SALINITY GRADIENT ENERGY IN COLOMBIA: AN EFFICIENCY ANALYSIS

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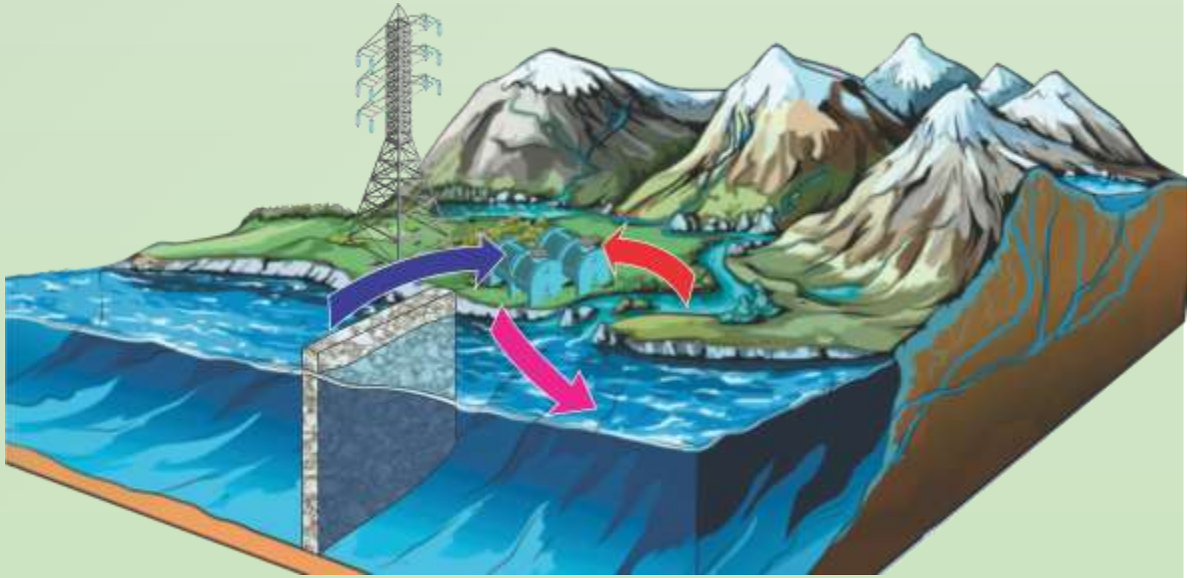
INTRODUCTION

Generalities of salinity gradient energy (SGE)



SOME IDEAS ABOUT SGE:

- ✓From the Gibbs free energy due to the difference in solute concentration (salinity).
- ✓~2 kJ per liter of fresh water.
- ✓Even from industrial wastewater.
- ✓Great potential in Colombia and South America.

MAIN GOAL OF THIS WORK:

A methodology is presented to quantify the energy consumed and/or the net energy produced in the conversion process at the plant while maintaining the salinity gradient as stable as possible.

MAIN GOALS

- An efficiency analysis for several river mouth systems located on the Caribbean and Pacific coasts from Colombia is presented.
- Analysis includes the facility locations used for the energy conversion as well as the points for intake and discharge streams.
- We also provide the performance of the PRO and RED technologies, and the estimation of the net energy.
- The feasibility of using plants to convert energy from the salinity gradient in Colombia is evaluated by estimating the technical potential which includes the selection of suitable locations for the intake and discharge of the streams, the projected capacity of the main technologies for the conversion of the salinity gradient, as well as the estimation of energy consumption during the process, which determines the efficiency of the conversion for each river mouth system.

River Mouth System	River Discharge (m^3/s)	Plant altitude (m.a.s.l)
Magdalena	7233	4
Canal Dique	299	2
Ranchería	12.4	4
Mira	743	12
Chagüi	134	15
Dagua	126	9

Methodology

- The net energy generated in a SGE plant was estimated from the **effective potential**, which includes the inefficiencies and energy losses in the conversion according to the technology used for the conversion.
- This effective potential depends on the **theoretical potential**, which is estimated as a function of the technology.

