Effects of Recovery Rate on Variable Speed Direct-Driven Tidal Energy Desalination

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Problem: the need for fresh water

1 Living with water

Half of the world population is concentrated in a 50 km strip along a coastline[1,2].

Among the 20 largest cities of the world, 16 are close to the sea.

2 Urgency

About one fifth of the population have no access to a secure source of fresh water and by 2030 water shortages will affect up to the 40% of world inhabitants[3,4].

→ Remote areas and islands

Isolation limits their availability to import low cost fresh water and/or fuel

- ❑ Connection to the grid not always available
- ❑ They make use of fossil fuel-powered desalination, opportunity for renewable energies to take over

[1] Crossett et al (2004) *National Ocean service USA*
[2] NWA (2016) *Portfolio for research and innovation*
[3] Mekonnen and Hoekstra (2016), *Four billion people facing severe water scarcity*
[4] UNESCO (2015), *Water for a Sustainable World*

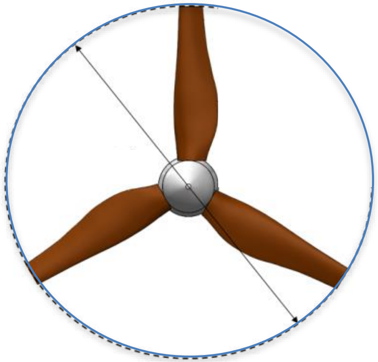
‘Closing the loops’ with renewable energy: using tidal energy for seawater desalination

Tidal stream to **eliminate CO2 emissions** from fossil fuel-powered desalination

Fresh water

Agriculture and horticulture **70% of all fresh water** consumption and **~30%** of worldwide **energy consumption**[2]

IRENA (2017) *Perspectives for the energy transition*



Energy transition

Roadmap towards the energy transition – 2050
Renewables will rise from 19% to over 60% (3x)

≥1 GW of ocean energy capacity (e.g. wave and tidal) by 2030

European Green Deal ;
EU Offshore Renewable Energy strategy (2023)

Sustainable production of safe and healthy food

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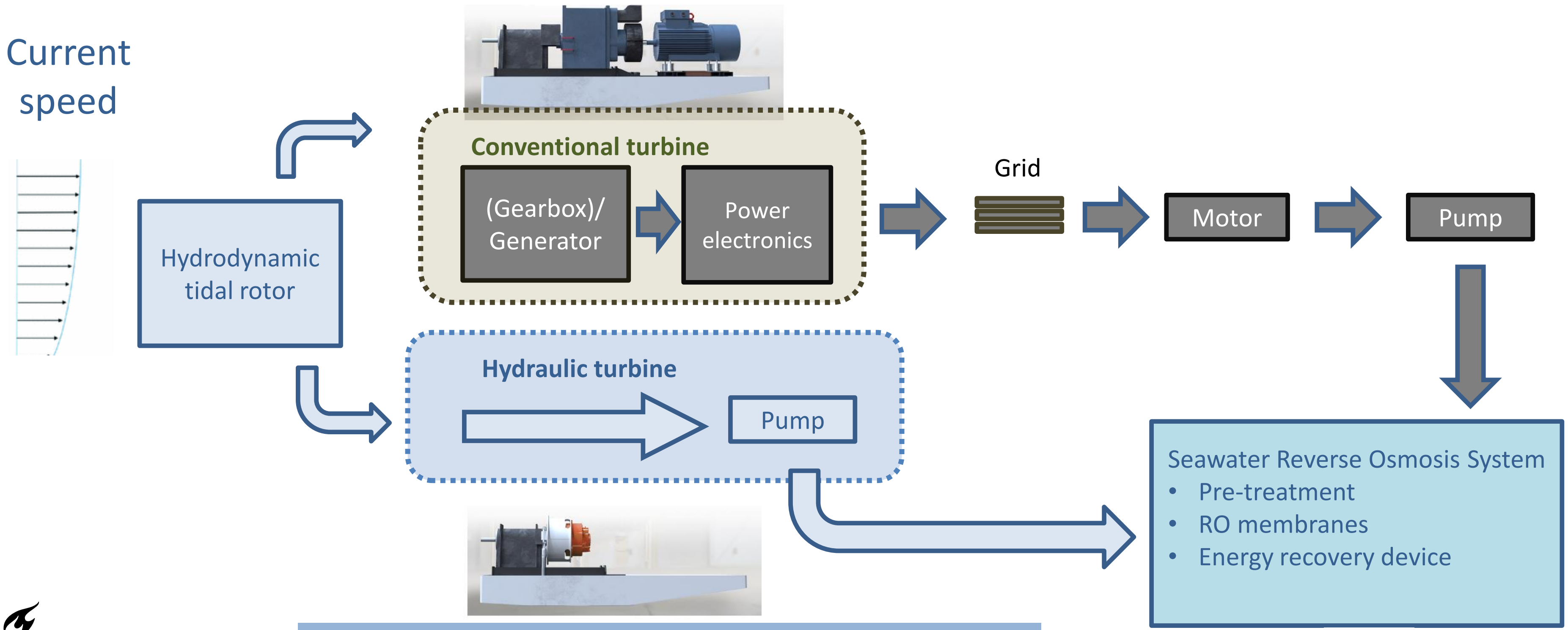
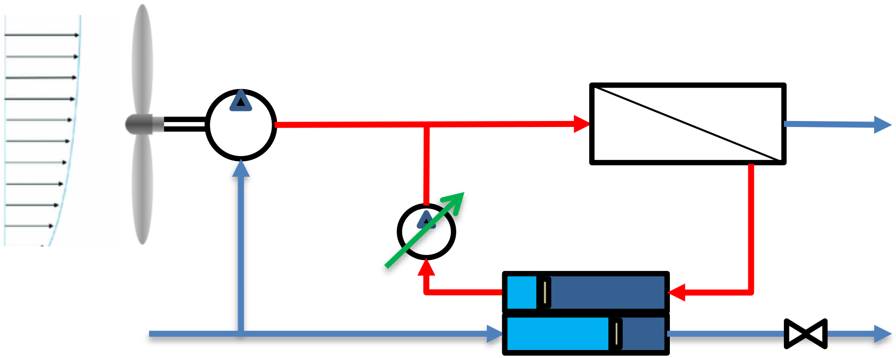
The proposal: eliminate intermediate electrical conversion using fluid power



