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Quantitative sustainability analysis of water desalination – A didactic example for reverse osmosis

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ABSTRACT

Water desalination continues to evolve to a currently mature stage that, similarly to all large human endeavors, must be planned, designed, and operated according to the quantitative holistic sustainability paradigm and criteria that are defined by the interrelated aspects of the environmental, economic, and social pillars of the endeavor. A methodology for such evaluation was described in [1], including equations for formulating a composite sustainability index as a function of relevant parameters, which thus allows mathematical analysis in general and sensitivity analysis and optimization in particular. This is the first paper that demonstrates this methodology and its use for desalination by presenting an example of a comprehensive and detailed original sustainability analysis of reverse osmosis (RO) desalination plants and of their comparison. It includes the selection and calculation of metrics (for simplicity, a small number and partially synthetic) and weights, as well as their aggregation to a composite sustainability indicator, using typical data values. The aggregation is performed by an original concept of impact quantification and monetization. An analysis of sensitivity to choice of weights and to the combined environmental and social impact factors was conducted. The presented sustainability analysis example should be helpful for both didactic and practical purposes, and the methodology is flexible, modular, adaptable, and enhancable to meet other and evolving needs.

1. Introduction and objectives

Water desalination has evolved into a regionally important and substantial water source, with an exponential growth rate. Like all large human endeavors, it is accompanied by significant economic, environmental and social impacts. It is also regarded as a potential part of the solution for the rising magnitude of the global water crisis and of its supply and demand quantities, exacerbated by the accelerated and foreseen global warming consequences. It obviously continues to evolve to a currently mature stage. There is broad agreement that its continuing success and rising contribution to the world's vitally needed development must, like all large human endeavors, be planned, designed and operated according to the quantitative holistic sustainability paradigm and criteria that are defined by the interrelated aspects of the environmental, economic and social *pillars* of the endeavor (some studies use more than these three pillars, but three are generally sufficient). A methodology for such evaluation, including ample literature references, was described in [1]. It includes the equations for formulating a composite sustainability index as a function of relevant design and operation parameters, which thus allows mathematical analysis in general and sensitivity analysis and optimization in particular.

This paper demonstrates this methodology and its use by presenting a comprehensive and detailed yet sufficiently simple and straightforward original sustainability analysis of reverse osmosis (RO) desalination plants. It includes the selection and calculation of metrics (for simplicity, a small number) and weights, their aggregation to a composite sustainability indicator, using typical data values, and a sensitivity analysis of the effects of choice of weights and of the combined environmental and social impact factors on the results, both for didactic and practical purposes. At the same time, we re-clarify that while the choice and definitions of indicators and weights and their quantities, of the used data, and of the aggregation method, as well as therefore of the obtained sustainability results, are representative for such analyses and serve well the didactic purpose of this paper, sustainability analysts must adapt their work carefully to the specific systems they analyze.

2. The RO system

RO is currently the most used water desalination process, and it, as well as other desalination plants, is in most cases subject to design, construction, and operation that follow separately employed and analyzed methods, such as environmental impact assessment (EIA), life cycle analysis (LCA), best available technology (BAT), economic

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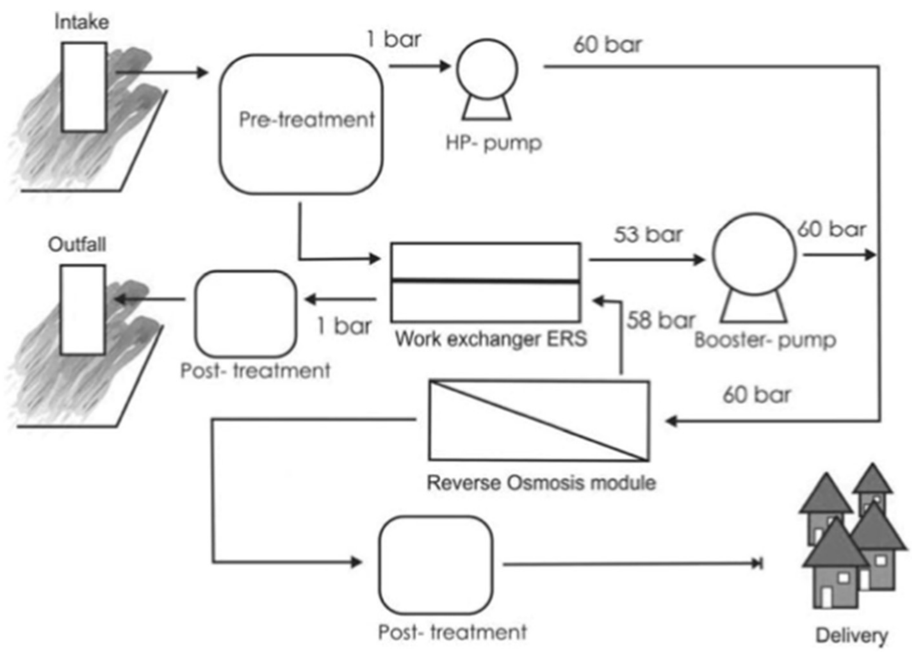