The theoretical potential:

Pressure Retarded Osmosis (PRO)

$$\Delta\pi = \frac{2R}{PM_{NaCl}}\left((T \cdot S)|_{concentrated} - (T \cdot S)|_{diluted}\right) \quad (1)$$

Reverse Electrodialysis (RED)

$$\Delta\phi = (\Delta G_{diluted} + \Delta G_{concentrated}) - \Delta G_{Mix} \quad (2)$$

Where

$$\Delta G_i = CRT\left(x_{NaCl}\ln(x_{NaCl}) + x_{H_2O}\ln(x_{H_2O})\right) \quad (3)$$

Methodology

The effective potential:

The effective osmotic potential-**PRO**:

$$\Delta\pi_{eff} = \pi_{concentrated} - \pi_{diluted}e^{kJw}$$

Includes the fact that the support of the semipermeable membrane increases the NaCl concentration, decreasing the osmotic gradient. Therefore, a support resistance (k) and the volumetric flux of pure water (Jw) are used.

The effective potential **RED**:

$$\Delta\phi_{eff} = \alpha\Delta\phi$$

Includes the inefficiencies and energy losses in the conversion of chemical potential into electricity. A loss of electromotive force in reverse electrodialysis is expected due to the flow of counterions through the membrane. The potential must be corrected using the membrane permselectivity coefficient (α) ej: 91%

The energy consumption in a SGE plant includes the water pre-treatment of the intake streams and the water transport from the intake points (freshwater and seawater) until the plant and from the plant until the discharge point (brackish stream).

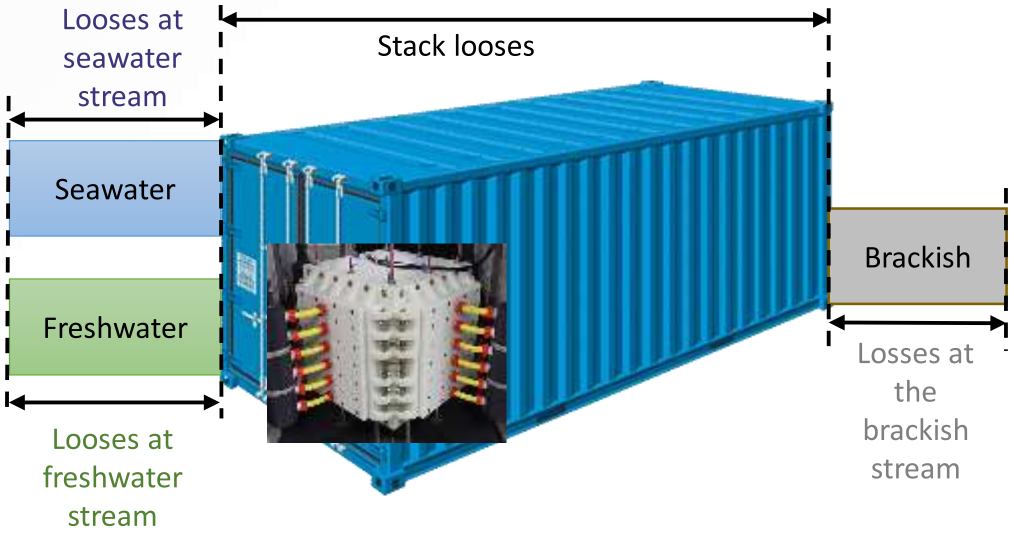
Reverse Electrodialysis (RED):

Theoretical potential:

$$\Delta G_i = CRT\left(x_{\mathrm{NaCl}} \ln(x_{\mathrm{NaCl}}) + x_{\mathrm{H_2O}} \ln(x_{\mathrm{H_2O}})\right)$$
$$\Delta\phi = (\Delta G_{\mathrm{diluted}} + \Delta G_{\mathrm{concentrated}}) - \Delta G_{\mathrm{Mix}}$$