Proposed tidal stream powered seawater desalination
(no grid connection)

How? Use of fluid power technology with Reverse Osmosis (RO) technology



Proposed configuration
(active controlled)

1 Tidal turbine with hydraulic transmission

- Direct driven positive displacement radial-pump
- Seawater as medium of energy transport
- Water is freely available with no hazards/ environmental friendly

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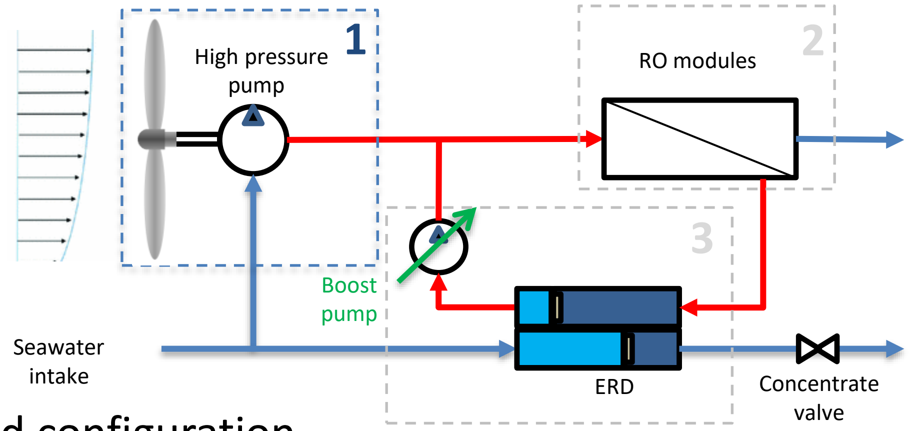
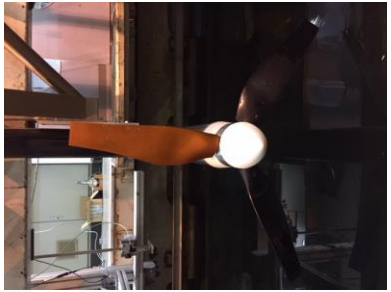
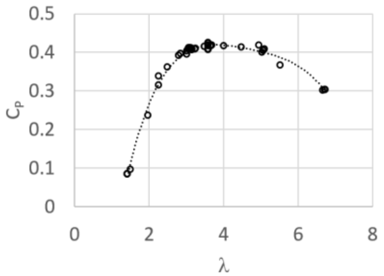
How? Use of fluid power technology with Reverse Osmosis (RO) technology



Proposed configuration
(active controlled)





Ordoñez-Sánchez et al., (2019) *Energies, vol. 12*

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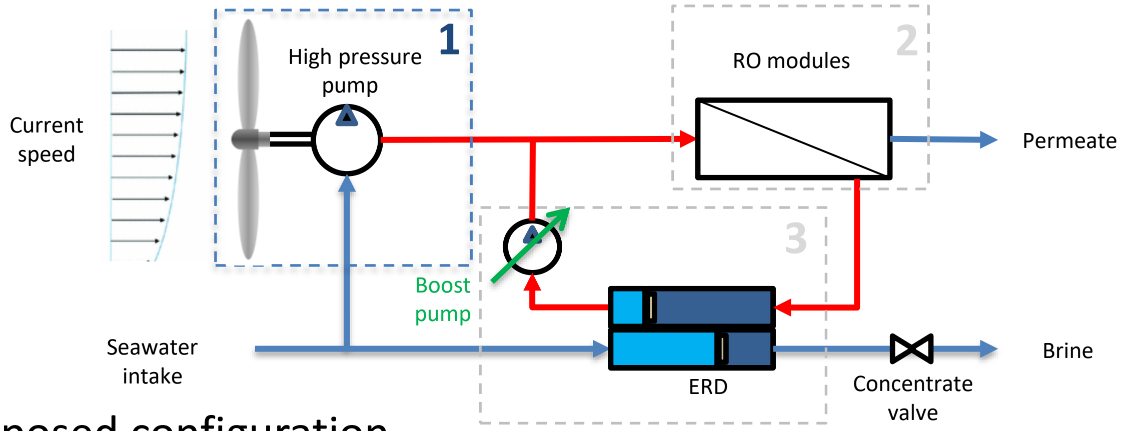
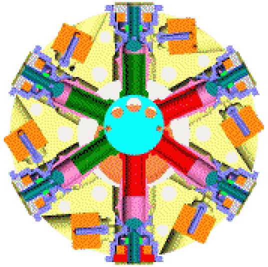


