CoNISMa
Consorzio Nazionale Interuniversitario per le Scienze del Mare

Naples Shipping Week
Napoli 27 giugno - 2 luglio 2016

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ASSOCIAZIONE ITALIANA DI TECNICA NAVALE
Sezione Napoli – Sud Italia

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Consorzio inter-Universitario per la Previsione e Prevenzione dei Grandi RIschi
Università di Salerno - Università di Napoli "Federico II"

Atti del Seminario
"ENERGIA DAL MARE"
Mercoledi 29 Giugno 2016 - Ore 14
Aula Magna dell'Università Parthenope, Via Acton 38 Napoli

Energia da onda nell'offshore italiano: tecnologie a confronto

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OCEAN WAVES AS ENERGY RESOURCE

Waves result from the integrated action of **wind** over large ocean areas

Waves are an indirect form of **solar** energy

SOLAR ENERGY	WIND ENERGY	WAVE ENERGY
		
0.1 – 0.3 kW/m^2	0.4 – 0.6 kW/m^2	2 – 3 kW/m^2

Falnes, 2007

Predictable

High availability

Low land use

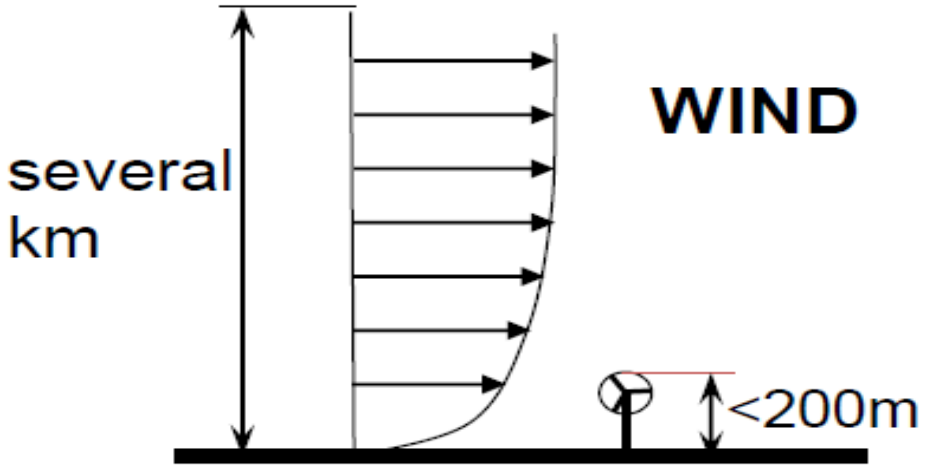
Why ocean wave energy ?

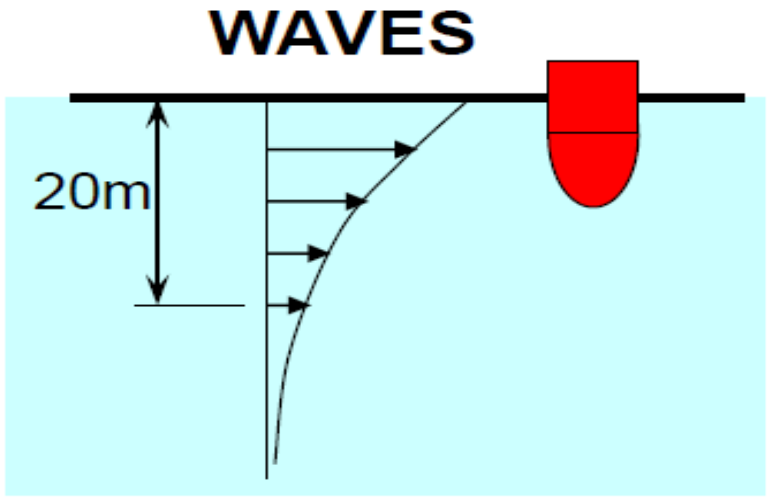
High energy flux

Low visual impact

Persistent

WAVE VS WIND ENERGY





The wind velocity profile extends over several km.

Wind farms explore only a tiny sublayer

Wave energy is concentrated near the surface.

Wave farms can absorb a large part of the wave energy flux.

Wave energy flux per unit vertical area near the surface is about **5 times** larger than **wind energy flux**

Waves are a more concentrated form of energy than wind

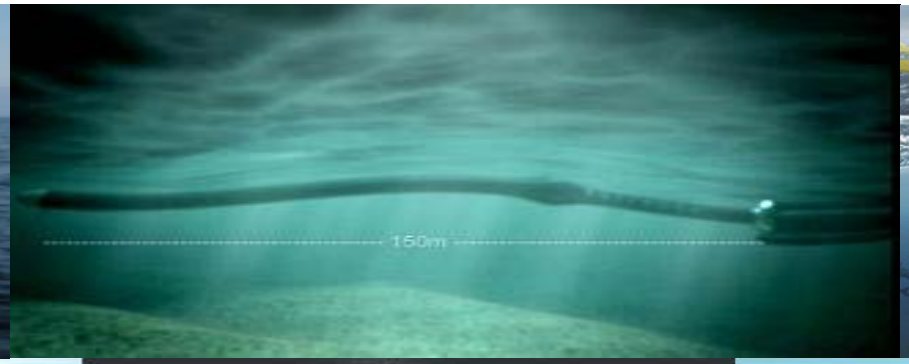
Falcao, 2012

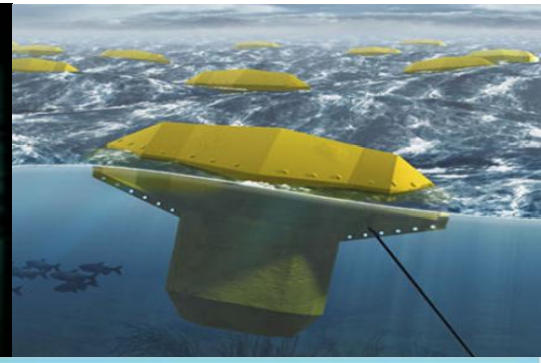
WAVE ENERGYCONVERTERS (WECs)

Unlike the case of wind technologies there are several effective ways of absorbing energy from waves …

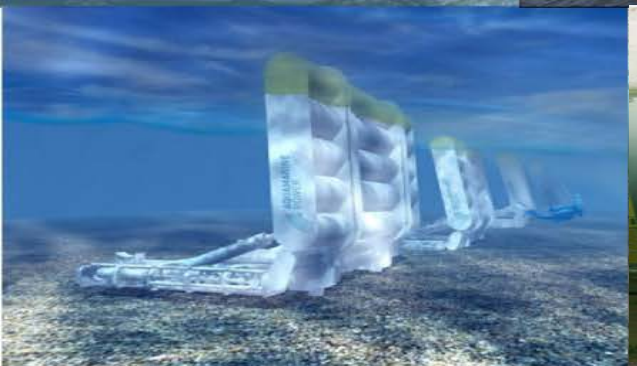
… there is a wide range of wave energy devices, at different development stages, competing against each other



