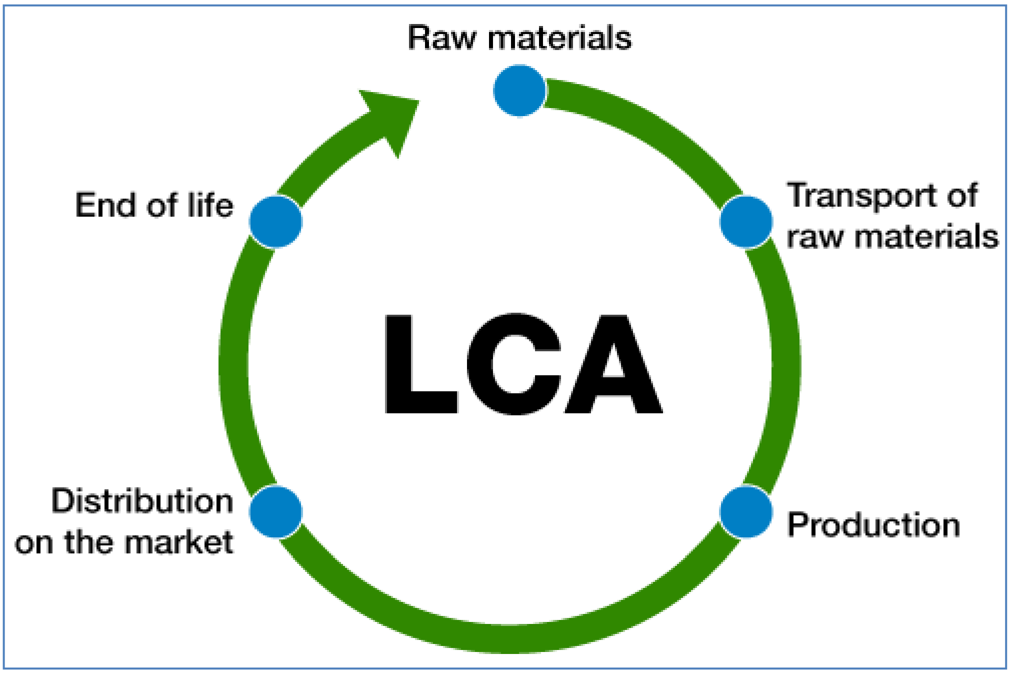
PROPOSAL LIFE 16-ENV-ES-000341

"DESALINATED SEAWATER FOR ALTERNATIVE AND SUSTAINABLE SOILLESS CROP PRODUCTION"



"REPORT ON CARBON DIOXIDE EMISSION"

ACCIÓN A1. "Characterization of current and expected desalinated seawater production for crop irrigation in the water-stressed south Eastern Spain"

"15 May 2018"

Abstract

This deliverable analyzes the relationship between water, energy and Greenhouse Gases (GHG) in SeaWater Desalination Plants (SWDPs) for agricultural use, through the methodology of Life Cycle Assessment (LCA). The source data from this deliverable were the Deliverable DA1.1, where they are exposed the main characteristics of SWDPs located in the Mediterranean area. The data sources to assessment the LCA have been obtained mainly from Carboneras SWDP, because this plant will be supply desalinated seawater for the test plots. Process-based LCA was used, following the international standards ISO 14.040, applying 'cradle to gate' approach, with SimaPro 8.5 software. Global Warming Potential (GWP) and Cumulative Energy Demand (CED) have been analyzed as environmental impact categories. The GHG emissions calculated for the production of 1 m^3 of desalinated seawater were 4.82 kg of CO_{2eq} including distribution process to irrigators community. The CED required for the process was 88.62 MJ/m^3. The most relevant processes for the production of desalinated seawater were treatment stage (86%), being the electricity the key input contributor to the GHG emissions (59%). The strategies to reduce GHG emissions associated to desalinated seawater are extremely limited in the frame of DESEACROP project, since the potential of decreasing the environmental impact of desalination seawater it is directly related to change of energy policy model in Spain.