Effective potential:

$$\Delta\phi_{eff} = \alpha\Delta\phi$$



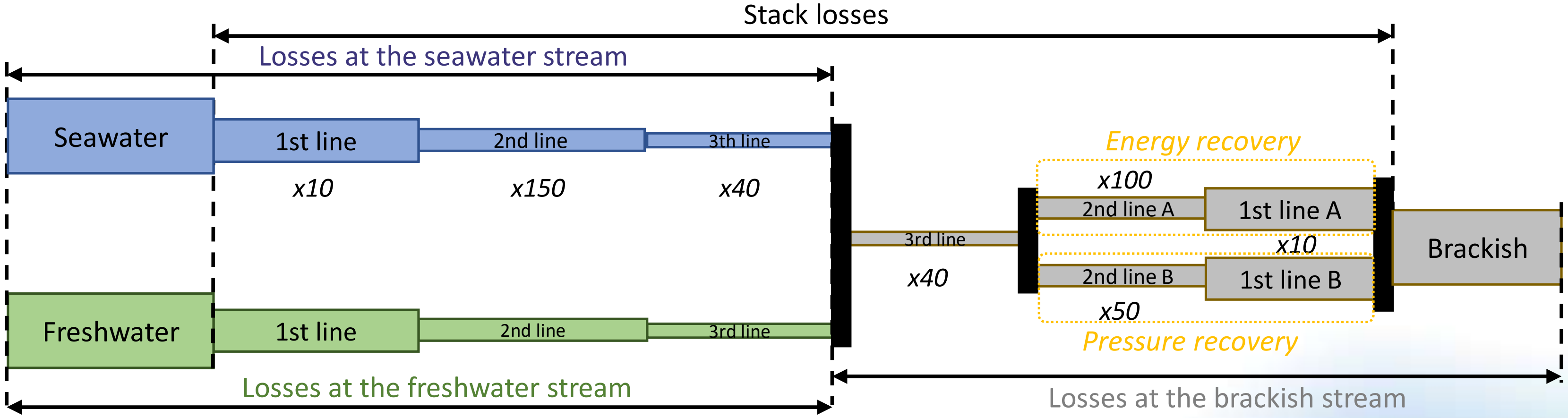
Pressure Retarded Osmosis (PRO):

Theoretical potential:

$$\Delta\pi = \frac{2R}{PM_{\mathrm{NaCl}}}\left((T\cdot S)\Big|_{\mathrm{concentrated}} - (T\cdot S)\Big|_{\mathrm{diluted}}\right)$$

Effective potential:

$$\Delta\pi_{eff} = \pi_{\mathrm{concentrated}} - \pi_{\mathrm{diluted}} e^{kJ_w}$$