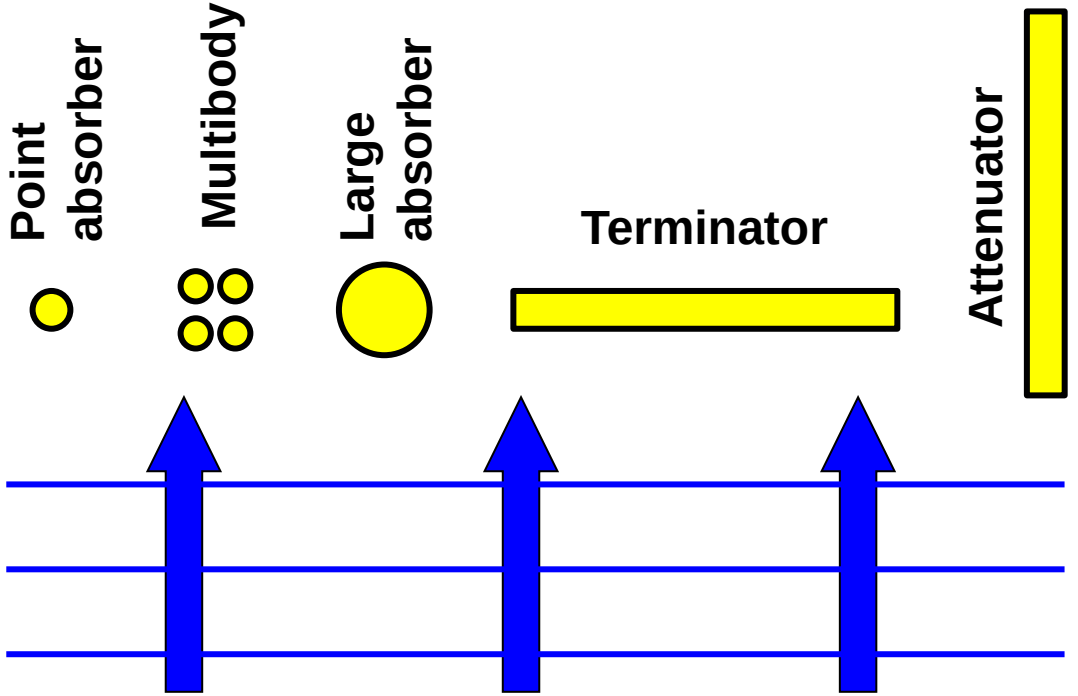


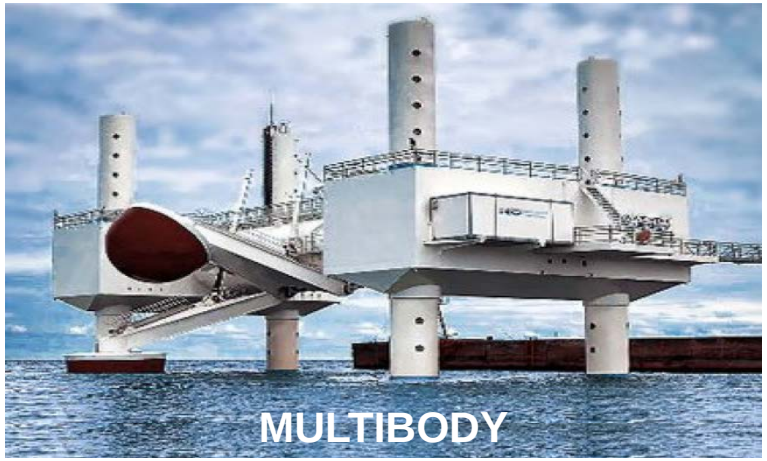




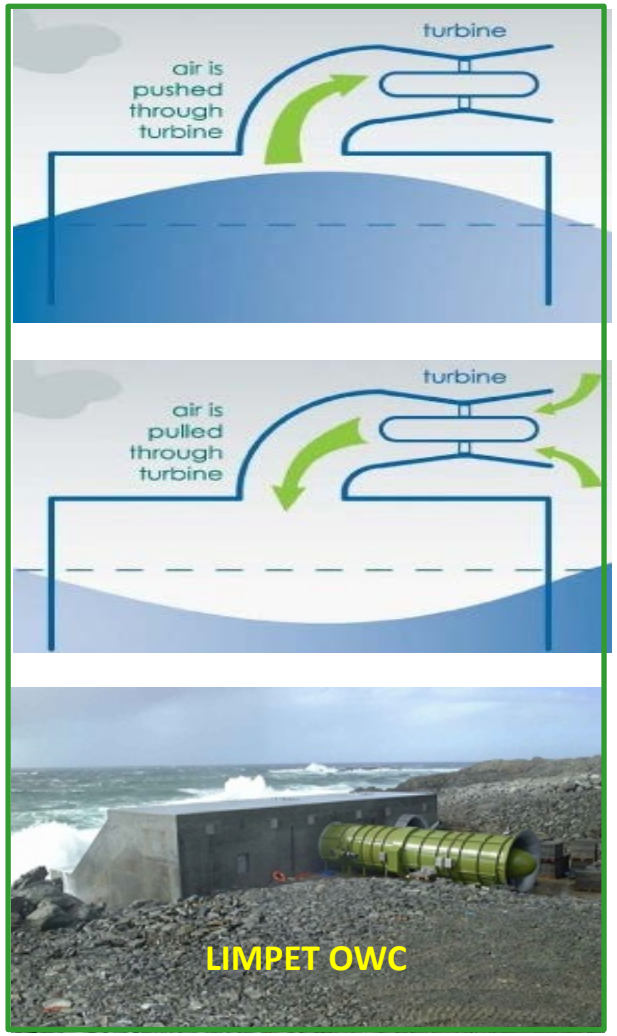

WAVE ENERGY CONVERTERS: CLASSIFICATION





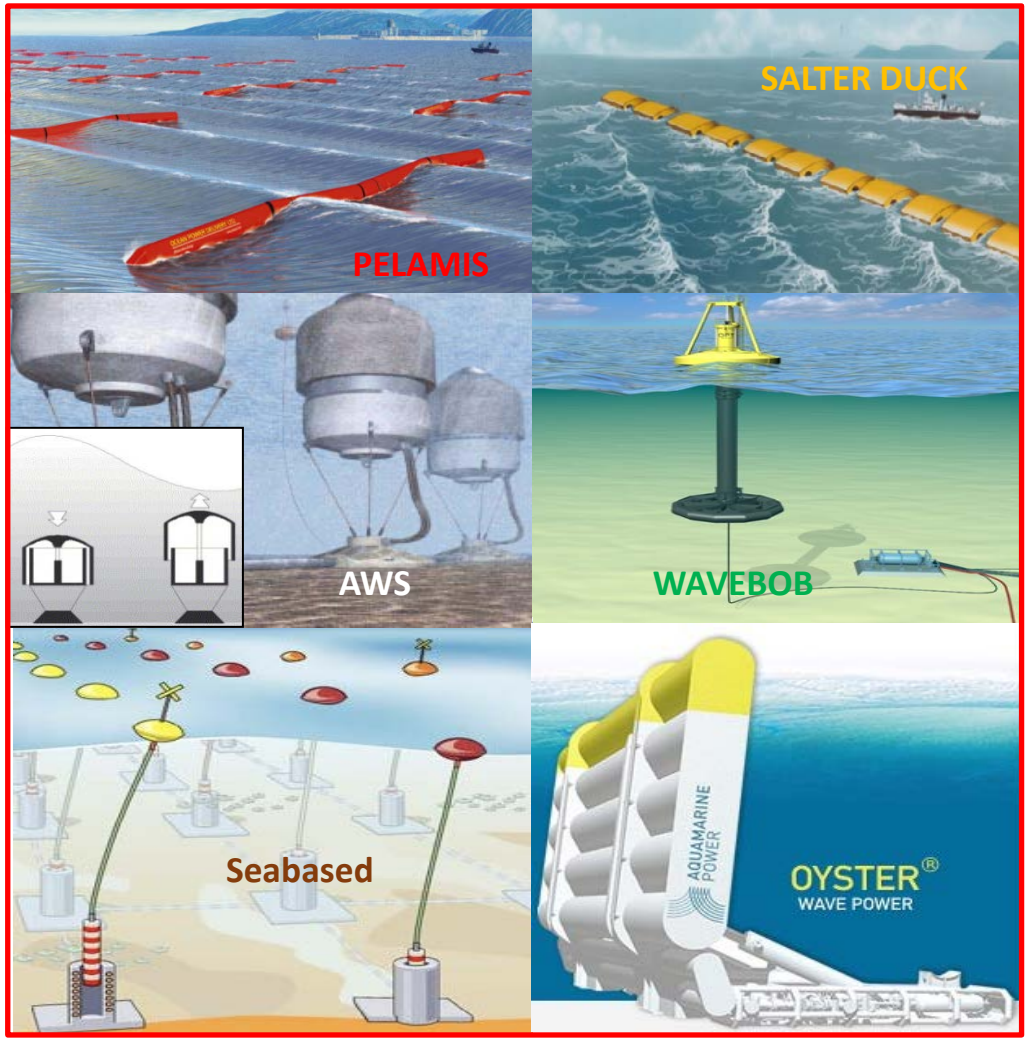
WAVE ENERGY CONVERTERS: CLASSIFICATION

OSCILLATING WATER COLUMNS

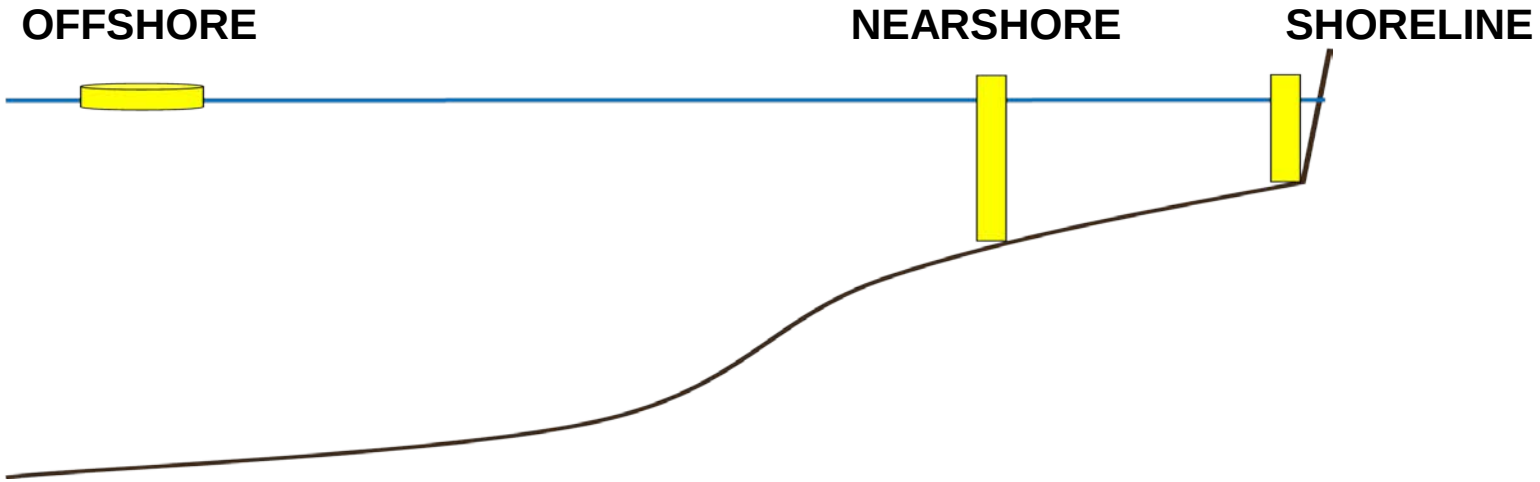


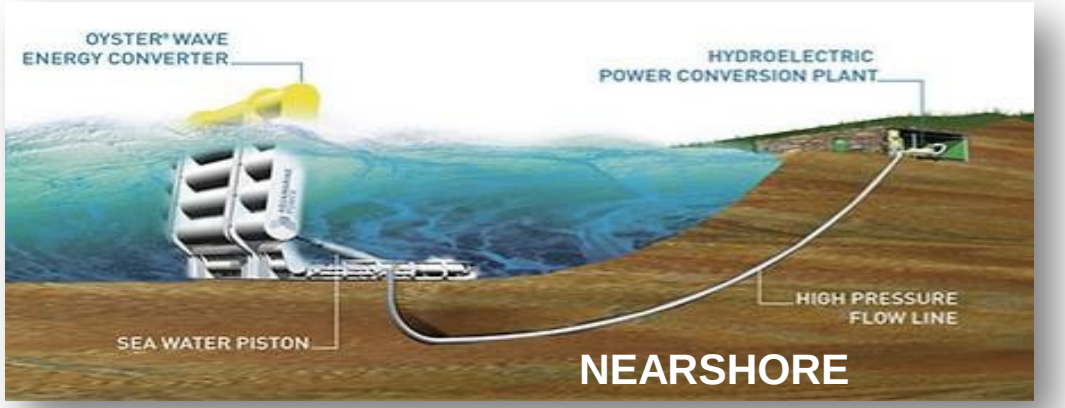
OVERTOPPING SYSTEMS

WAVE ACTIVATED BODIES



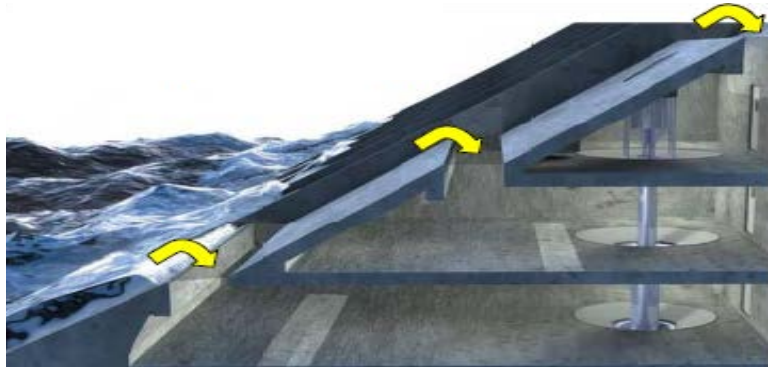
WAVE ENERGY CONVERTERS: CLASSIFICATION



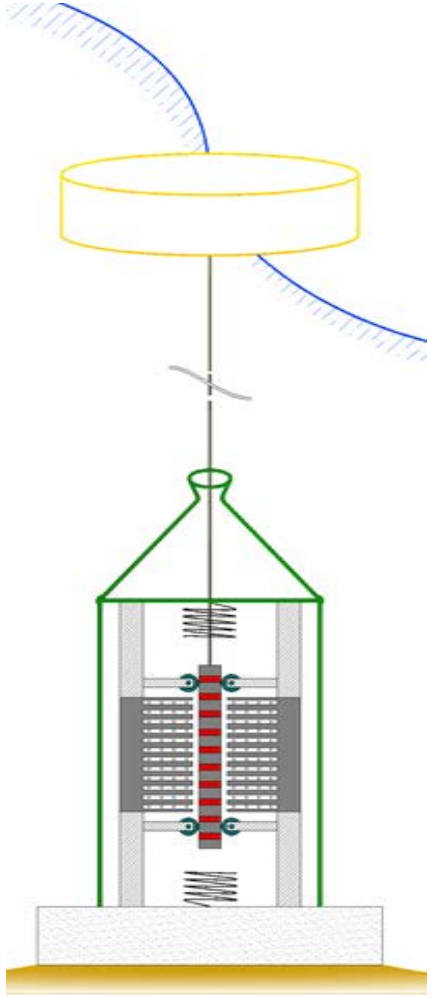


WAVE ENERGY CONVERTERS: CLASSIFICATION

Low-head hydraulic turbines

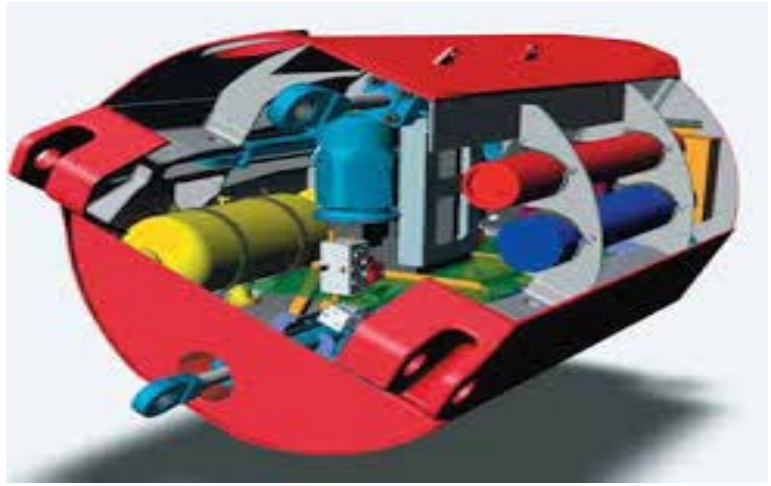


Linear electric generator

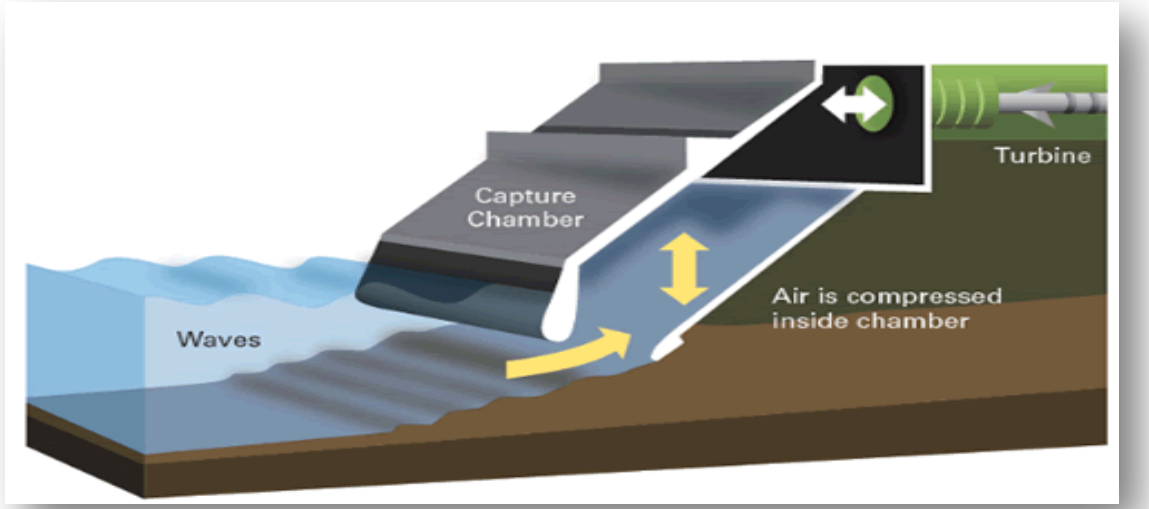


