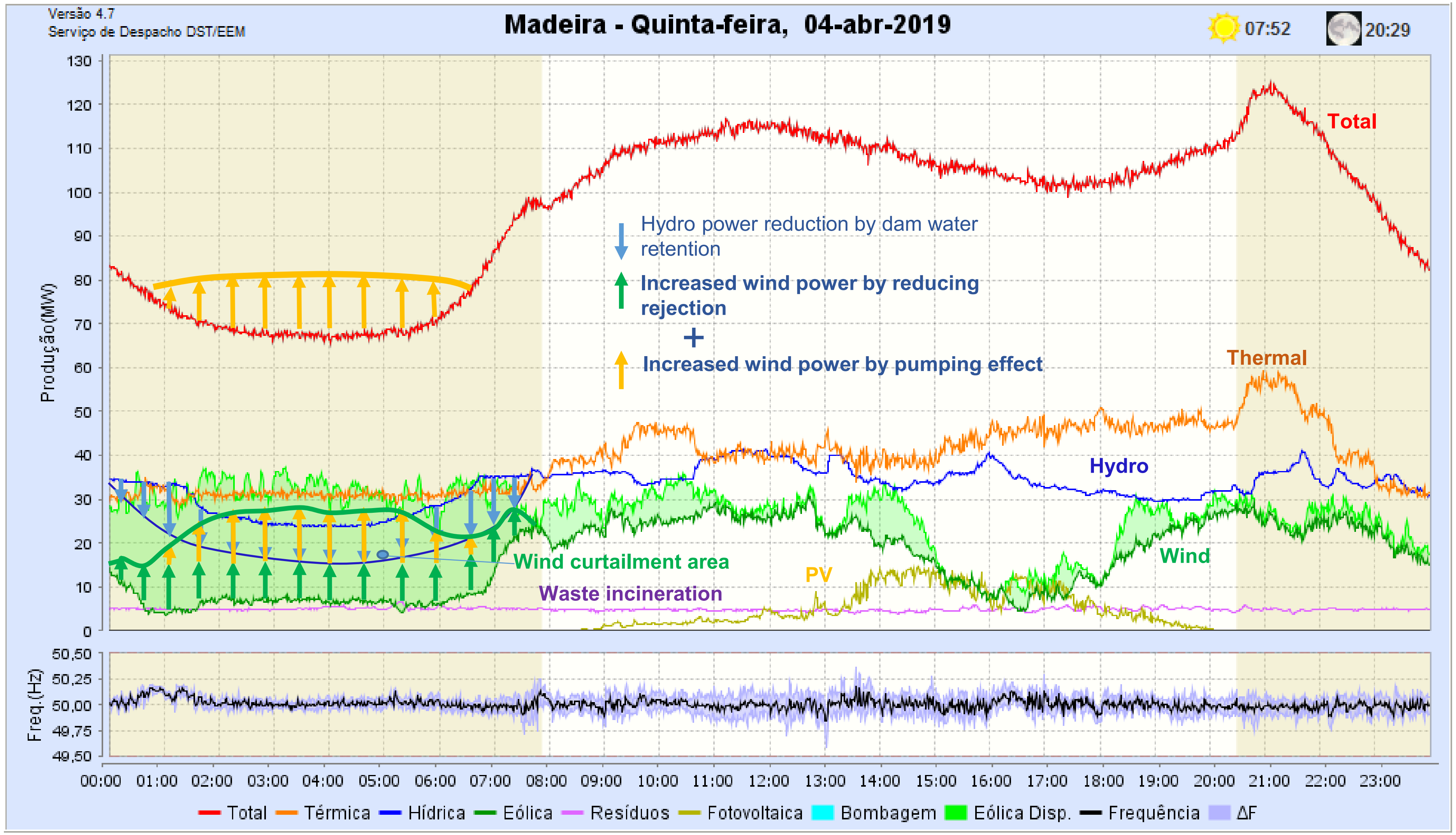
Main contributions of Calheta III project for the electrical system regulation

3-Improvement of wind energy capture
(curtailment reduction)

a) By accumulation of water inflows

b) By pumping effect



Ponta: 124.96MW às 21:06 **Vazio:** 65.59 MW às 04:02

Main contributions of Calheta III project for the electrical system regulation

Electricidade da Madeira

4-Secondary regulation capacity, up to 30 MW: Contribution for the security of system operation and improvement of intermittent energy integration

- Generation (reduction of wind or PV power)
- Reversible system: Ensures power availability at any time of year

PV production control strategies for new PV (P>1MW):

a) Limiting production rate through ramps and setpoints
b) Battery Support
c) Hydro secondary regulation

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EEM Strategy Summary

Main target: Maximize renewable electricity contribution → Operate the electrical system without fossil fuels

- Batteries allow to remove fossil fuels based generators from the grid (primary regulation, spinning reserve replacement)
- Synchronous condensers (hydro or other) add inertia, voltage regulation and short-circuit power
- Hydro power plants allow secondary regulation
- Reversible hydro power plants allow reduction of renewables curtailment
- Management Dispatch, near real time of all relevant generation installations
- Explore strategies for demand side management (DSM)
- Improvement of intermittent renewables forecast
- Storage optimization
- Use renewable energy curtailment in another storable source of energy

Thank you.