Radial pump
Hagglunds™ (2021)



Digital Displacement*
pump technology (2021)

Proposed configuration
(active controlled)

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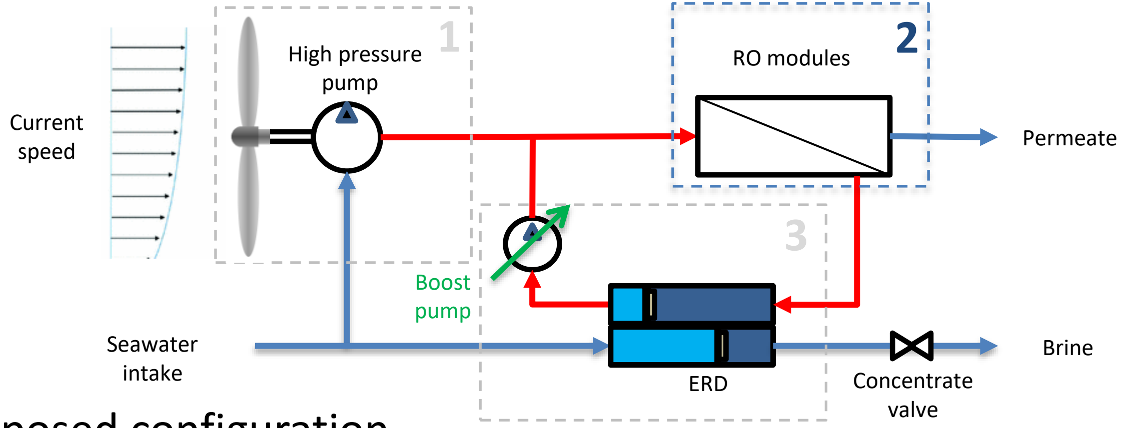
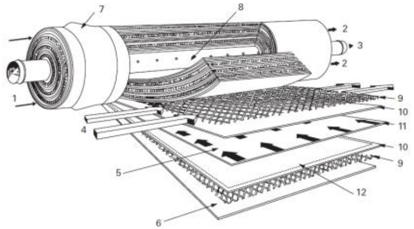


Proposed configuration
(active controlled)

1. Water inlet
2. Concentrate outlet
3. Permeate collection tube
4. Raw water direction of flow
5. Permeate direction of flow
6. Protective material
7. Seal between module and casing
8. Permeate collection perforations
9. Spacer
10. Membrane
11. Permeate collector
12. Weld line between two membranes



Degremont® (2021), https://www.suezwaterhandbook.com/

DOW FILMTEC™ (2021)

2 Seawater Reverse Osmosis desalination (SWRO)

- Membrane-based desalination system (no moving parts)
- Lowest energy consuming desalination processes
- Requires to overcome the osmotic pressure ~25-30 bar

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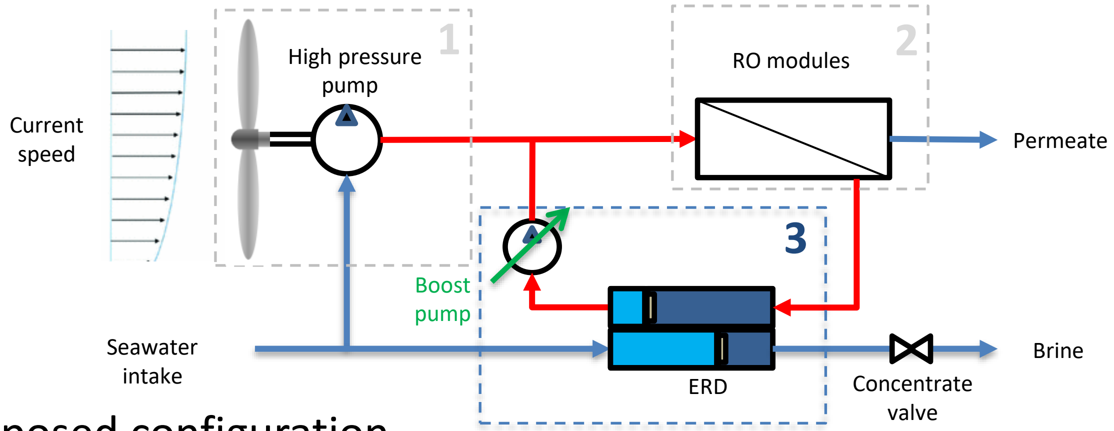
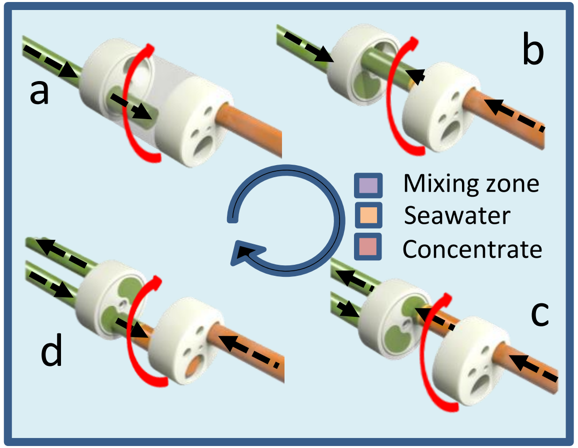
How? Use of fluid power technology with Reverse Osmosis (RO) technology