High-head hydraulic turbines

High-pressure oil PTO



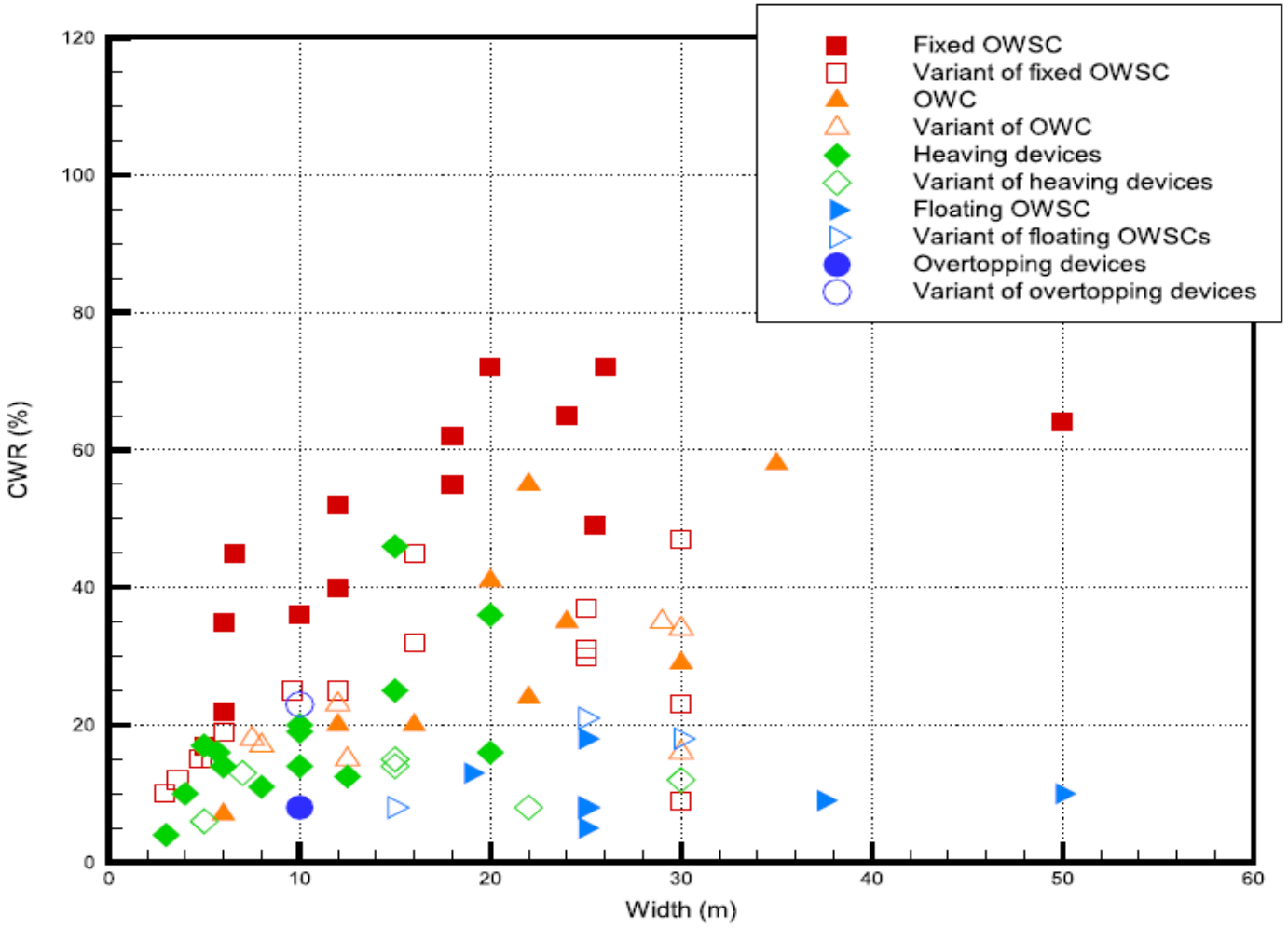
Air turbines



WAVE ENERGY CONVERTERS: EFFICIENCY

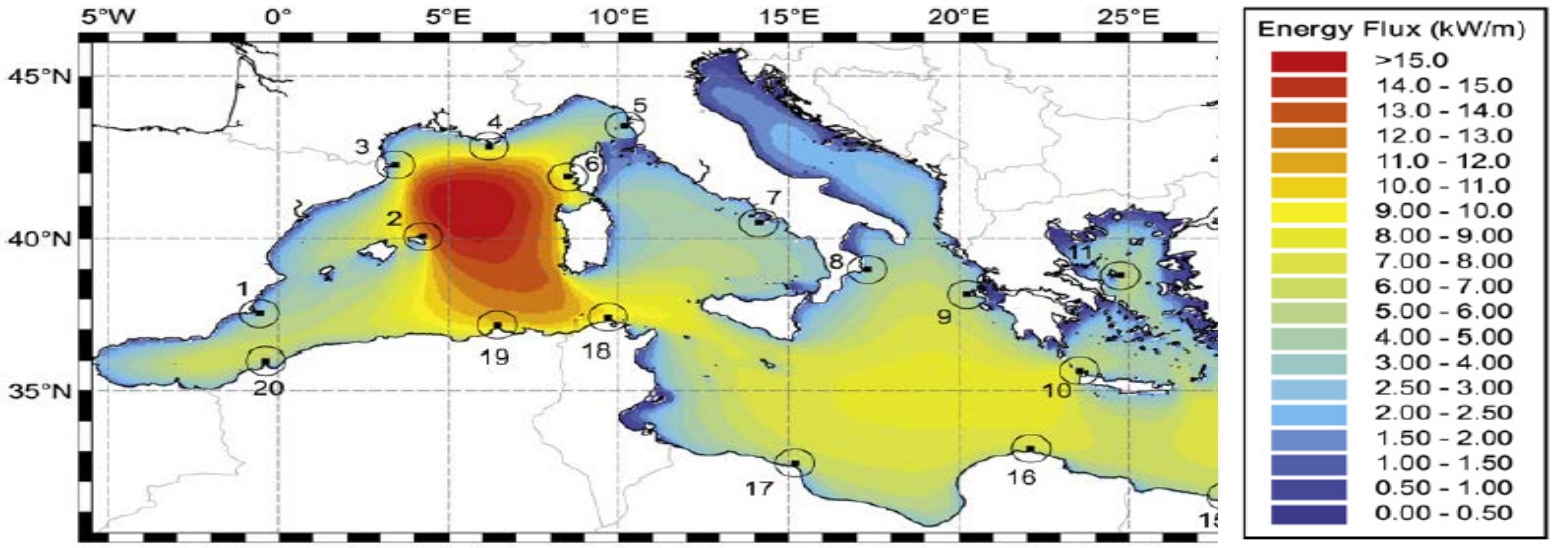
CAPTURE WIDTH RATIO = $\dfrac{\text{Absorbed power}}{\text{Incident power * device width}}$ **=** **Fraction of wave power flowing through the device that is absorbed**

The amount of energy that can be extracted from waves depends on the technology



Babarit, 2015

WAVE ENERGY IN ITALY: THE RESOURCE



Liberti et al., 2013

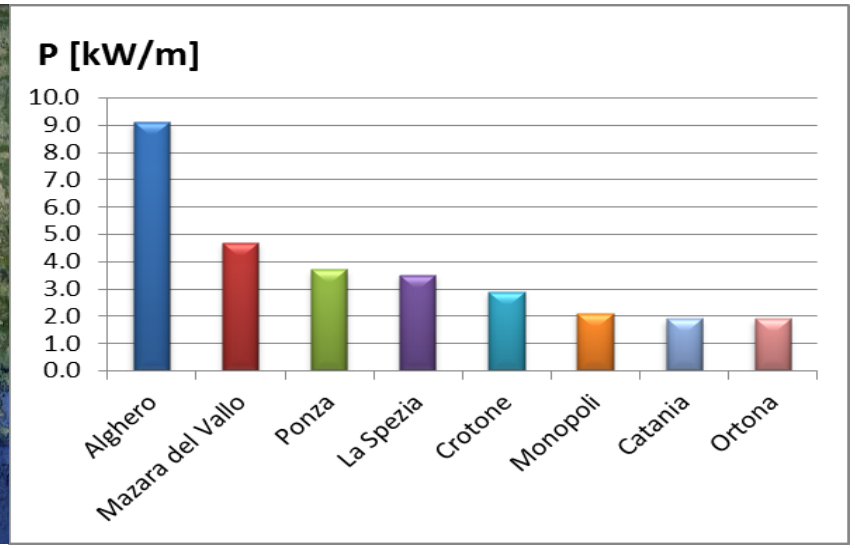
Wave energy potential of the Mediterranean basin

30 GW

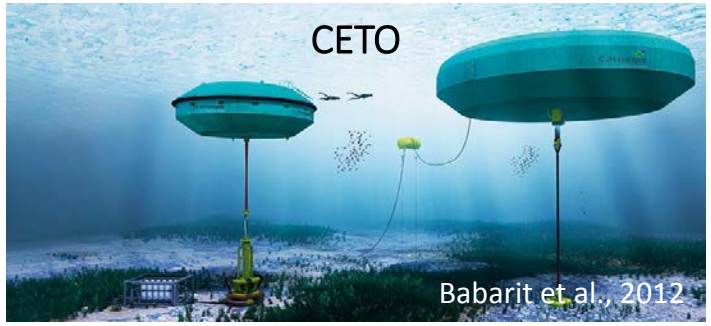
Wave energy potential off the Italian coasts:

