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**“Energy and Climate Change”**

# “An overview of wave energy devices. Case study: wave energy in Agios Efstratios, the first greek green island”


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# Outline

1. Objectives
2. Wave Energy
3. Methodological Framework
4. Case Study: Agios Efstratios
5. Analysis
6. Conclusions – Further Research

# 1. Objectives

- Traditional methods of energy production are contributing to serious environmental problems
- Need for new energy sources
- Renewable
- Low impact on the environment

most widespread exploitable RES
are wind and solar

# 1. Objectives

**Wave energy**

- One of the most promising sources
- Demonstrates a relatively high power density
- Could alone supply the world's electricity needs
- Contains roughly 1000 times the kinetic energy of wind (Kumar, 2007)

# 2. Wave Energy

Total power of waves breaking on the world's coastlines is estimated at 2 to 3 million MW.

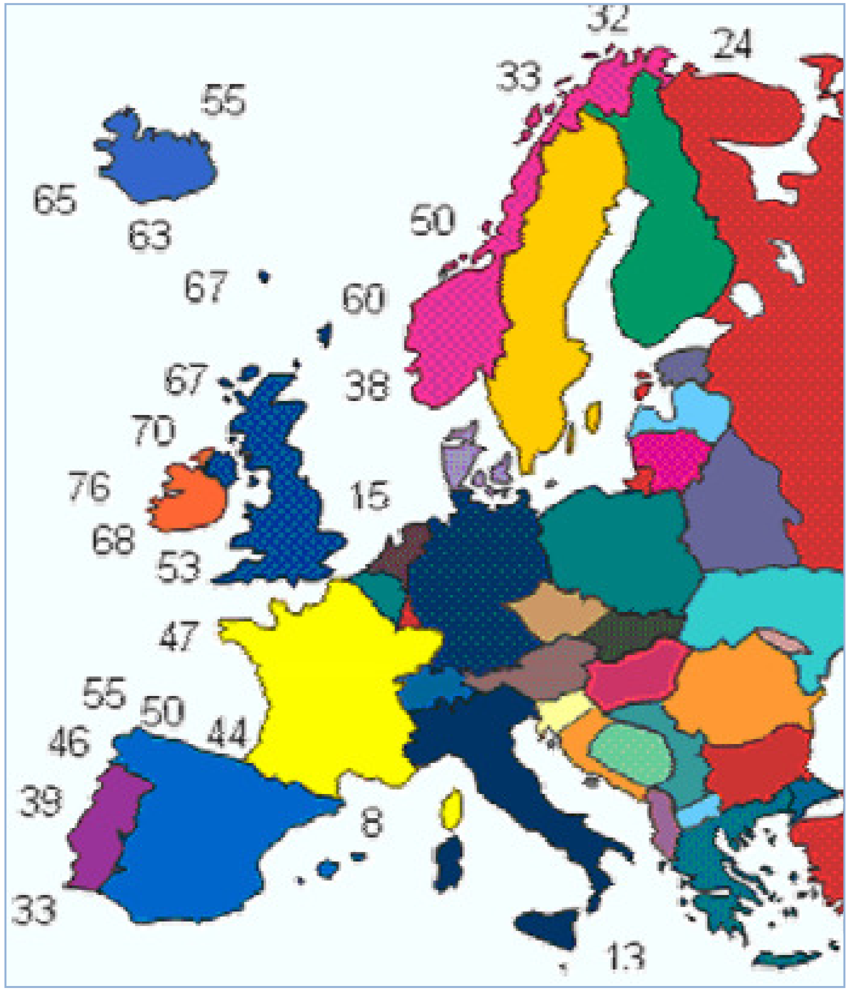
The theoretical global ocean energy resource is estimated to be on the order of (IEA, 2007):

- 2.000 TWh/year for osmotic energy
- 10.000 TWh/year for ocean thermal energy (OTEC)
- 800 TWh/year for tidal current energy
- 8.000 – 80.000 TWh/year for wave energy

Theoretical potential is several times greater than the actual global electricity demand, and equivalent to 4000 – 18000 MToE.