Proposed configuration
(active controlled)

a Low pressure seawater stream in

b.- High pressure brine stream in



d.- High pressure seawater stream out

c.- Pressure transfer to seawater stream

3 Energy recovery device (ERD)

- Pressure exchange between the disposed brine and feed seawater
- Can improve specific energy consumption up to 60%
- Typically integrated with a boost pump in order to adjust the recovery rate

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Numerically study of the recovery rate effect

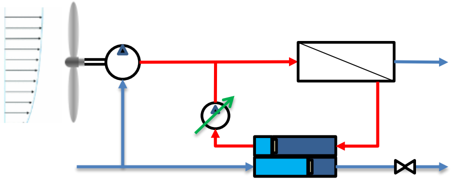
Numerical model

Integrate coupling between the tidal stream rotor hydrodynamics and the behavior of the desalination system*

- _Based on physical principles_: set of coupled algebraic and ordinary differential equations
- Solved through *numerical integration* -> simulation environment software
- Simplified control strategy and controller

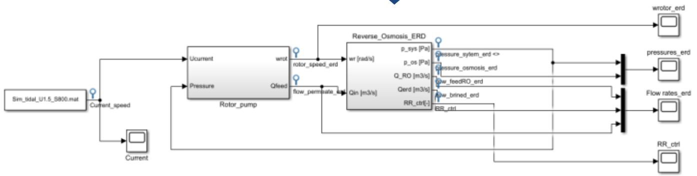
Intermediate results on:

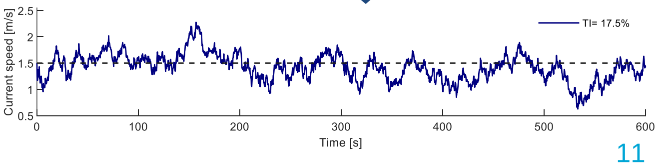
- ***Steady-state performance*** for operating current speeds
- ***Dynamic response*** for three recovery rates



$$\tau_{\text{hydro}} = C_\tau(\lambda,\beta)\frac{1}{2}\rho_w \pi R^3 U_c^2 \qquad J_r\dot{\omega}_r = \tau_{\text{hydro}}(U,\beta,\omega_r) - \tau_p(\omega_r,\Delta p_p)$$

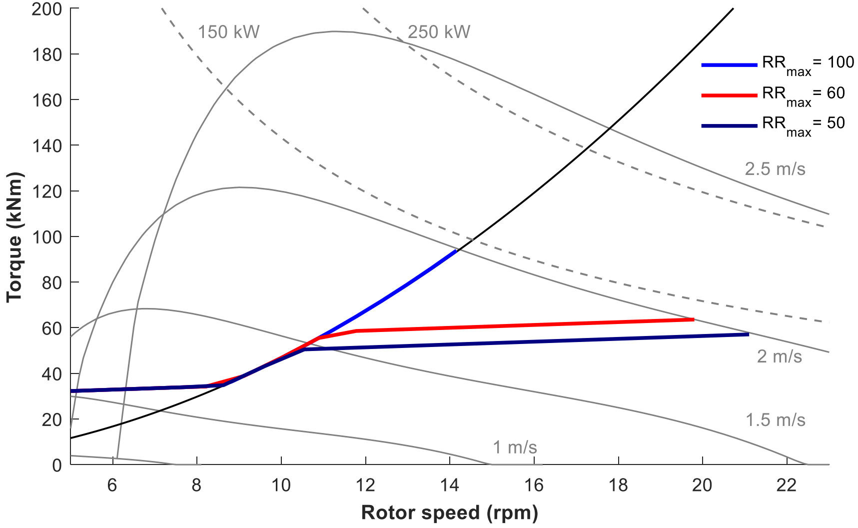
$$\frac{dm_{\text{b, out}}}{dt} = F_{\text{f,in}}C_{\text{f,in}} + F_{\text{b,in}}C_{\text{b,in}} - F_{\text{f, out}}C_{\text{f, out}}$$