Sea of Sardinia
12 kW/m

Strait of Sicily
7 kW/m



WAVE ENERGY IN ITALY: A FEASIBILITY STUDY



WAVE ENERGY IN ITALY: A FEASIBILITY STUDY

PTO

Hydraulic motor

Pelamis
Wavebob
Wavestar

Hydraulic turbine

AquaBuOY
Wave dragon
Oyster
CETO

Linear generator

Seabased

Location

Offshore

AquaBuOY
Pelamis
Wave dragon
Wavebob
Seabased

Nearshore

Oyster
CETO
Wavestar

Working principle

Heave

AquaBuOY
Pelamis
Wavebob
Seabased
CETO
Wavestar

Pitch

Oyster

Overtopping

Wave dragon

Size

Point absorber

AquaBuOY
Wavebob
Seabased
CETO
Wavestar

Attenuator

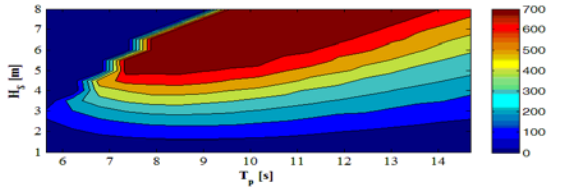
Pelamis

Terminator

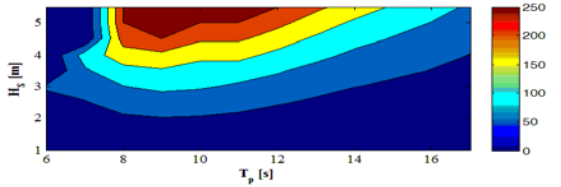
Oyster
Wave dragon

WAVE ENERGY IN ITALY: A FEASIBILITY STUDY

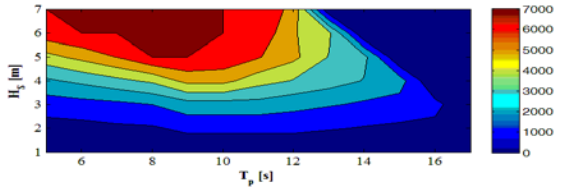
Pelamis

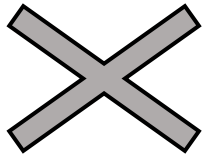


AquaBuOY

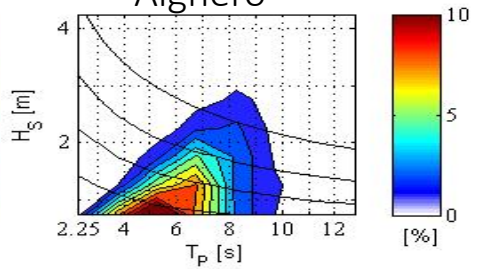


Wave Dragon

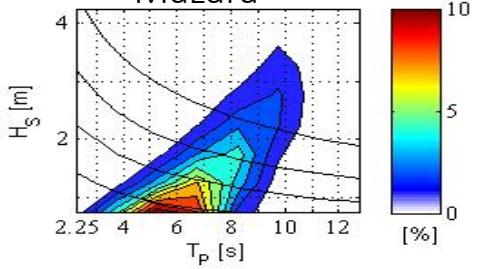




Alghero



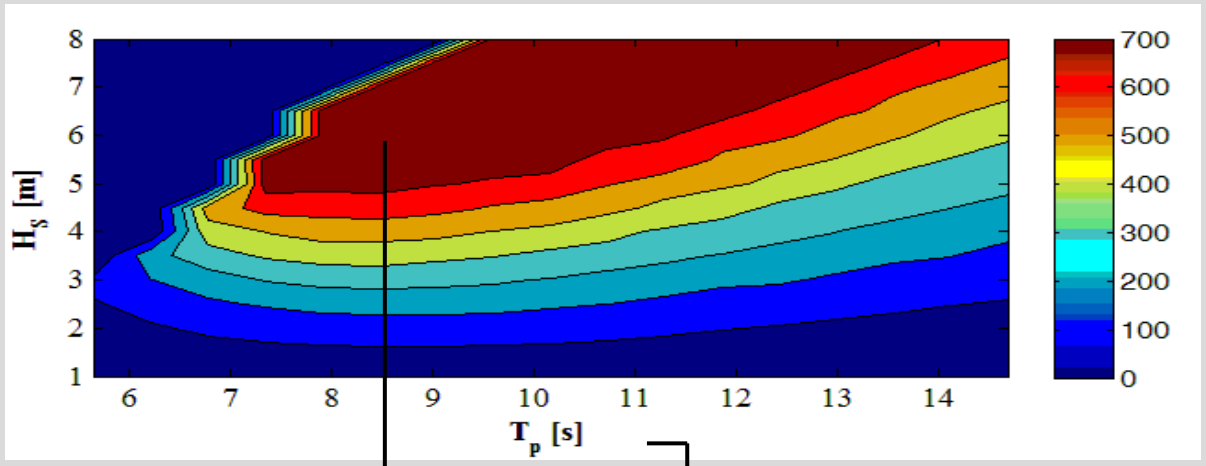
Mazara



	Alghero			Mazara		
	AquaBuOY	**Pelamis**	**Wave Dragon**	**AquaBuOY**	**Pelamis**	**Wave Dragon**
Rated power[kW]	250	750	7000	250	750	7000
Mean power [kW]	22	71	616	9	32	270
Annual energy production[MWh]	192	619	5400	81	278	2362
Capacity factor [%]	8.7%	9.4%	8.8%	3.7%	4.2%	3.9%

Bozzi S, Archetti R, Passoni G. Wave electricity production in Italian offshore: A preliminary investigation. Renewable Energy 2014 (62), 407 – 416

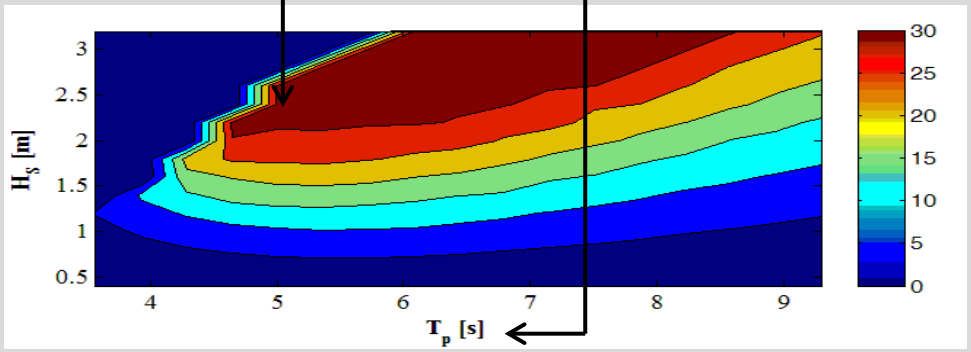
Resizing … to tailor the devices for the Italian wave climate



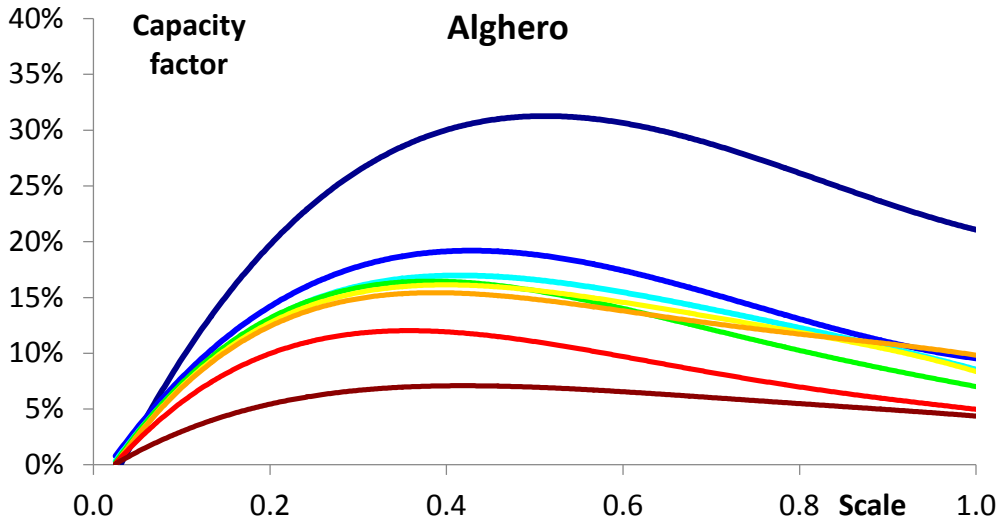
$H_S \propto \lambda$

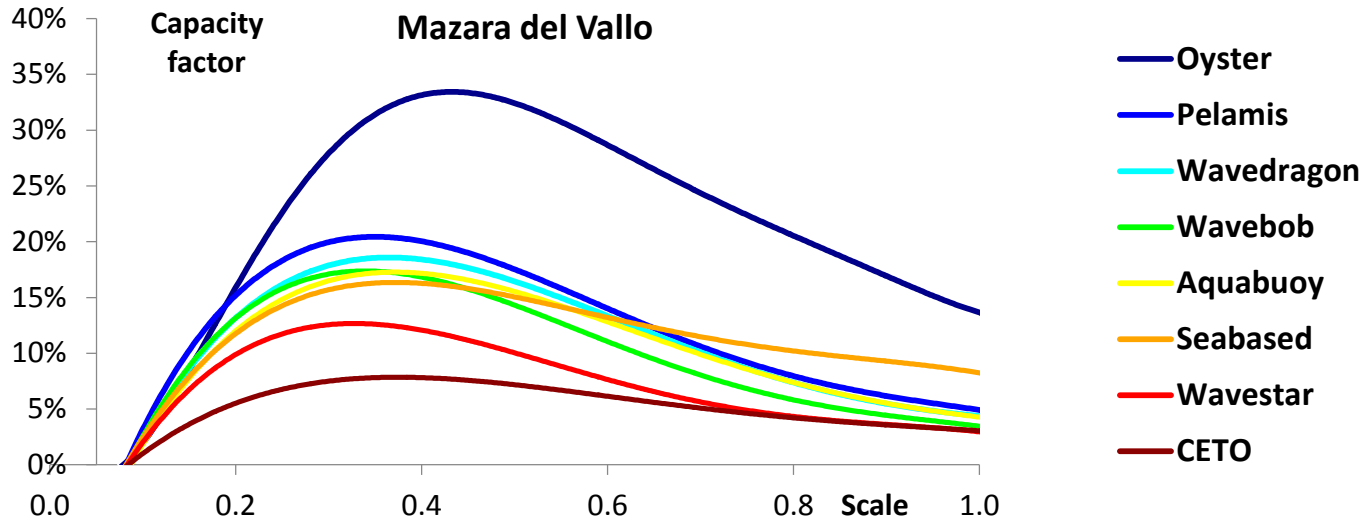
$P \propto \lambda^{3.5}$

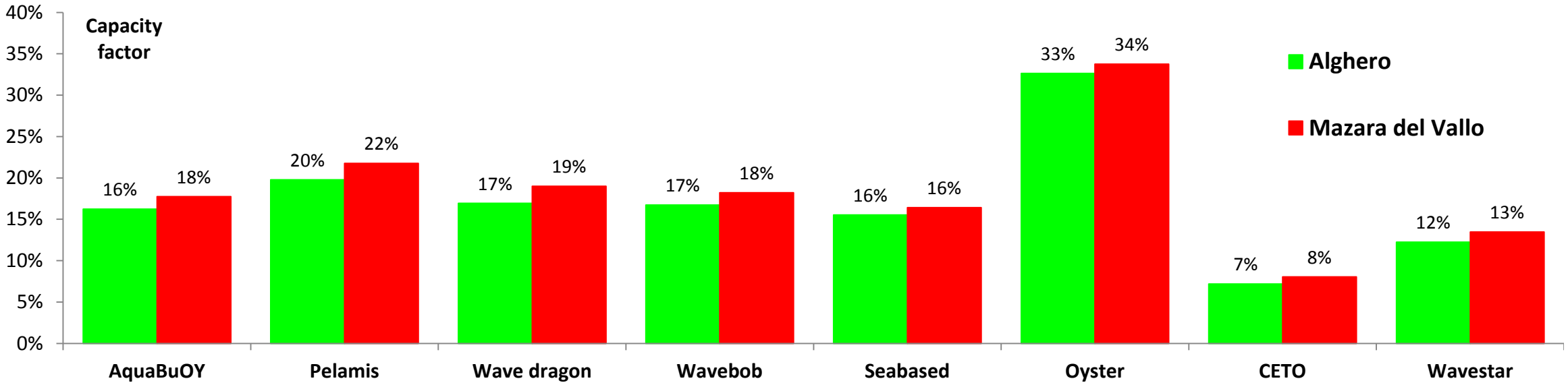
$T_P \propto \lambda^{0.5}$



WAVE ENERGY IN ITALY: A FEASIBILITY STUDY







WAVE ENERGY CONVERSION MODELLING

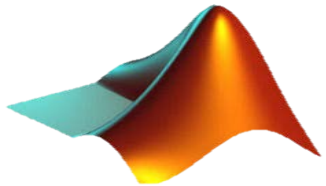
Waves

Hydrodynamic coefficients (BEM solver)

Radiation stress
Excitation force

Generator parameters (FEM solver)