# 2. Wave Energy

## Europe



# 2. Wave Energy

**Mediterranean sea**:

- the annual power level varies between 4-11 kW/m
- the highest values occurring in the area of the south-western Aegean Sea (Clement et al., 2002)
- the entire annual deep-water resource along the European coasts is of the order of 30 GW
- the total wave energy resource for Europe resulting thus to 320 GW (Clement et al., 2002).

# 2. Wave Energy

- There are numerous suggestions on how to convert wave energy into electricity in the literature.

- Some of these are currently being tested in different parts of the world.

- The broad majority of these approaches use involved interfaces to match the low speed reciprocal wave motion to a conventional electrical generator (Leijon et. al., 2006).

# 2. Wave Energy

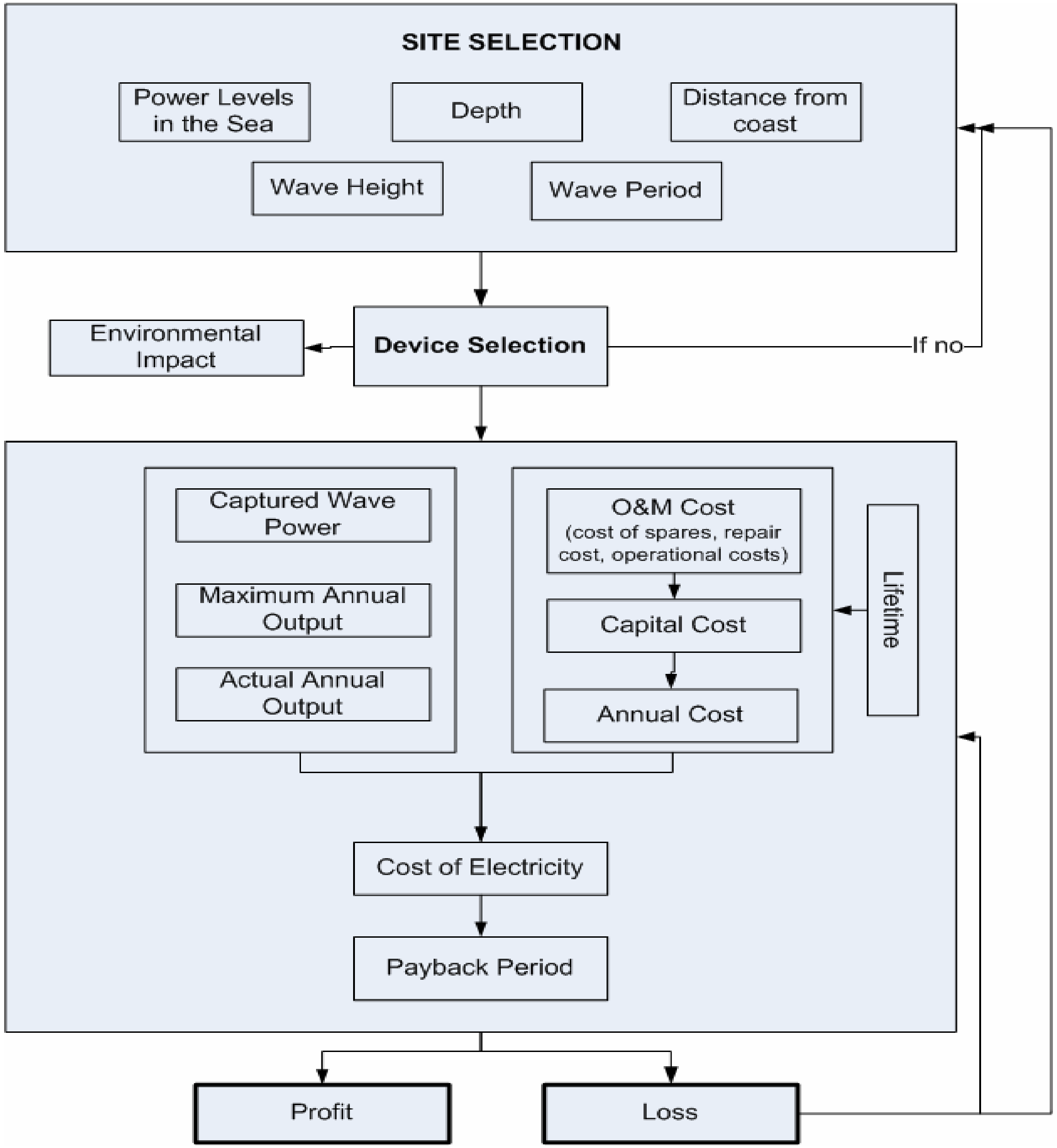
**Wave Energy Devices**

- floats or pitching
- oscillating water columns (OWC)
- wave surge or focusing devices