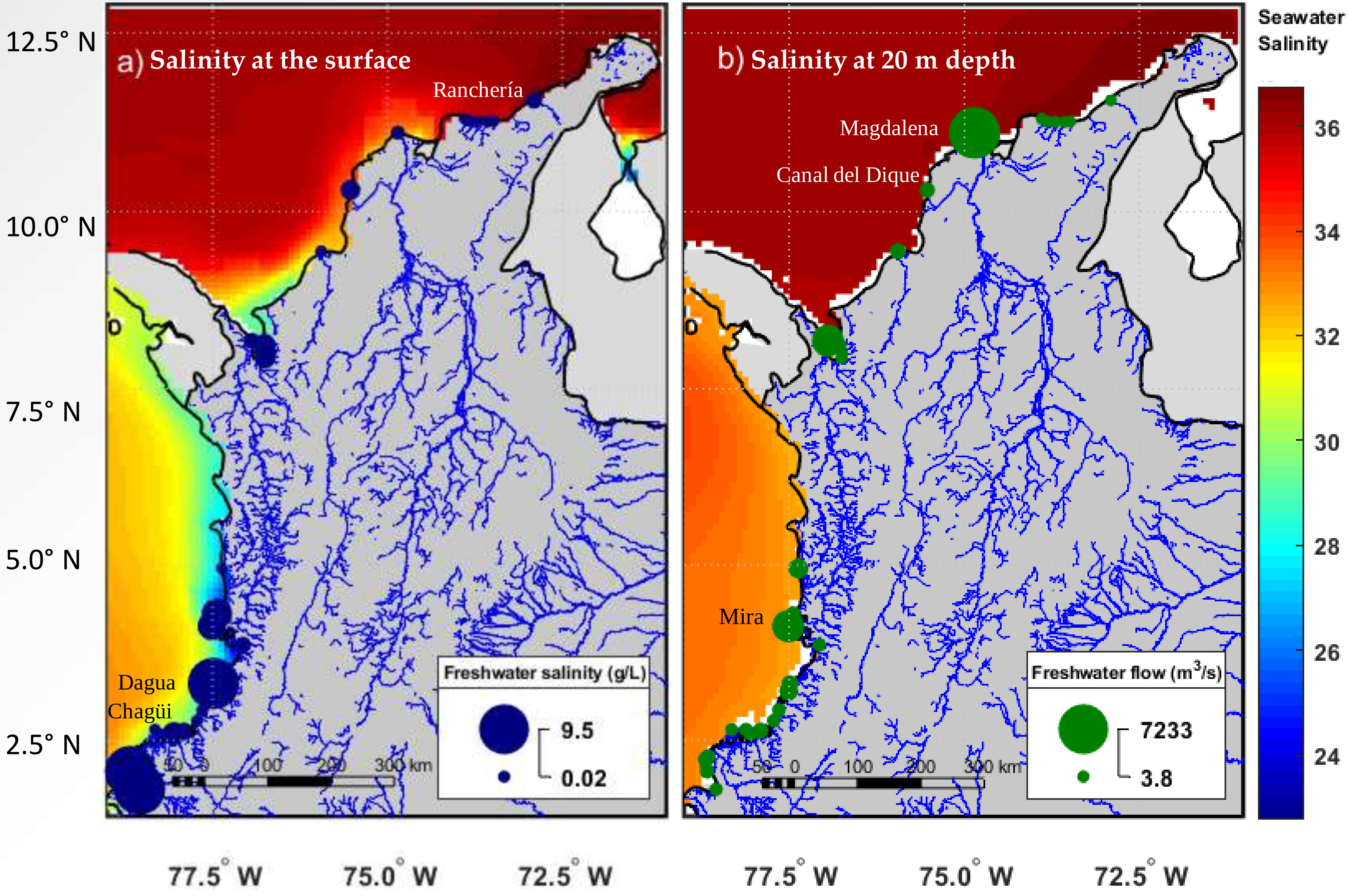
Pump power:

$$\Delta P_{\mathrm{L}} = f\frac{L}{D}\frac{\rho V^2}{2}$$
$$W_{\mathrm{Pump}} = Q\Delta P_{\mathrm{L}}$$

Pretreatment: 0.22* MJ/m^3

RESULTS

Salinity for the main river mouths (blue bubbles) and seawater (color map)



Distances for intake and discharge waters

River Mouth System	Distance to seawater intake (km)	Distance to freshwater intake (km)	Distance to brackish water discharge (km)
Magdalena	2.0	0.1	1.0
Canal Dique	1.5	1.5	0.3
Ranchería	6.3	0.1	2.5
Mira	1.9	3.4	1.1
Chagüi	27.8	0.3	0.5
Dagua	36.9	0.5	1

- ✓ The seawater salinity in the Caribbean is higher than that for the Pacific region.
- ✓ The Pacific region has a higher number of river discharge systems.
- ✓ Magdalena River has the highest flow of freshwater discharge.
- ✓ The freshwater salinization in the Caribbean is lower than that in the Pacific.
- ✓ Greater distances and heights for Pacific sites plus tidal range (hight mixing) is a drawback for SGE.