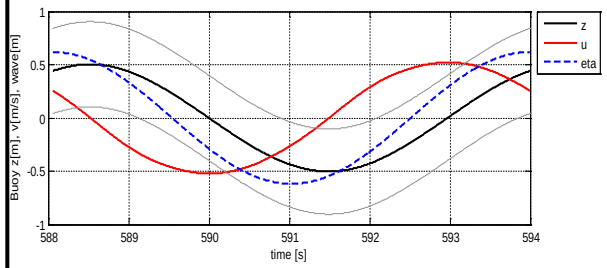
Magnet's flux linkage
Inductances

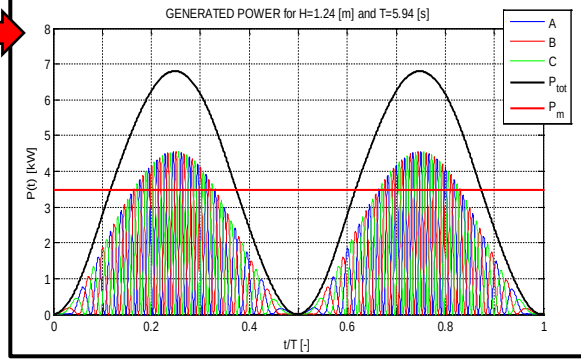


Hydro-mechanic model

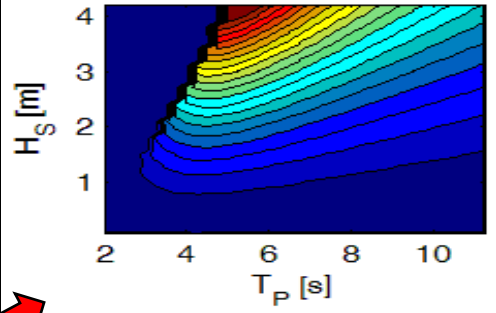
Electromagnetic model

RESULTS: displacements, electric power

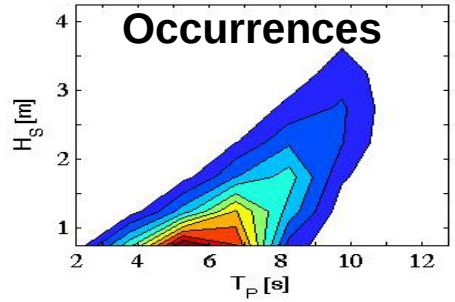




Power matrix



Occurrences

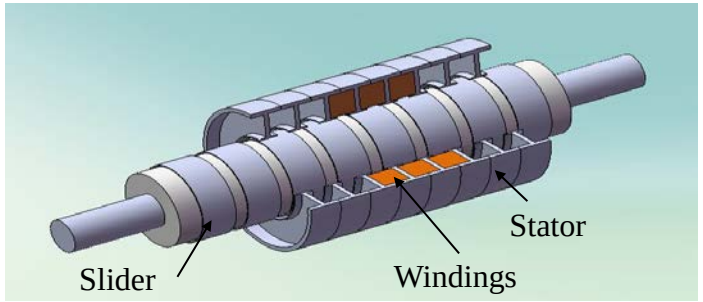


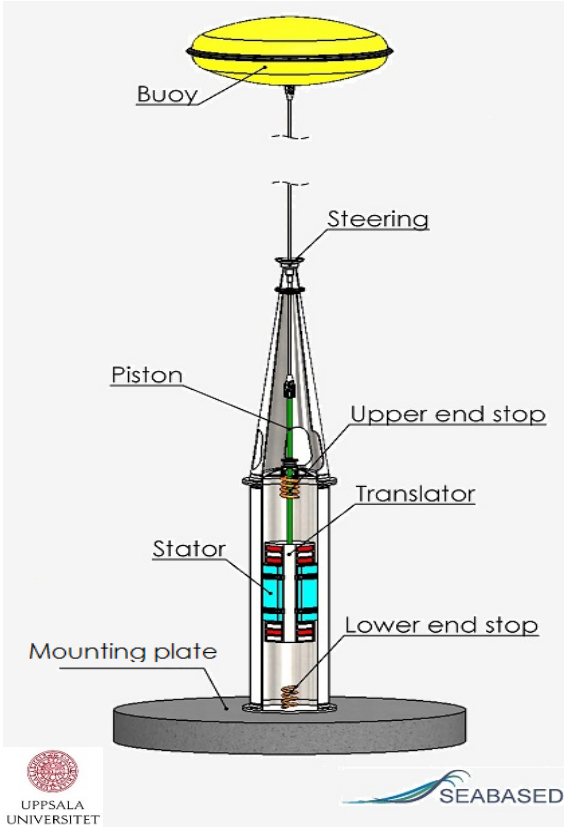
Electricity production
Capacity factor
Efficiency

SINGLE-BODY HEAVING POINT ABSORBER

ASSUMPTIONS

- Linear wave theory
- Regular waves
- 1D approximation
- Heave motion





NUMERICAL MODEL

HYDRODYNAMIC FORCES **ELECTROMAGNETIC FORCE** **MECHANICAL FORCE**

$$m \cdot \ddot{z} = F_{exc}(t) + F_{rad}(t, \dot{z}, \ddot{z}) + F_H(t, z) + F_{drag}(t, \dot{z}) + F_{GEN}(t, z, \dot{z}, i) + F_{spring}(t, z)$$

Equation of motion

$$emf_{ph}(t, z, \dot{z}) = R_t \cdot i_{ph}(t, z, \dot{z}) + L \cdot \frac{di_{ph}}{dt}$$

Electromagnetic model

Bozzi S., Miquel A.M., Antonini A., Passoni G., Archetti R. Modeling of a point absorber for energy conversion in Italian seas. Energies 2013 (6)>

DUAL-BODY HEAVING POINT ABSORBER

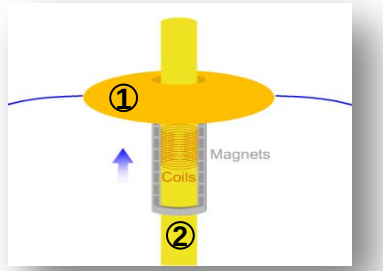
Assumptions:

- Linear wave theory
- Regular waves
- Heave motion

Equation of motion

$$M_1\ddot{z}_1 = F_{exc1}(t) + F_{rad11}(t,\dot{z}_1,\ddot{z}_1) + F_{rad12}(t,\dot{z}_2,\ddot{z}_2) + \\ +F_{drag1}(t,\dot{z}_1,\dot{\eta}) + F_{H1}(t,z_1) + F_{gen1}(t,z,\dot{z},i)$$

$$M_2\ddot{z}_2 = F_{exc2}(t) + F_{rad21}(t,\dot{z}_1,\ddot{z}_1) + F_{rad22}(t,\dot{z}_2,\ddot{z}_2) + \\ +F_{drag2}(t,\dot{z}_2,\dot{\eta}) + F_{H2}(t,z_2) + F_{moor2}(t,z_2) + F_{gen2}(t,z,\dot{z},i)$$



Coupling

$$F_{gen} = \sum_{A,B,C} \frac{emf \cdot i}{\dot{z}}$$

Electromagnetic model

$$emf_A(t,z,\dot{z}) = R_t i_A\,(t,z,\dot{z}) + L_{AA}\frac{di_A}{dt} + L_{AB}\frac{di_B}{dt} + L_{AC}\frac{di_C}{dt}$$

$$emf_B(t,z,\dot{z}) = R_t i_B\,(t,z,\dot{z}) + L_{BA}\frac{di_A}{dt} + L_{BB}\frac{di_B}{dt} + L_{BC}\frac{di_C}{dt}$$

$$emf_C(t,z,\dot{z}) = R_t i_C\,(t,z,\dot{z}) + L_{CA}\frac{di_A}{dt} + L_{CB}\frac{di_B}{dt} + L_{CC}\frac{di_C}{dt}$$

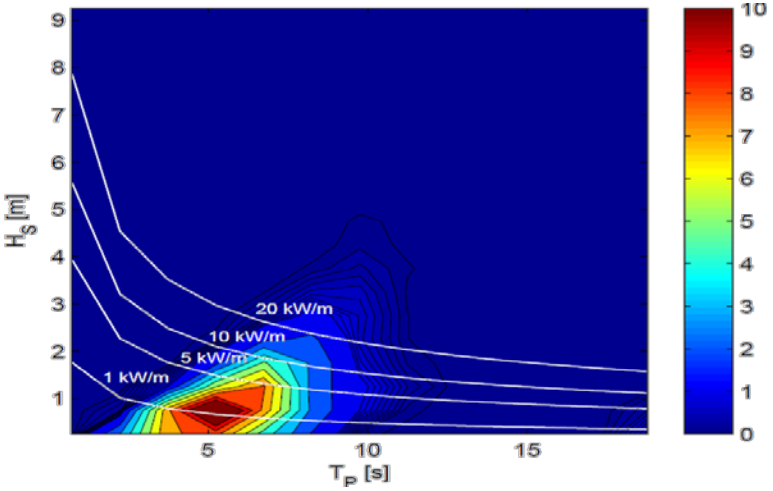
APPLICATION TO ITALIAN SEAS

National wave metric network

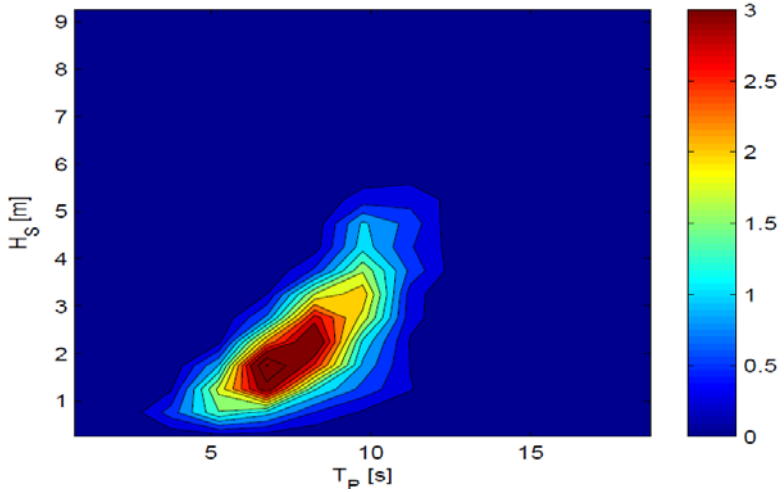
8 Italian locations

Wave climate characterization

Occurrences [%]



Energy [MWh/m]