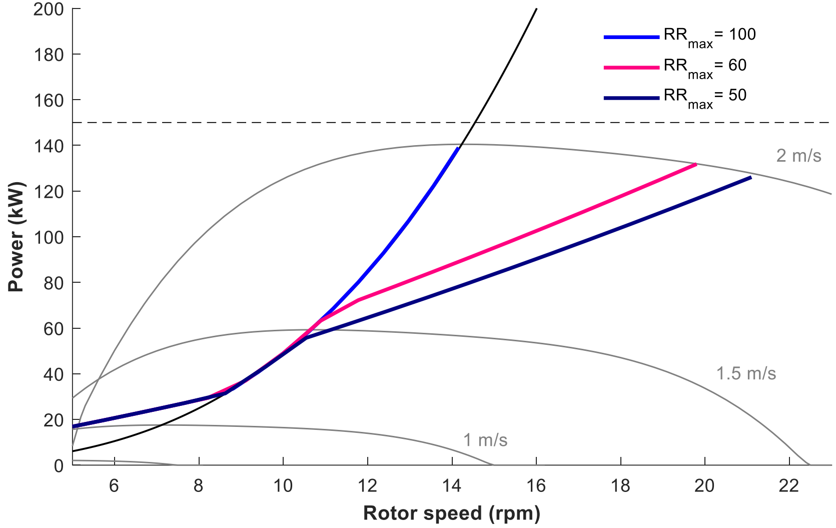


*For model details: Jarquin-Laguna & Ordonez-Sanchez, EWTEC 2021

Steady-state operational envelopes



Torque-speed curves



Power-speed curves

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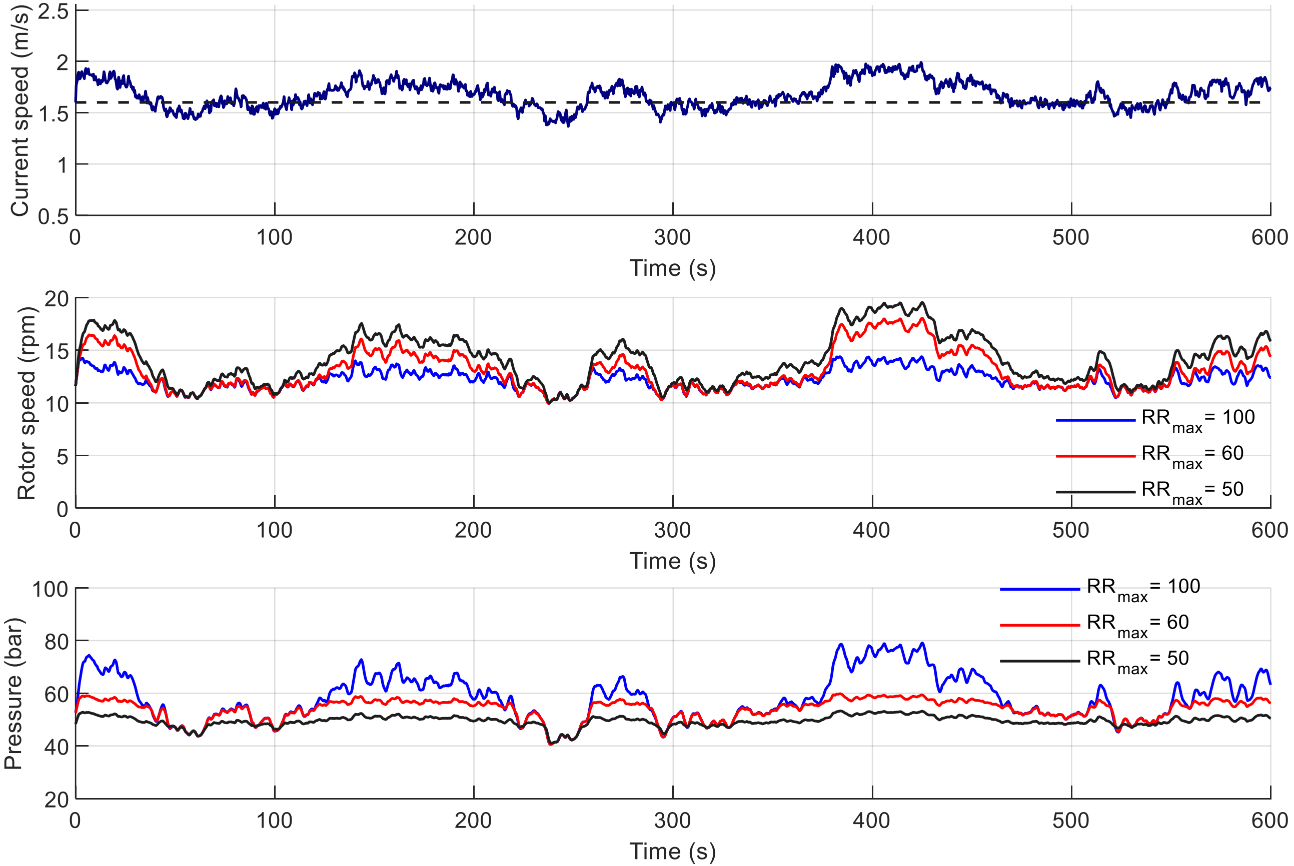
Graphs shown up to rated current speed of 2 m/s