Energy collection devices can be placed either on the

- shoreline
- near the shoreline,
- offshore (Wave Energy, 2010)

# 3. Methodological framework



# 4. Case study: Agios Efstratios

- Agios Efstratios is a small island with 250 residents, located between Lesvos and Lemnos

- First "green" island, entirely powered by renewable energy sources (RES), its residents relying on solar and wind generated energy and moving around the island on bicycles and in electric cars

# 4. Case study: Agios Efstratios

Main characteristics of Agios Efstratios' electricity demand (year 2008):

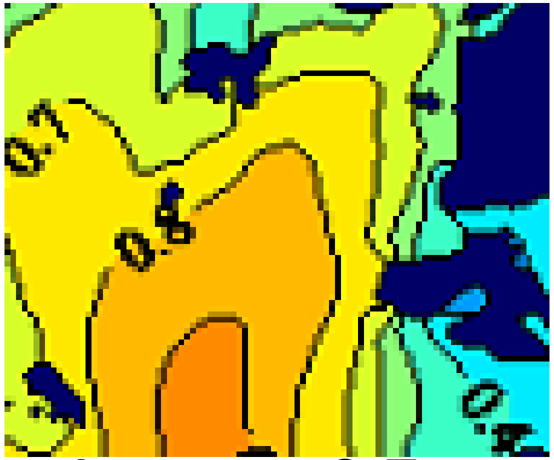
- Electricity Demand 2008:
  300 kW(mean), 350 kW (max)
- Min Electricity Demand 2008:
  70 kW
- Annual Electricity Demand 2008:
  1020 MWh
- Expected RES Output:
  +150% base year 2008 (power and energy)