Simulated sea states

$$0.25\ m \leq H_s \leq 5\ m$$

$$2\ s \leq T_p \leq 12\ s$$

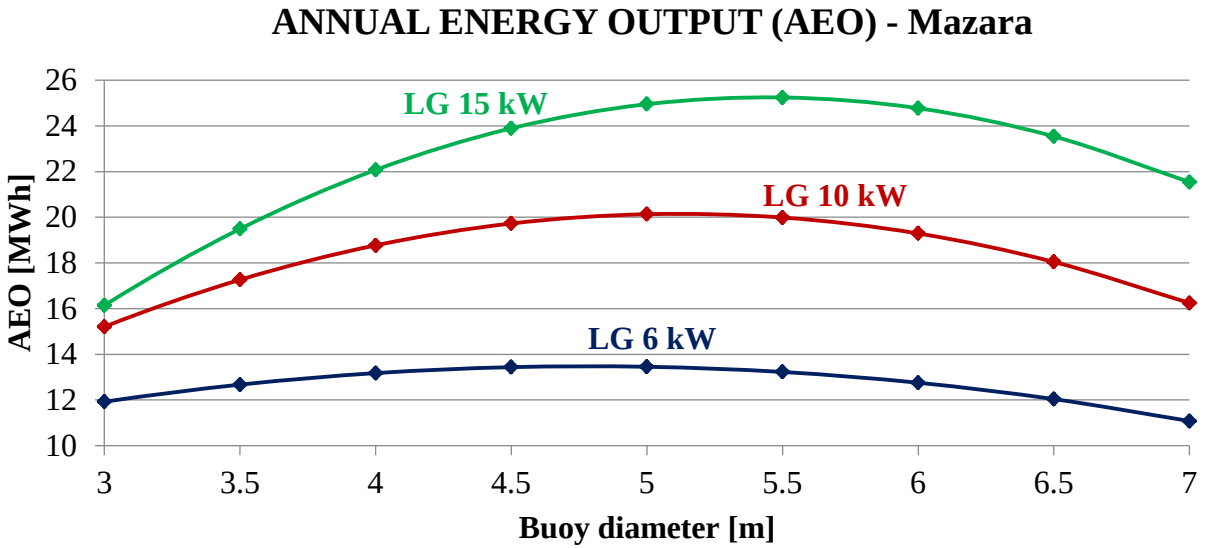
APPLICATION TO ITALIAN SEAS

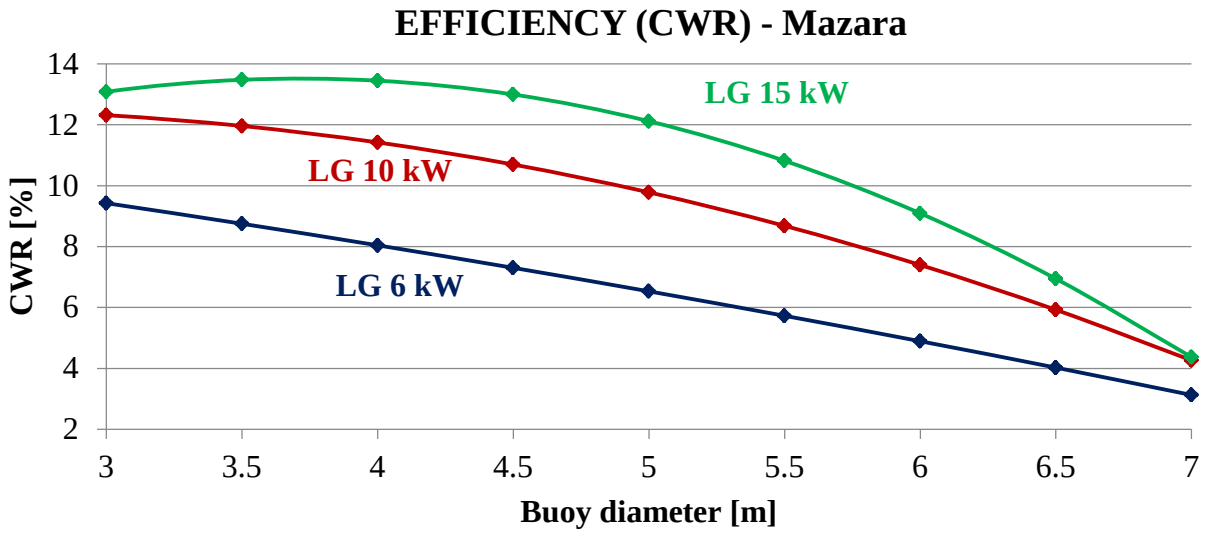
Target parameters

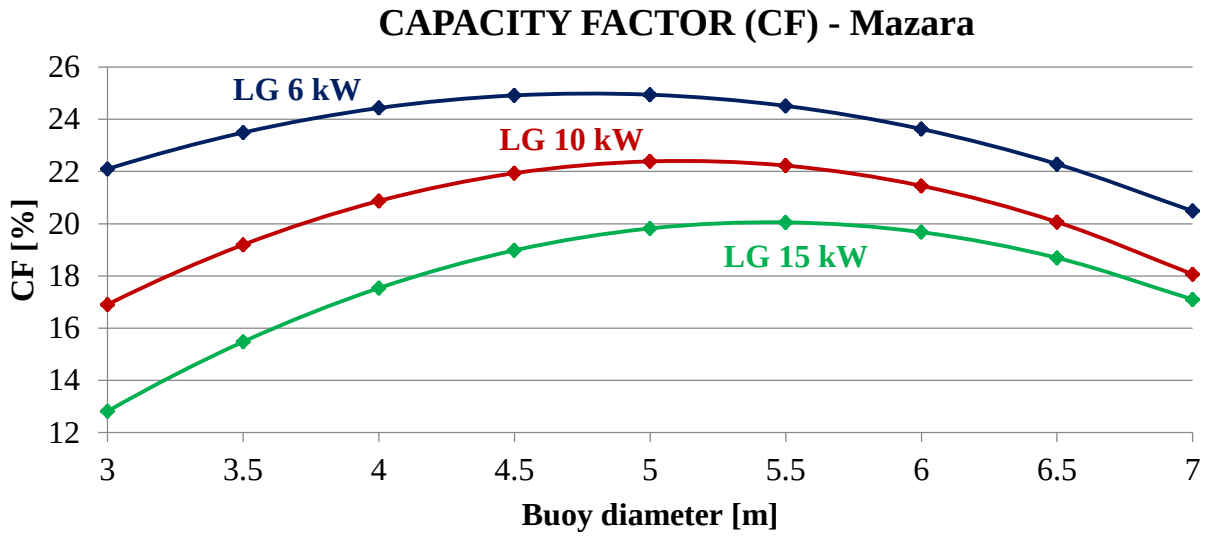
$$AEO = \sum_{hk} MP_{hk} Hour_{hk} \; [MWh]$$