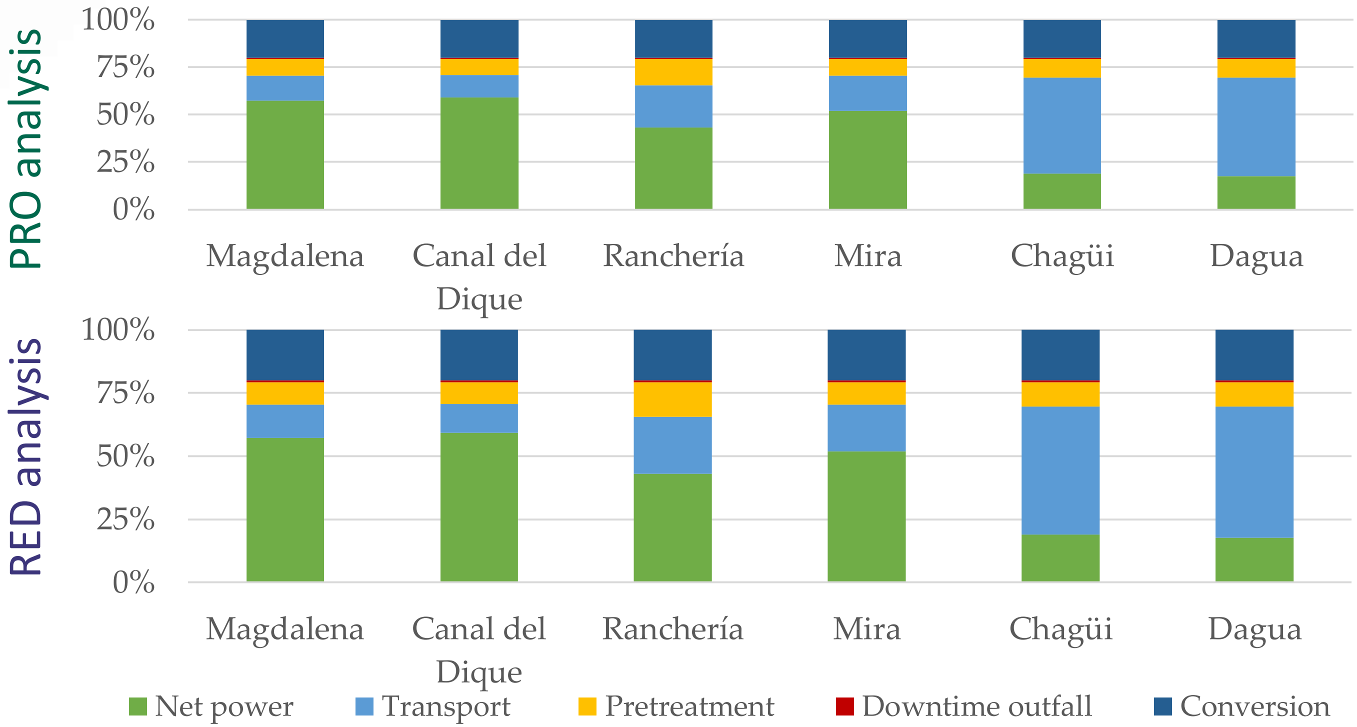
RESULTS

Effective potential and nominal power

River Mouth System	$\Delta\pi_{eff}$ (MW/m³)	$\Delta\phi_{eff}$ (MW/m³)	Freshwater flow (m³/s)	Nominal power (MW)
Magdalena	2.444	1.788	150	200
Canal Dique	2.254	1.524	20	36
Ranchería	2.257	1.565	1.0	1.0
Mira	2.538	1.815	21.0	36
Chagüi	2.446	1.892	13.0	19
Dagua	1.600	1.189	12.0	19