Source: Ministry of Development, 2009

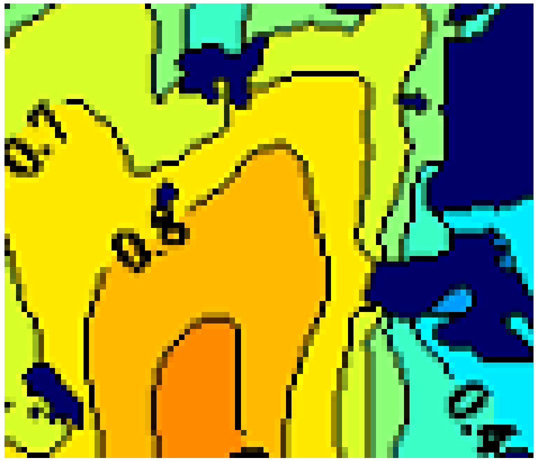
# 4. Case study: Agios Efstratios

## Wave Height per Season

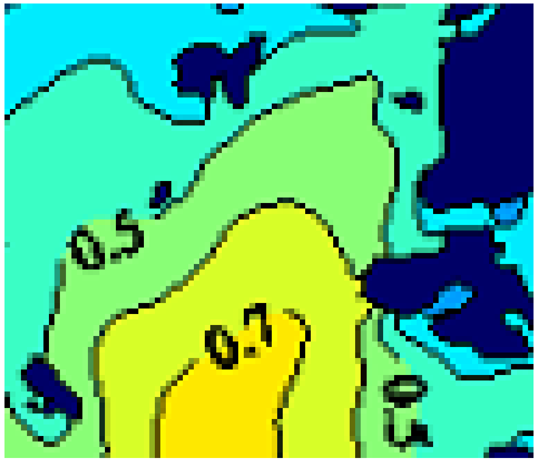


Autumn:0.7m

Winter:1.1m



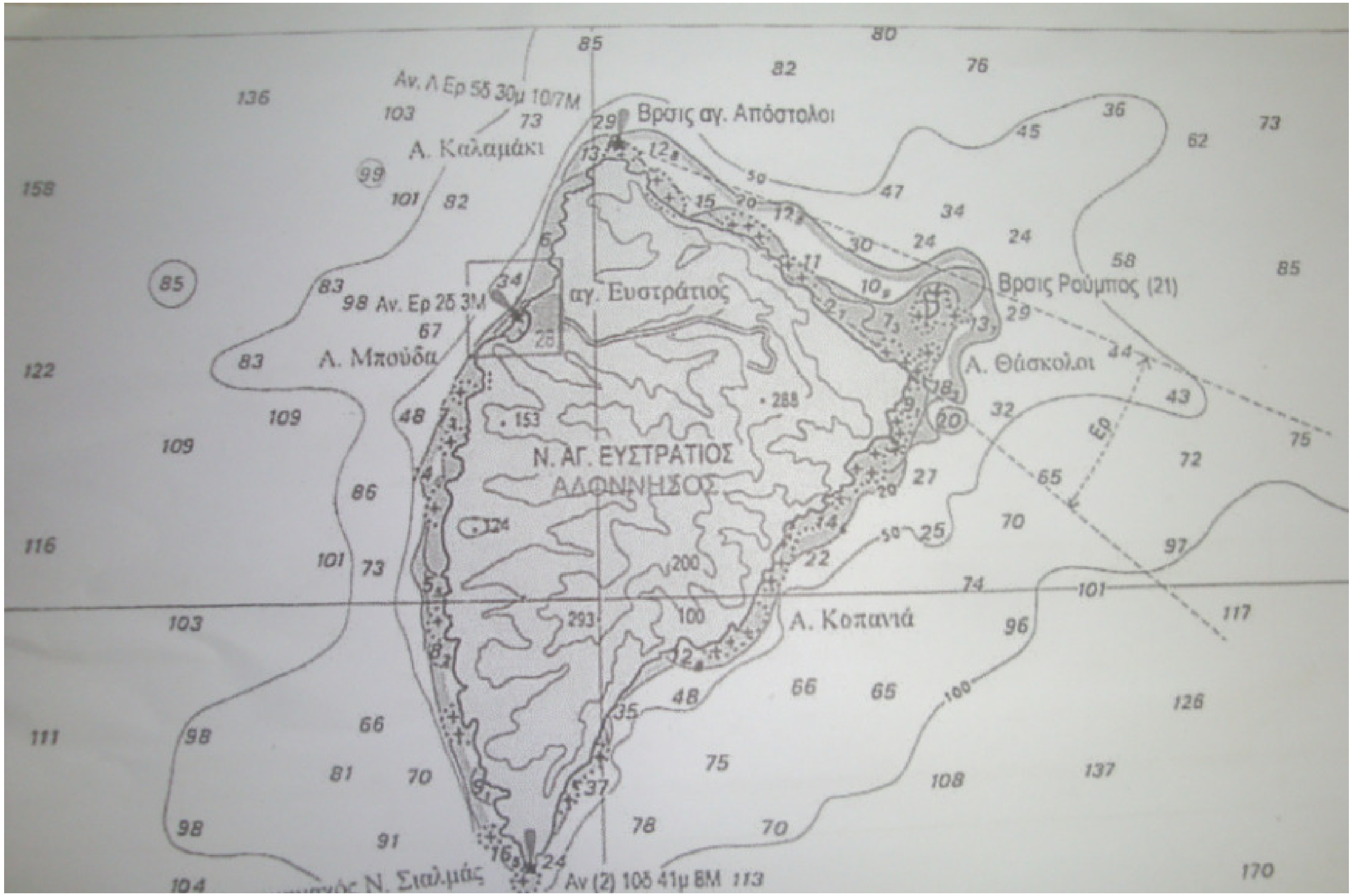
Spring: 0.7m



Summer:0.5m

Average Annual Wave Height : 0.7m

## Sea Depth


Αν. Λ Ερ 5δ 30μ 10/7Μ
Βρσις αγ. Απόστολοι
Α. Καλαμάκι
αγ. Ευστράτιος
Βρσις Ρούμπος (21)
Αν. Ερ 2δ 3Μ
Α. Μπούδα
Α. Θάσκολοι
Ν. ΑΓ. ΕΥΣΤΡΑΤΙΟΣ
ΑΛΟΝΝΗΣΟΣ
Α. Κοπανά
Ν. Σιαλμάς
Αν (2) 10δ 41μ 8Μ