Dynamic response simulation

$U_{mean} = 1.6$ m/s

TI = 14%



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Dynamic response simulation

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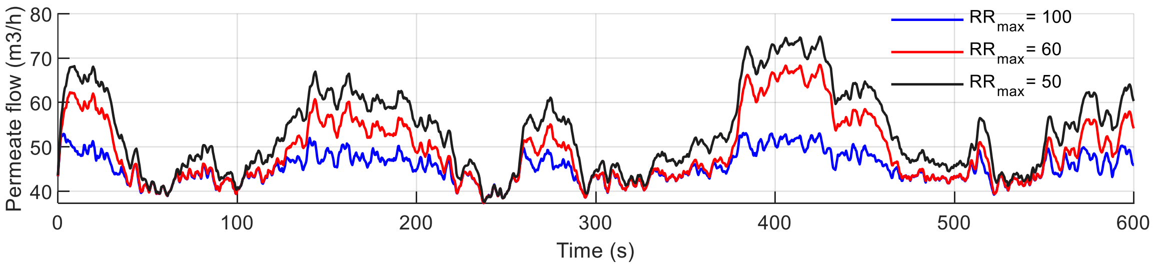
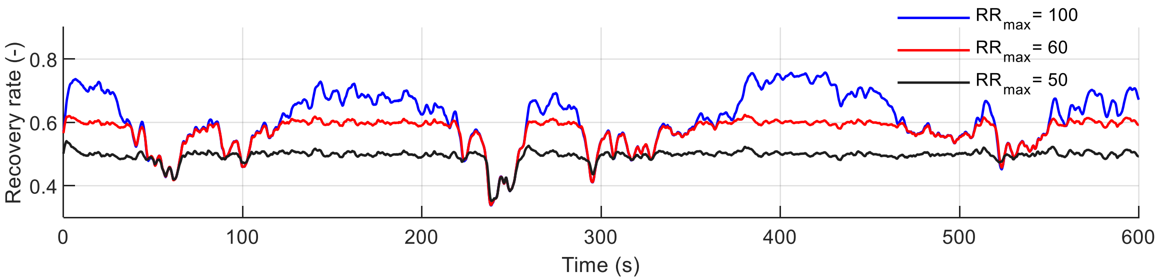
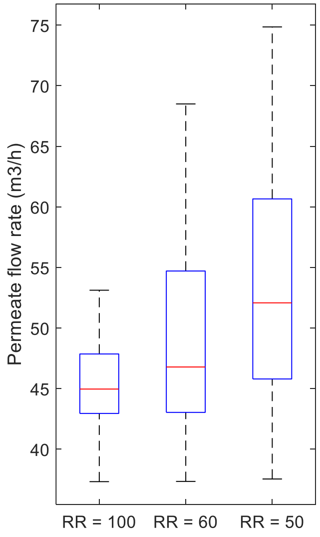
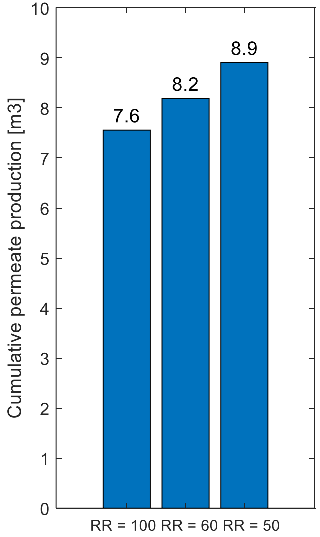






Permeate flow rate [m^3/h]



Cumulative water production [m^3]

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Conclusions

- A hydraulic tidal turbine with SWRO desalination system without any electrical intermediate conversion is proposed

- Time-domain numerical model of the integrate system allows to evaluate different configurations and design for preliminary studies
    - In this work the dynamic response of the turbine and fresh water production was evaluated for different settings of the recovery rate

- For a 10 m tidal turbine, lower recovery rates may increase the fresh water production, however there might be large fluctuations in the operating tip speed ratio for the proposed control strategy

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Thank you for your attention!
Muchas gracias!

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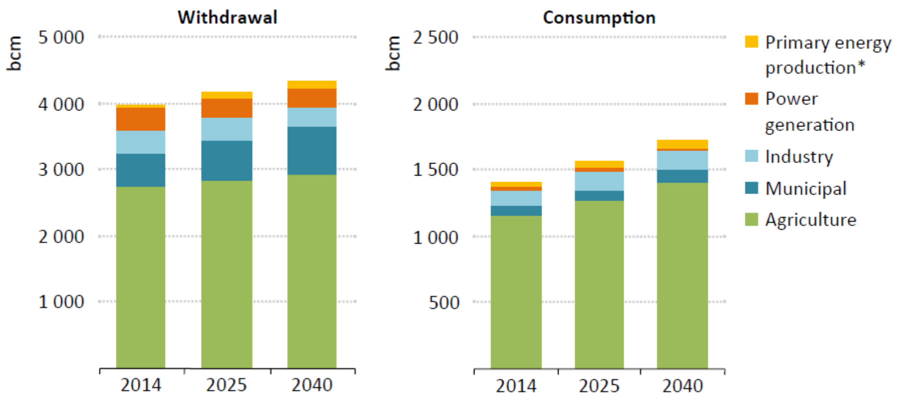
Global water demand by sector to 2040

A lot of water needed for energy!!

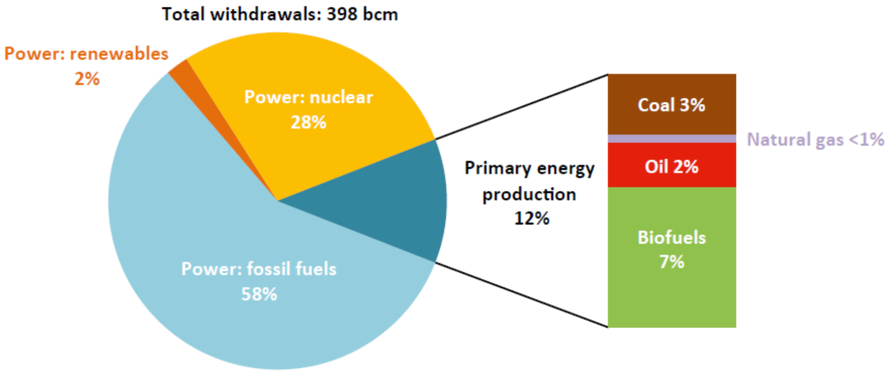


Agriculture remains the primary source of global water demand, but other sectors gain ground

* Primary energy production includes fossil fuels and biofuels.