- ✓ The potentials for PRO are larger than that those for RED, probably due to the necessity of more restrictive membranes in the case of the RED technology (i.e., semipermeable and ion exchange membranes for PRO and RED, respectively).
- ✓ The differences in energy consumption among these technologies are compensated in the conversion of the salinity gradient, leading to similar net powers for both PRO and RED technologies

Net energy for some river mouth systems in Colombia

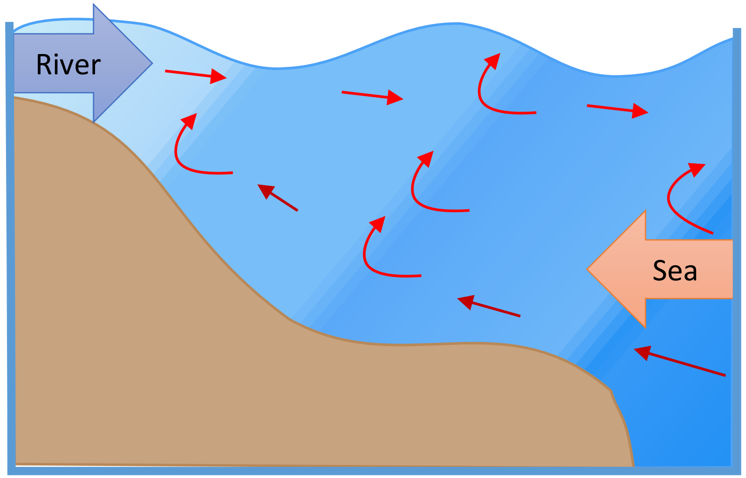


- ✓ Chagüi and Dagua river mouth systems possess water quality, recirculation processes, and site properties that involve high energy consumption for a SGE plant.
- ✓ Magdalena and Canal del Dique have high potential for a SGE project (the percentage of net power were estimated at 58% and 61%, respectively.
- ✓ Mira River exhibits a significative percentage of recovered energy, suggesting a potential of application despite the long pipe networks needed to transport the water.

DISCUSSION & CONCLUSION

- The larger values of salinity for river mouths in the Pacific than those on the Caribbean coast can be attributed to the considerable effect of the **tidal stream** and the **local geography** at each point:

  A mean tidal range larger than 1 m for the Pacific Sea has been reported on the Colombian coast, whereas a microtidal range ranging from 0.2 to 0.4 m of tidal amplitude for the Caribbean coast.



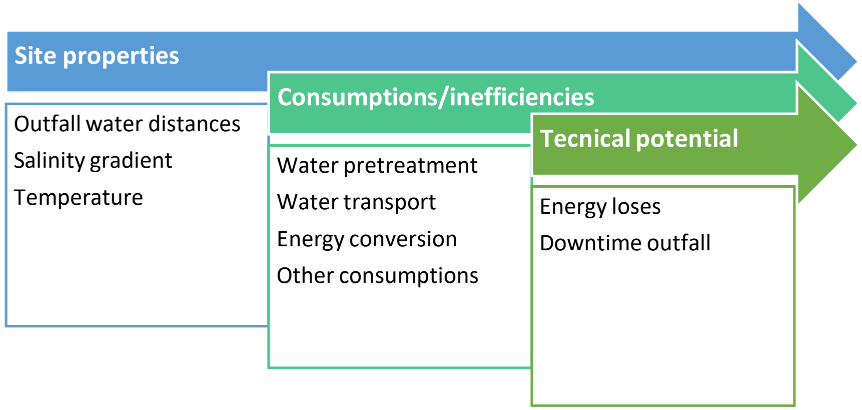
- The water circulation at the river mouth system impacts the **gap distances among the water outfalls** and plant, **and the plant altitude**:

  The great distance between the intake points of freshwater and seawater and the discharge point of brackish water influences the energy used to transport these streams. This distance is obtained by considering a stable salinity gradient as possible.