$$CF = \frac{AEO/8760}{NP} \; [\%]$$

$$CWR = \frac{AEO/8760}{J\,D} \; [\%]$$

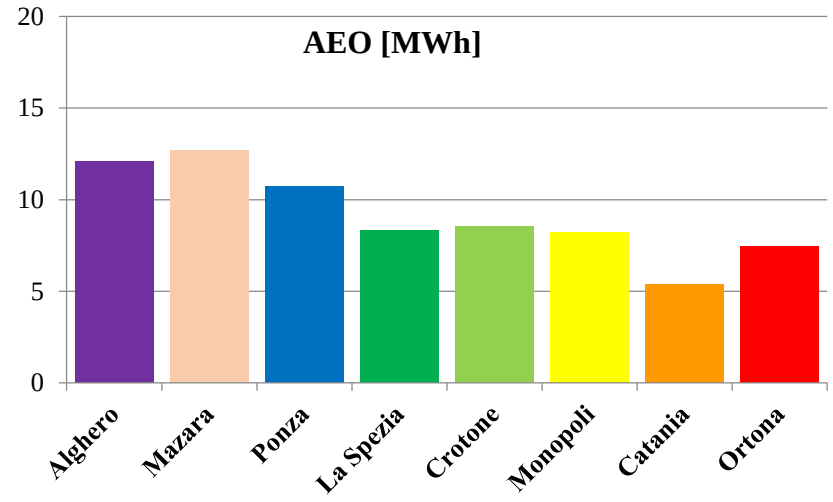


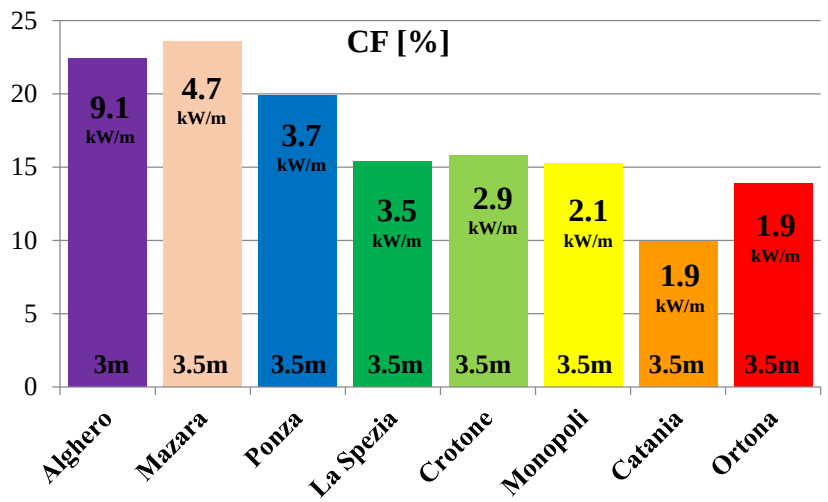


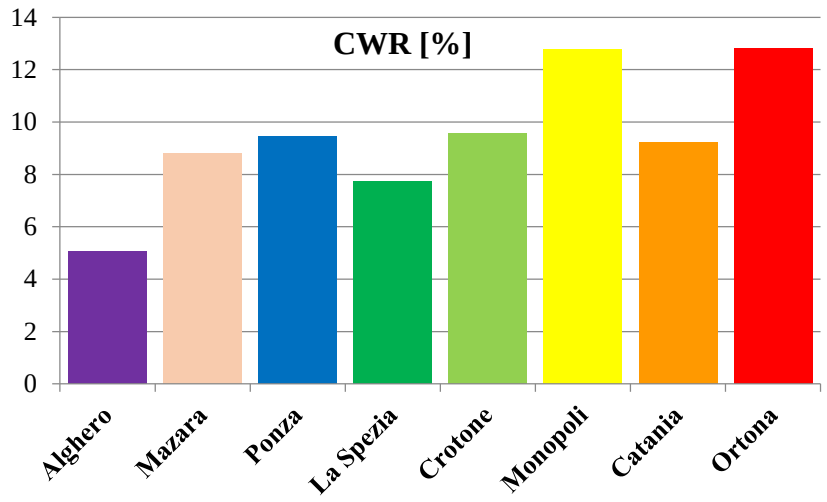


APPLICATION TO ITALIAN SEAS

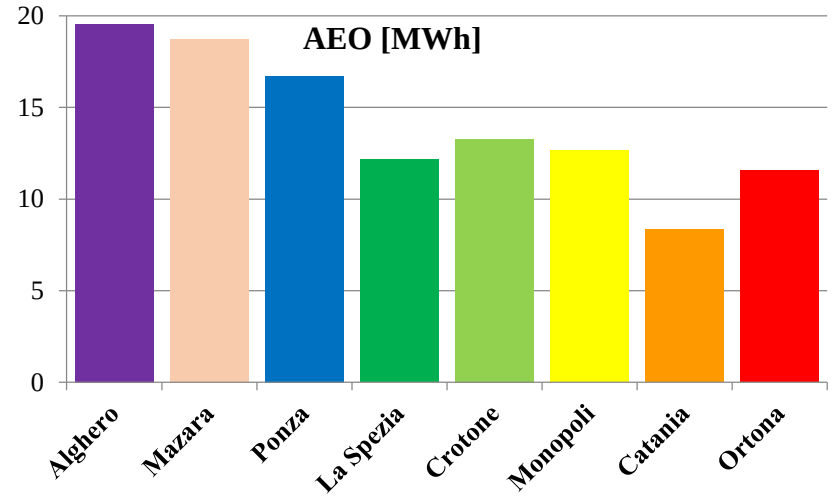
6 kW Linear generator

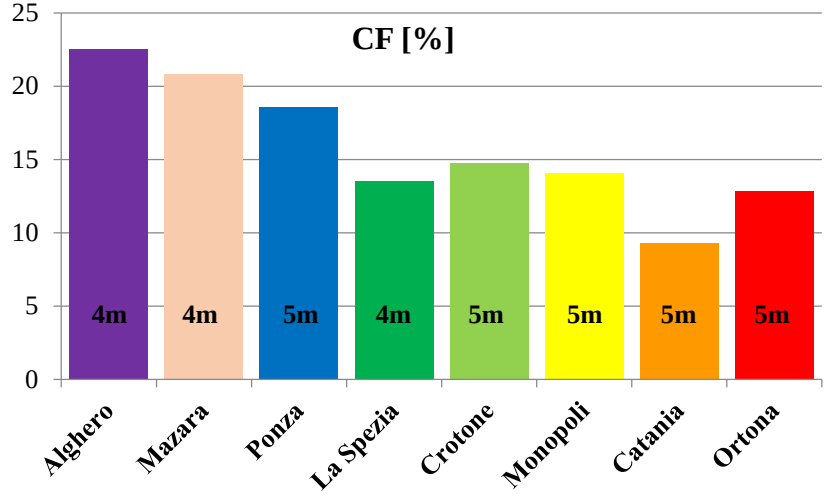


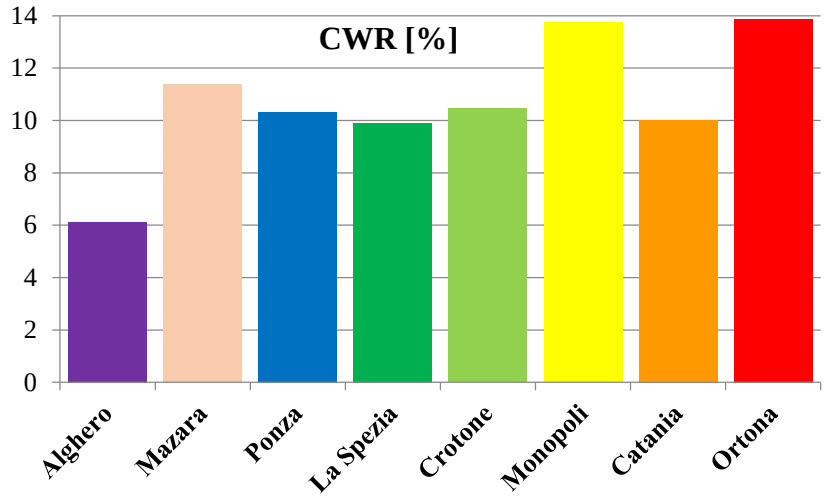




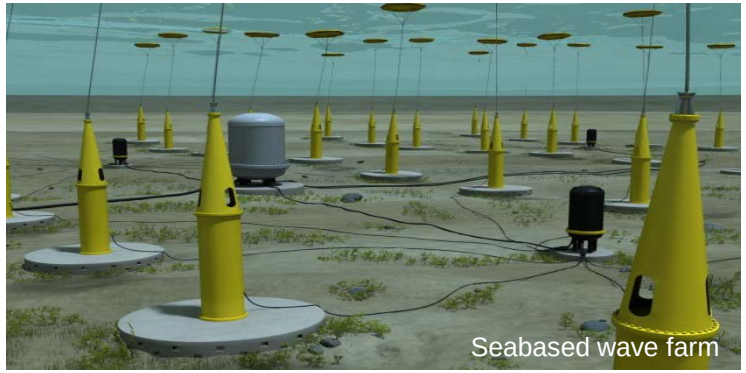
10 kW Linear generator







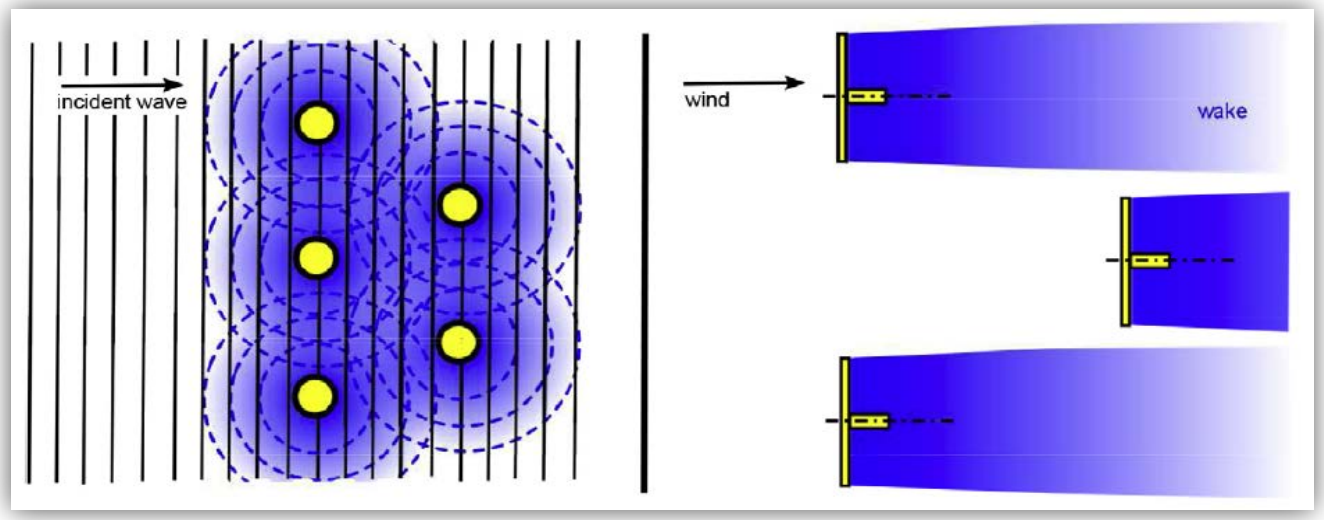
WAVE ENERGY FARMS


Seabased wave farm

Oscillating wave energy converters are designed to be deployed in arrays of many units


Pelamis wave farm

In WEC arrays the wave field is perturbed in all the directions, due to radiated waves



Babarit, 2013

Depending on array design, hydrodynamic interactions can have a positive or negative effect on power production and power quality

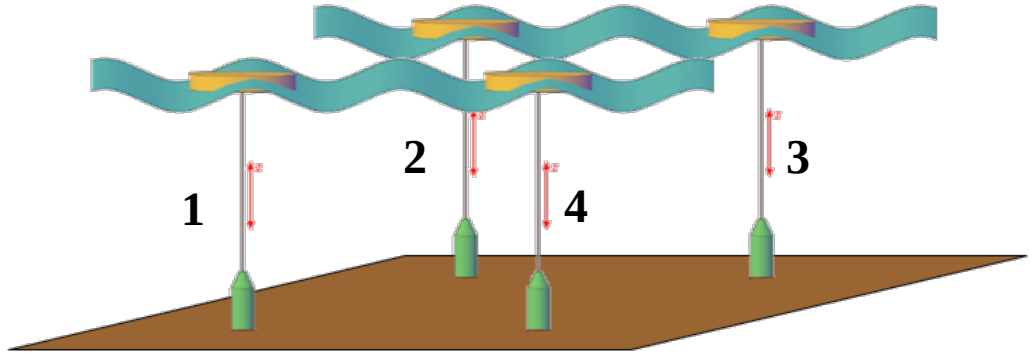
WAVE FARM MODEL

Assumptions:

Linear wave theory

Regular waves

Heave motion



Power take-off system:

Permanent magnet linear electric generator

(10 kW)

Equation of motion

$$\begin{bmatrix} M_1 & 0 & 0 & 0 \\ 0 & M_2 & 0 & 0 \\ 0 & 0 & M_3 & 0 \\ 0 & 0 & 0 & M_4 \end{bmatrix} \begin{bmatrix} \ddot{z}_1 \\ \ddot{z}_2 \\ \ddot{z}_3 \\ \ddot{z}_4 \end{bmatrix} = \begin{bmatrix} F_{t1} \\ F_{t2} \\ F_{t3} \\ F_{t4} \end{bmatrix}$$

$$M_1 \cdot \ddot{z}_1 = F_{exc1}(t) + F_{drag1}(t, \dot{z}_1, \dot{\eta}_1) + F_{rad11}(t, \dot{z}_1, \ddot{z}_1) + F_{rad21}(t, \dot{z}_2, \ddot{z}_2) + F_{rad31}(t, \dot{z}_3, \ddot{z}_3) + F_{rad41}(t, \dot{z}_4, \ddot{z}_4) + F_{float1}(t, z_1) + F_{spring1}(t, z_1) + \boldsymbol{F_{gen1}(t, z_1, \dot{z}_1, i)}$$

COUPLING

$$F_{gen} = \sum_{A,B,C} \frac{emf \cdot i}{\eta \dot{z}}$$

Electromagnetic model

$$emf_A\,(t, z, \dot{z}) = R_t i_A(t, z, \dot{z}) + L_{aa}\frac{di_A}{dt} + L_{ab}\frac{di_B}{dt} + L_{ac}\frac{di_C}{dt}$$

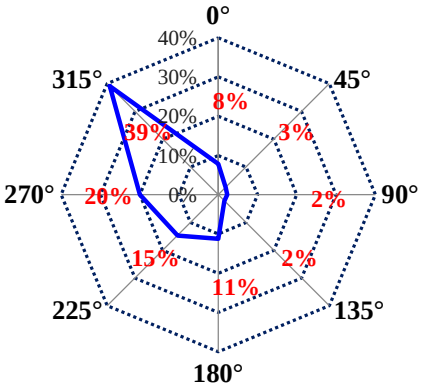
$$emf_B\,(t, z, \dot{z}) = R_t i_B(t, z, \dot{z}) + L_{ba}\frac{di_A}{dt} + L_{bb}\frac{di_B}{dt} + L_{bc}\frac{di_C}{dt}$$

$$emf_C\,(t, z, \dot{z}) = R_t i_C(t, z, \dot{z}) + L_{ca}\frac{di_A}{dt} + L_{cb}\frac{di_B}{dt} + L_{cc}\frac{di_C}{dt}$$

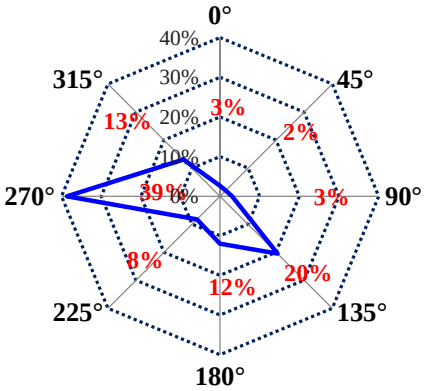
WAVE FARM DESIGN IN THE ITALIAN OFFSHORE

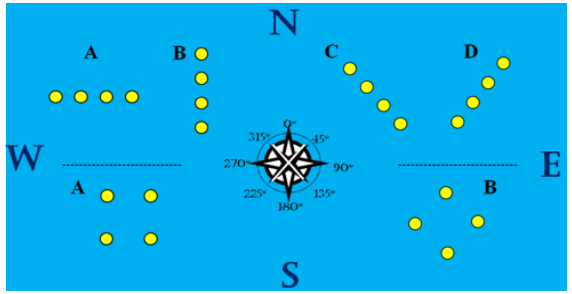
Which are the best wave farm designs (geometric layout, WEC distance and geographical orientation) for the Italian seas?