Notes: bcm = billion cubic metres. Water withdrawals and consumption for crops grown as feedstock for biofuels is included in primary energy production, not in agriculture. See Box 2 for a detailed description of the methodology used to project water availability and demand.

Sources: Luck, et al. (2015); Bijl, et al. (2016); Wada, et al. (2016); IEA analysis.



Power generation is by far the largest source of energy-related water withdrawals

Notes: Renewables includes solar PV, CSP, wind, geothermal and bioenergy. Water requirements are quantified for "source-to-carrier" primary energy production (oil, gas, coal), a definition which includes extraction, processing and transport. Water withdrawals and consumption for biofuels account for the irrigation of dedicated feedstock and water use for processing. For electricity generation, freshwater requirements are for the operational phase, including cleaning, cooling and other process related needs; water used for the production of input fuels is excluded. Hydropower is excluded.

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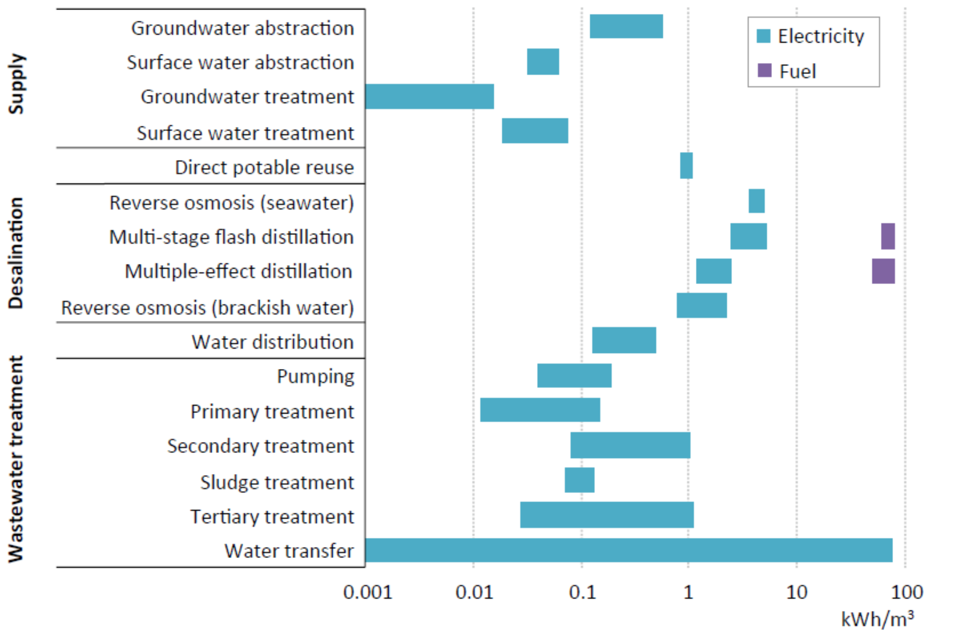
IEA world energy outlook (2016), Water Energy Nexus

Energy use for various processes in the water sector



Seawater desalination and wastewater treatment are the most energy-intensive processes in the water sector

Notes: See Box 2 for more detail on methodology. See *www.worldenergyoutlook.org/resources/water-energynexus/* for the detailed list including the numerical averages for each process.

Sources: EPRI (2002); Pabi, et al. (2013); Jones and Sowby (2014); Plappally and Lienhard V (2012); Spooner (2014); Li, et al (2016); Japan Water Research Center (n.d.); (Choi, 2015); Miller, et al. (2013); Singh, et al. (2012); Noyola, et al. (2012); Liu (2012); DWA-Leistungsvergleich (n.d.); Caffoor (2008); World Bank Group, (2015); Fillmore, et al. (2011); Brandt, et al. (2010); IEA analysis.

Model parameters

TABLE I
MAIN PARAMETERS OF THE INTEGRATED TIDAL AND SWRO MODEL

Symbol	Quantity	Value
R	Rotor radius (m)	5
λ_{opt}	Optimal tip speed ratio[a] (-)	3.8
P_{rated}	Rated mech power (kW)	150
U_{rated}	Rated current speed (m/s)	2.0
V_p	Pump volumetric displacement (l/rev)	66.13
C_s	Pump leakage coefficient (m^3/sPa)	1.5e-10
p_{max}	Maximum membrane pressure (Pa)	6.9e6
K_w	RO Mass transfer coefficient (s/m)	6.4e-9
A_m	Total membrane area (m^2)	2.97e3
δ	Osmotic pressure coefficient (Pa/ppm/K)	0.2641
C_{fin}	Intake feed concentration (ppm)	35500
M	ERD volumetric mixing (-)	0.06
V	System volume (m^3)	8
ρ_w	Seawater density (m^3/s)	1025
T	Water temperature (K)	295

[a]The optimal tip speed ratio λ=$\omega R/U$ is defined where a maximum power coefficient of the rotor is achieved at Cp=0.42