DISCUSSION & CONCLUSION

- The methodology proposed in the present work includes the **quantification of the net power**, **the selection of the site for the plant**, and **the analysis of the technology for the conversion**, approaching the efficiency of the entire process:

  It can be very useful in supporting the decision-making involved in the implementation of SGE projects

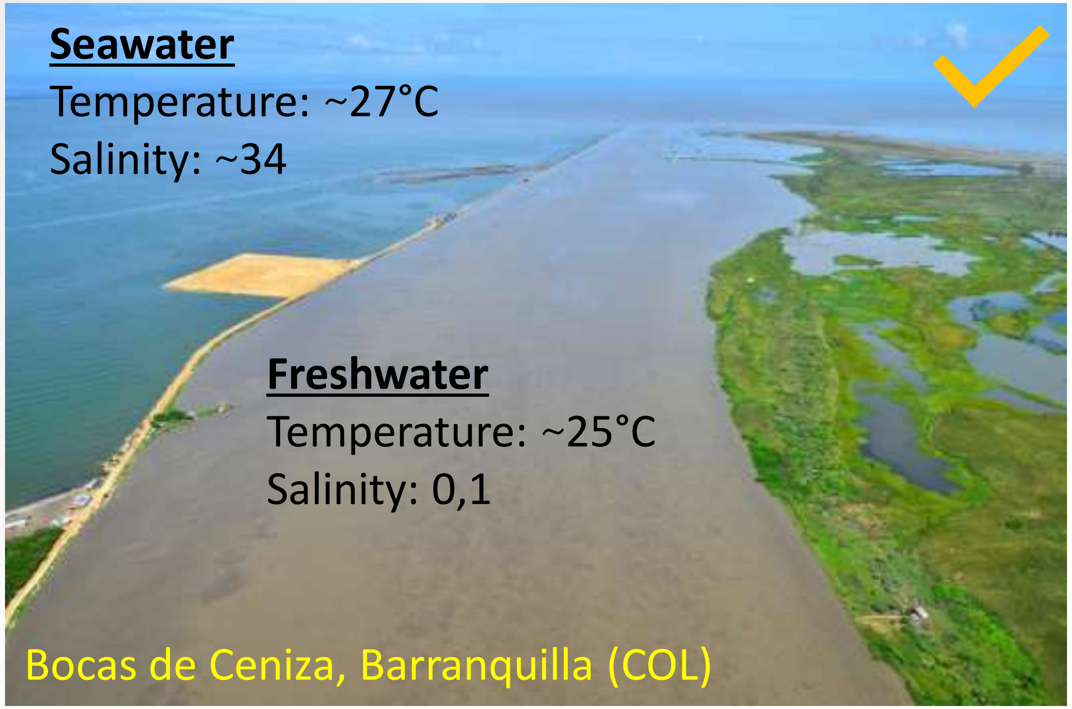


- The efficiency of the main components of PRO and RED technologies based on the site constraints and the potential that the salinity gradient entails for net power allow a **quantitative evaluation of the technical feasibility of a SGE project:**

  River mouth systems such as the Magdalena River, Canal del Dique, and Mira River show a high potential for a SGE implementation, including the stability of the salinity gradient, the environmental flow of the river, and the performance of the technology for the energy conversion, including pressure-reduced osmosis and reverse electrodialysis.

DISCUSSION & CONCLUSION

Magdalena River Mouth



Design information

Installed capacity: 200 MW
Fresh water flow: ~105 m^3/s
Seawater outfall: 2 km
Freshwater outfall: 0,1 km
Brackish outfall: 1 km
Annual energy production: ~1250 GWh/y

Canal del Dique River Mouth

Design information

Installed capacity: 36 MW
Fresh water flow: ~30 m^3/s
Seawater outfall: 5 km
Freshwater outfall: 0,1 km
Brackish outfall: 1,7 km
Annual energy production: ~192 GWh/y