# 5. Analysis

It is examined the technical and economic characteristics of 30 wave energy devices

Data:

- Manufacturer companies
- Universities / Research teams
- Web sites of the wave devices

# 5. Analysis – Shored Base

| Wave Energy Device | Site Selection: Agios Efstratios | Economic Valuation (+) | Economic Valuation (-) |
|---|---|---|---|
| **SHORE BASED** | | | |
| **1. LIMPET** | Construction cost: €1.34m. Capital cost too high. | | × |
| **2. WECA** | Immature technology. Not applicable. | | × |
| **3. Mighty Whale** | Sea Depth: 40m.<br>Construction cost:€13,5 εκατ. | | × |
| **4. SARA MWEC** | Output: medium<br>Construction Cost: low<br>O&M Cost: low | √ | |
| **5. MAWEC** | Output: low (Wave Height: 0,6cm, Wave Period: 0,9sec – collects 75%wave energy -> output 16%)<br>Construction cost: low | | × |
| **6. Oceanlinx** | Ideal for oceans, not for the Aegean sea.<br>Wave Height: 2m, Wave Period: 0,7sec. | | × |
| **7. Sperboy™** | Construction Cost: low<br>Cost of Electricity: €67-187/MWh<br>Sea Depth: 50m<br>Location: SE of the Island | √ | |
| **8. WaveMaster** | Construction Cost: high<br>O&M Costs: high<br>Wave Height: 5m | | × |

# 5. Analysis – **Above Waterline with Overtopping**

| ABOVE WATERLINE WITH OVERTOPPING | | | |
|---|---|---|---|
| **1.SSG**  | Construction Cost: high<br>Output: low<br>Wave Height: 4m | | × |
| **2.Wave Dragon**  | Immature technology<br>Sea Depth: 6m (0,4kW/m)<br>Not appropriate for the site -> low mean wave height | | × |

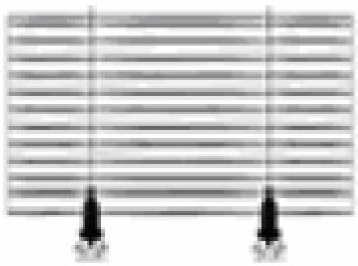
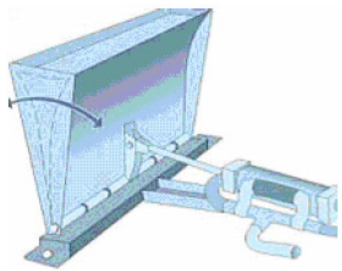
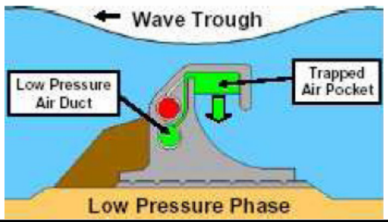
# 5. Analysis – Above Water (1/2)

| ABOVE WATER | | | |
|---|---|---|---|
| **1. LabBuoy** | Ideal for the selected location.<br>Cost of Electricity: low (€0,07-0,09/kW) | √ | |
| **2. SDE** | The most ideal for the selected site.<br>Construction Cost: €600.000<br>Cost of Electricity: low (€0,02/kW)<br>Payback Period: 3 years | √ | |
| **3.WET EnGen™** | Applicable to the selected site<br>Construction Cost: low<br>Output: 10-15kW/m | √ | |
| **4. Trotman Unit** | Sea Depth: 12m on coast | | × |
| **5. Wave Star©** | Distance from coast: 10-20km<br>Cost of Electricity: €0,33-0,8/kW<br>O&M Costs: low (every 10years)<br>Lifetime: 50years | √ | |
| **6. AquaBuoy** | Ideal for open seas, not for the Aegean sea. | | × |
| **7. Manchester Bobber** | Sea Depth: 30-60m | | × |