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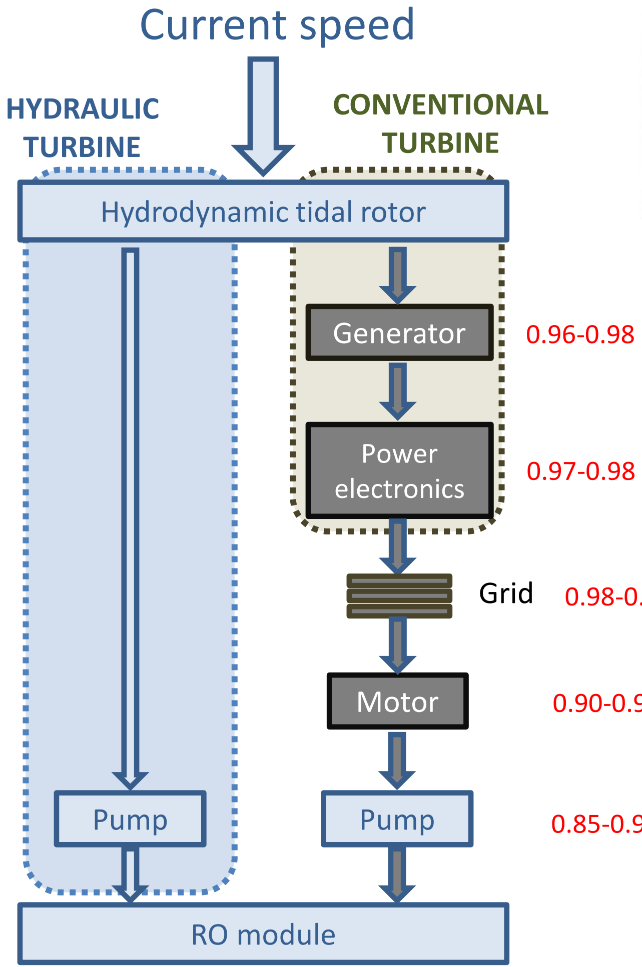
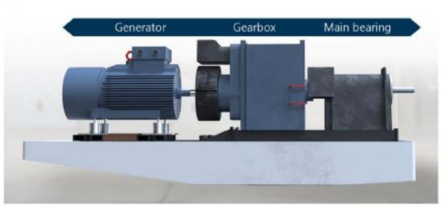
Water pump
Main bearing


Current speed
HYDRAULIC TURBINE
CONVENTIONAL TURBINE
Hydrodynamic tidal rotor
Generator
0.96-0.98
Power electronics
0.97-0.98
Grid
0.98-0.99
Motor
0.90-0.97
Pump
Pump
0.85-0.90
0.82-0.92
0.70-0.82
RO module


Generator
Gearbox
Main bearing

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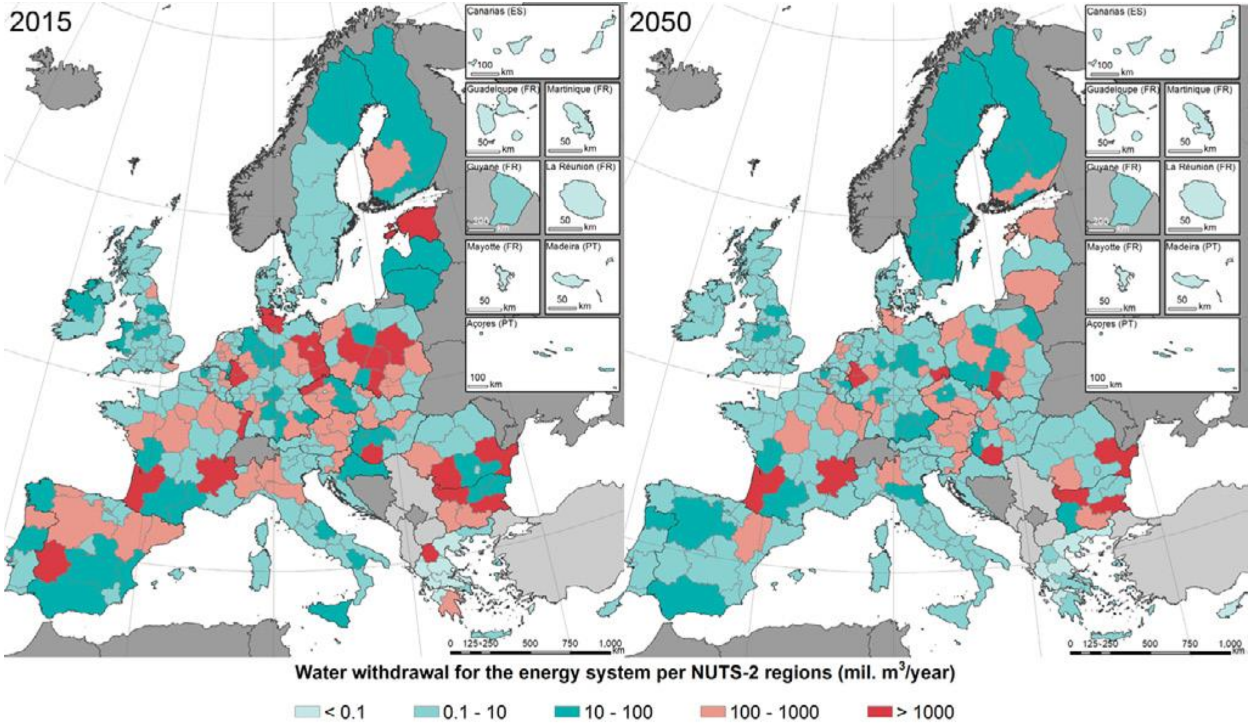
EU water energy system



Regional energy-related freshwater withdrawal for 2015 and 2050