Fig. 1. A simplified reverse osmosis water desalination system flow diagram with energy recovery [2].

analysis in its different forms, and social impact analysis, and their combinations, and sometimes are evaluated by the research-oriented Driver-Pressure-State-Impact-Response (DPSIR) method [1]. Compliance with such evaluations is mandatory if regulations are available (and enforced…).

As described in [1], sustainability analysis holistically integrates but also significantly transcends the above-mentioned methods and thus produces much more complete and useful information and evaluation.

A simplified example of a typical RO system is shown in Fig. 1. The water to be desalted is pumped from the source at the *Intake* and is treated in the *Pre-treatment* block to quality required by the RO membranes. The pretreated saline water is pumped by the *HP-pump* and *Booster-pump* to the operating pressure (here 60 bar), where a part of it recovers pressure (energy) from the concentrated discharge brine by using the *Work exchanger ERS*, and this pressurized water is desalted in the *Reverse osmosis module*. The high pressure concentrated brine from this module is passed through the *Work exchanger ERS* to pressurize the feed and is then treated in the upper *Post-treatment* module to the level desired (or required) for the ultimate *Outfall*. The desalted water is treated in the lower *Post-treatment* module to the level desired (or required) for its *Delivery*.

The primary economic impact is the cost of the plant (including the land), of its operation (including the used energy and the cost of money) and maintenance costs (including taxes and insurance). The primary environmental impacts take place at the intake, outfall (discharge), and long distance piping, as well as due to energy use and social impacts include water quality, supply, employment, and quality of life related to the water supply.

3. The analytical sustainability analysis methods

3.1. The typical general sustainability analysis method

The typical detailed mathematical definition of sustainability and its analysis are presented in [1], and specific to the example analyzed in this paper in Sections 3.2, 3.3, 4, and 5 below. A brief summary of the basic approach is:

- First, decide which are the pillars of the analysis, three are used in most sustainability analyses and here: environmental, economic, and social.
- Second, a sufficient number, i, of metrics, M_i (most often called indicators) that measure the environmental, economic and social impacts of the considered project/development are chosen.
- Third, their relative importance, expressed by their weights, w_i, is determined.
- Fourth/finally, the used $M_i w_i$ products are aggregated into a composite sustainability indicator (*CSI*) as illustrated in Fig. 2.

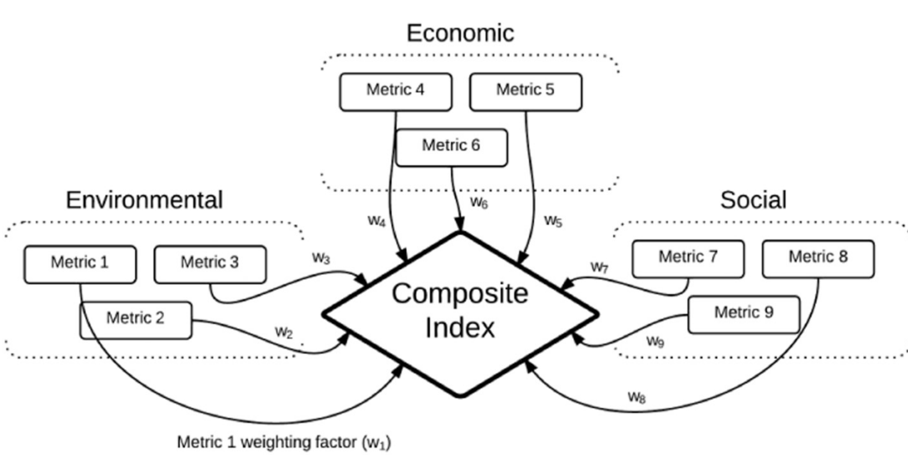

Fig. 2. A diagram for a 3-pillar Composite Sustainability Indicator (*CSI*) construction [1].