# 5. Analysis – Above Water (2/2)

| | | | |
|---|---|---|---|
| **7. CETO™** | Sea Depth: 15m<br>Cost of Electricity: €0,084/kW<br>Output: 23,6kW per 1m wave height<br>It can be used to produce fresh water through reverse osmosis. | √ | |
| **8. SyncWave™** | Construction Cost: Medium<br>Cost of Electricity: €0,03-0,05/kW<br>O&M Costs: Low | √ | |
| **9. Power Buoy®** | Ideal for open seas. | | × |
| **10. OWEC®** | Ideal for open seas and oceans. | | × |
| **11. FWEPS** | Its construction depends on the characteristics of the selected site.<br>Construction Cost: low O&M Costs: low | √ | |
| **12. Brandl Generator** | Construction Cost: low (€1300/kW)<br>O&M Costs: low<br>Electricity Cost: €0,033/kW<br>Profit: 8% of capital cost per year.<br>Payback Period: 10years | √ | |
| **13. WaveBlanket** | Wave power: 30-70kW. | | × |

# 5. Analysis - Bottom Mounted

| BOTTOM MOUNTED | | | |
|---|---|---|---|
| **1. Oyster™**  | Sea Depth: 10m<br>Wave Power: 15kW/m<br>Construction Cost: €1.200.000<br>O&M Costs: low (easy to reach) | √ | |
| **2. WaveRoller**  | Wave Period: High<br>It is applied in Crete (0,9-1,1m), where the output was 30% | | × |
| **3. bioWAVE™**   | Not enough information in order to evaluate | | × |

# 5. Analysis – Above Waterline With Hydraulic PTO

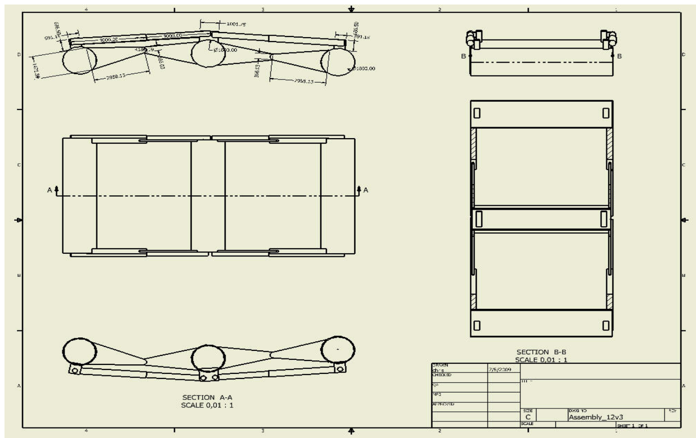
| ABOVE WATERLINE WITH HYDRAULIC PTO | | | |
|---|---|---|---|
| **1. Pelamis P-750 WEC** | Wave Power: 55kW/m.<br>Cost of Construction: €190m.<br>O&M Costs: €8,9m/year | | × |
| **2. DEXA** | Distance from coast: 16km<br>Cost of Capital: €13.130.000<br>O&M costs: €9.248.000 for 50years<br>Cost of Electricity: €0,068/kW. | | × |
| **3. Crestwing** | Immature technology. | | × |
| **4. McCabe Wave Pump** | Wave Height: 7m | | × |
| **5. Floating Wave Generator** | Its construction depends on the characteristics of the selected site.<br>Construction Cost: low (€3.400-6.800).<br>Cost of Electricity: €0,034/kW<br>Payback Period: 20-40 days | √ | |

# 5. Analysis - **Amphitrite**

Research Team: University of the Aegean, Department of Shipping, Trade & Transport

Supervisors: Prof. Nikitakos, N.,
Dr. Lilas, T.

Construction cost: €100.000
Output: 20kW



# 6. Conclusions

- Selected site in combination with the proper device, with the maximum output as well

- The cost of electricity is usually bigger than this of other RES. The mean cost of electricity in EU is €0,030-0,080/kWh, whereas the mean cost of electricity for wave energy is €0,06-0,10/kWh

- The wave power in greek seas is low and the majority of the wave energy devices are inappropriate with low output

# 6. Conclusions

- Wind and solar energy devices are more productive and more profitable than wave energy in Greece

- Although, wave energy can provide big amounts of electricity, the technology is still immature

- Further R&D is needed in order wave energy to become commercially competitive

**Think green !**

Thank you!

Maria Kamargianni, Nikitas Nikitakos, Theodoros Lilas