Alghero



Ponza





WEC distances

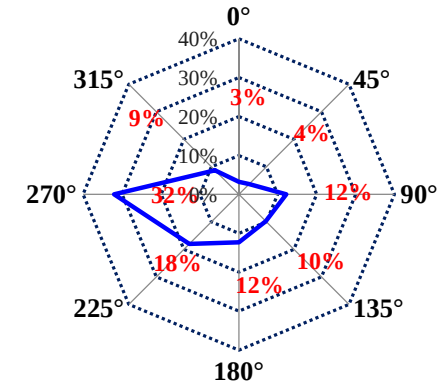
5 D

10 D

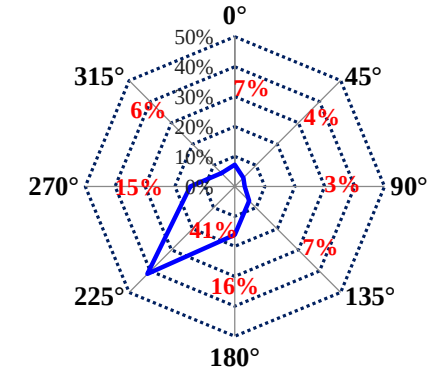
20 D

30 D

Mazara del Vallo

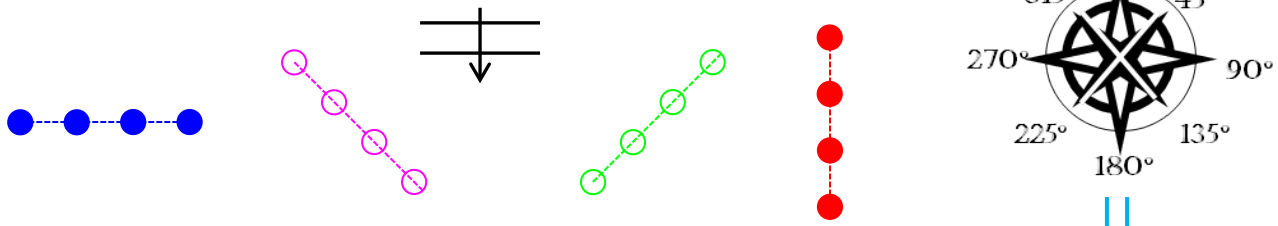


La Spezia

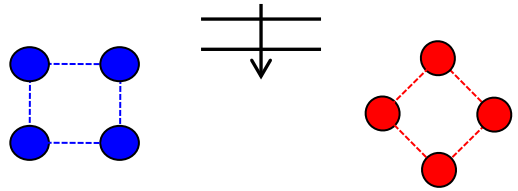


WAVE FARM DESIGN IN THE ITALIAN OFFSHORE: RESULTS

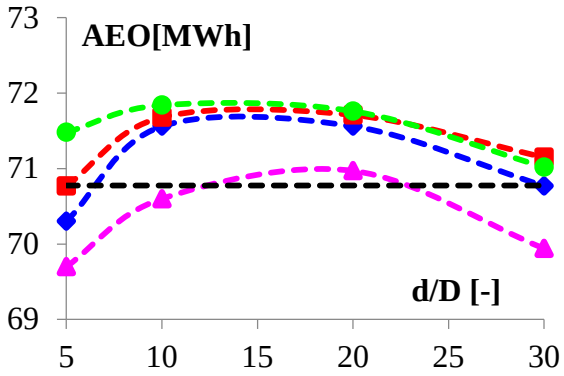
Linear layout



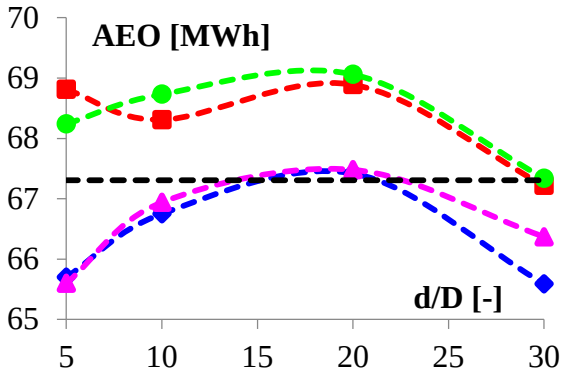
Square layout



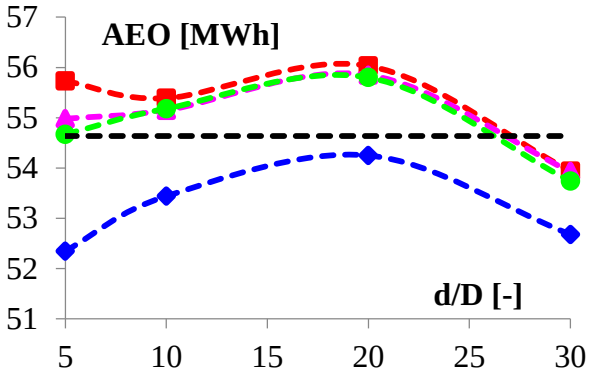
Alghero



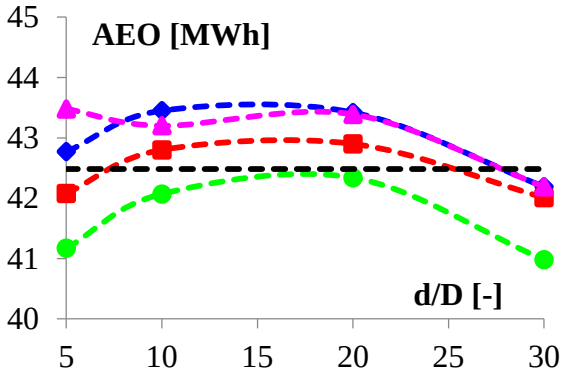
Mazara del Vallo



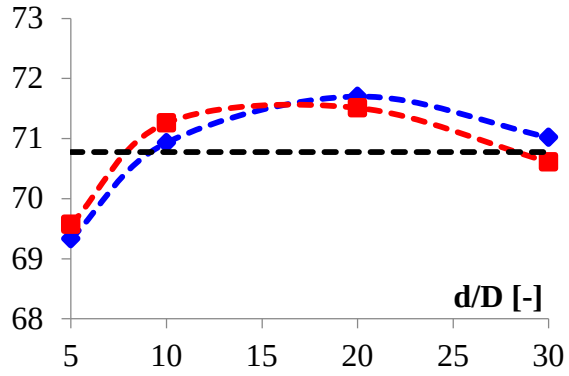
Ponza



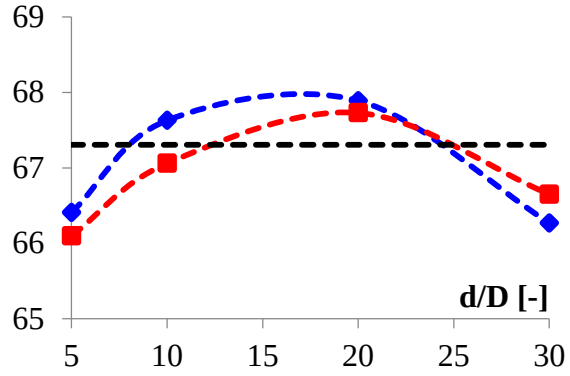
La Spezia



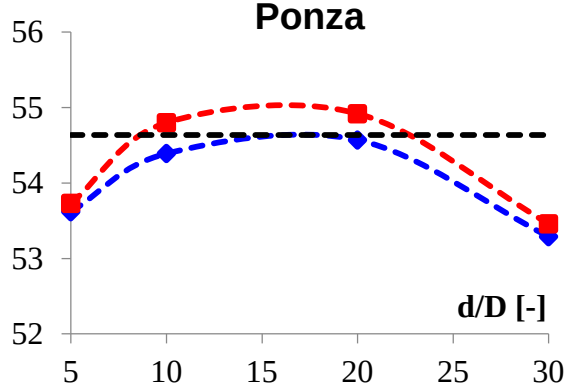
Alghero



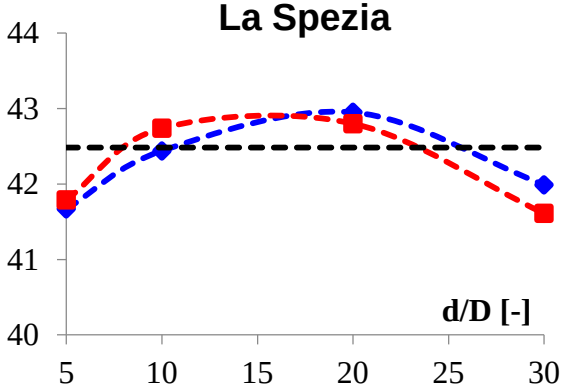
Mazara del Vallo



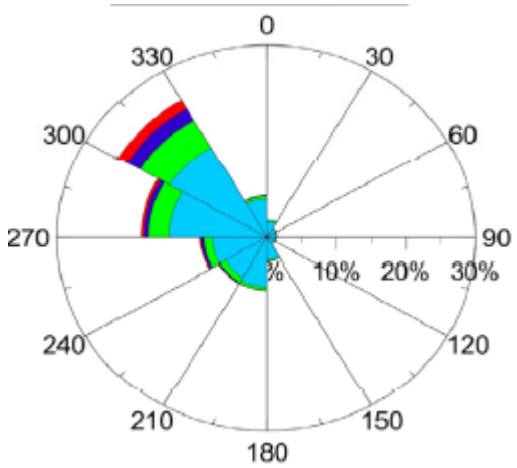
Ponza



La Spezia

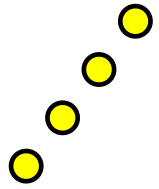


WAVE FARM DESIGN IN THE ITALIAN OFFSHORE: RESULTS



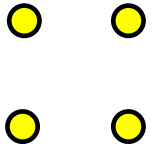
ALGHERO

+ 1.5 %

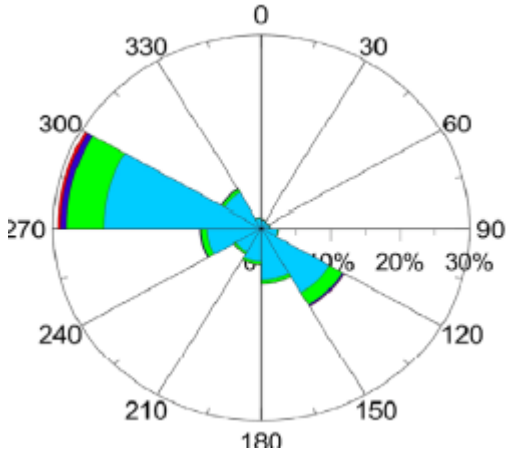


d = 10 D

+ 1.3 %

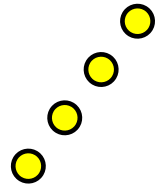


d = 20 D



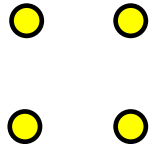
MAZARA del VALLO

+ 2.6 %

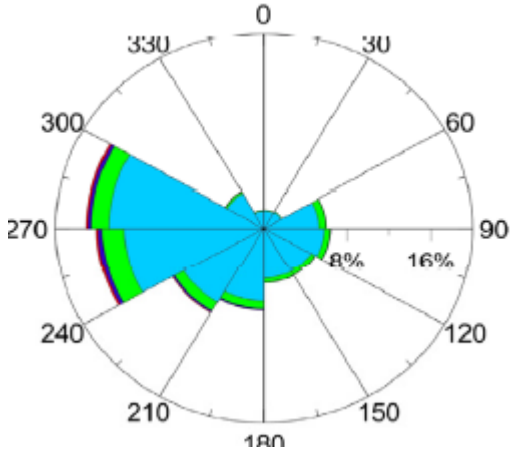


d = 20 D

+ 0.9 %

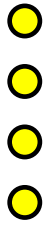


d = 20 D



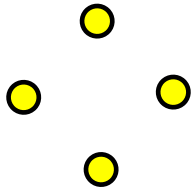
PONZA

+ 2.5 %

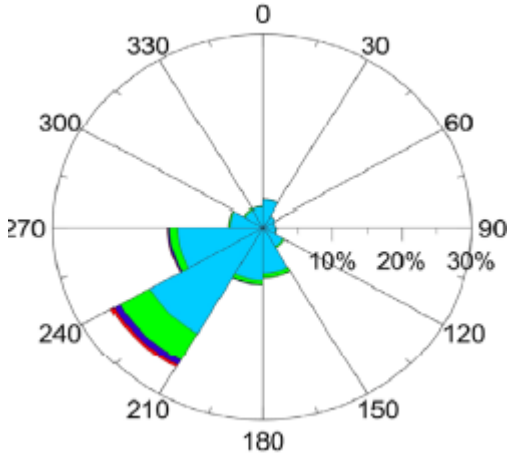


d = 20 D

+ 0.5 %

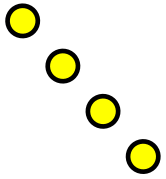


d = 20 D



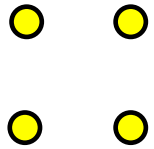
LA SPEZIA

+ 2.4 %



d = 5 D

+ 1.1 %



d = 20 D

PUBLICATIONS

SPEEDAM 2016
Analysis of interaction of point absorbers 'arrays for sea wave electrical energy generation in Italian seas

IECON 2016
Spatial interactions among oscillating wave energy converters: electricity production and power quality issues

IDRA 2016
Design of point absorber arrays in the Italian offshore

ICIT 2015
Sea wave generation: generator arrays combined with VOC converter for efficient energy conversion in Italian seas

ENEA 2014
Designing a point-absorber wave energy converter for the Mediterranean Sea

Renewable energy 2014
Wave electricity production in Italian offshore: a preliminary investigation

OMAE 2014
Assessment of the surge effects in a heaving point absorber in the Mediterranean Sea

SPEEDAM 2014
Dynamic model, parameter extraction, and analysis of two topologies of a tubular linear generator for sea wave energy production

IDRA 2014
Studio delle interazioni tra convertitori di energia da onda: indicazioni preliminari per la dislocazione di parchi nei mari italiani

AIOM 2013
Tecnologie esistenti per la conversione di energia nei mari italiani: uno studio di fattibilità

Energies 2013
Modeling of a point absorber for energy conversion in Italian seas

EWTEC 2013
Hydrodynamic modelling of a linear generator point absorber specifically designed for energy production off the Italian coasts

ICCEP 2013
Wave energy production in Italian offshore: preliminar design of a point absorber with linear generator

OWEMES 2012
Wave energy exploitation in Italian seas: a feasibility study

IDRA 2012
Electricity generation from wave power in the Tyrrhenian Sea

OMAE 2011
Feasibility study of a wave energy farm in the Mediterranean sea: comparison among different technologies

Thank you

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