Resumen

En este entregable se analiza la relación entre agua, energía y Gases de Efecto Invernadero (GEI) del proceso de producción de agua marina desalinizada (AMD) para riego agrícola mediante la metodología de Análisis de Ciclo de Vida (ACV). Se han tomado como referencias los datos del entregable DA1.1, donde se exponen de las principales características de plantas ubicadas de la cuenca mediterránea. Para realizar el ACV se han utilizado los datos de inventario de la planta de Carboneras, por ser la planta que suministra AMD a las parcelas de ensayo. Se ha utilizado la metodología propuesta por la familia de normas ISO 14.040, con el enfoque "de la cuna a la puerta", empleando el software SimaPro 8.5. Las categorías de impacto ambiental analizadas han sido el "Calentamiento Global" (CG) y el "Consumo de Recursos Energéticos" (CRE) referenciadas al metro cubico de AMD producido en planta y distribuido por la comunidad de regantes. Los resultados muestran que para producir 1 m^3 de agua desalinizada se emiten 4,82 kg de CO_{2eq}, incluyendo el proceso de distribución a la comunidad de regantes. El CRE requerido para el proceso fue de 88,62 MJ/m^3. La etapa más relevantes del proceso de producción de agua desalinizada fue la etapa de tratamiento (86%), siendo la electricidad el input clave que contribuye a las emisiones de GEI (59%). La estrategia para mitigar este impacto ambiental del proceso pasa por el incremento en el uso de energías renovables en el "mix eléctrico español", que depende más del modelo energético de España, que del proyecto DESEACROP.

ÍNDICE

1. Introduction

The aim of this deliverable is to determine the *carbon dioxide emission* at the desalinated seawater production sites (Task A.1.4). This is included in ACTION A1. *Characterization of current and expected desalinated seawater production for crop irrigation in the water-stressed south Eastern Spain*.

The purpose of this report is to review the nexus water-energy-greenhouse gas (GHG) emissions of seawater production sites in Mediterranean area cited in Deliverable DA1.1. A specific analysis of carbon dioxide emission focused in Carboneras SWDP has been also made. For this proposal, Life Cycle Assessment (LCA) has been used as methodology. The main sources of GHG emissions within the life cycle of SWDP has been identify and compared with already published values literature values. Finally the last strategies proposed by recent researches to mitigate the environmental impact of produce desalinated seawater (DSW) has been exposed.

2. Seawater production sites in Mediterranean area

The information used in this section has been obtained as a result of the Deliverable DA1.1.

2.1. Location seawater desalination plants

Table 1 shows a summary of characteristics of SWDPs of Mediterranea area, according to Deliverable (DA1.1).

Table 1. Summary of seawater desalination plants in Mediterranean area.

Seawater desalination plant	Locations	Water use	Total production (hm^3/year)	Production for agricultural use (%)	Specific energy consumption (kW/m^3)
CR Águilas	Águilas (Murcia)	agricultural use	*		
Desaladora de Águilas	Águilas (Murcia)	human consumption and agricultural use	60	80	4.6
Desaladora Alicante I	Agua Amarga (Alicante)	human consumption	21		4.5
Desaladora Alicante II	Agua Amarga (Alicante)	human consumption	24		3.5
Desaladora de Xàbia	Xábia (Alicante)	human consumption	10		
Desaladora de Marbella	Marbella (Málaga)	human consumption	21		4.5
Desaladora Almería	Almería (Almería)	human consumption	18	28	
Desaladora Rambla Morales	Almería (Almería)	agricultural use	*		
CR Marina de Cope	Paraje de la Marina (Murcia)	agricultural use	5	100	
Desaladora de Carboneras	Carboneras (Almería)	human consumption and agricultural use	42	60	4.98
Desaladora de Valdelentisco	Cartagena (Murcia)	human consumption and agricultural use	48	46	3.4
Desaladora de Escombreras	Cartagena (Murcia)	human consumption, industrial and agricultural use	23	30	
Desaladora Bajo Almanzora	Cuevas del Almanzora (Almería)	human consumption and agricultural use	*		4.04
Desaladora Campo de Dalías	El Ejido (Almería)	human consumption and agricultural use	30		
CR Virgen de los Milagros	Mazarrón (Murcia)	agricultural use	12	100	3.06
Desaladora Mutxamel	Marina Baja (Alicante)	human consumption	*		4.56
Desaladora San Pedro del Pinatar I	San Pedro del Pinatar (Murcia)	human consumption	24		3.75
Desaladora San Pedro del Pinatar II	San Pedro del Pinatar (Murcia)	*	24		3.75
Desaladora Torrevieja (Alicante)	Torrevieja (Alicante)	human consumption and agricultural use	44	70	4.75
Desaladora Oropesa del Mar (Castellón)	Oropesa del Mar (Castellón)	human consumption and agricultural use	*		
Desaladora Sagunto (Valencia)	Oropesa del Mar (Castellón)	human consumption and industrial use	*		

* data no available.

2.2. Carboneras seawater desalination plant

The Seawater Desalination Plant (SWDP) related directly whit the project is located in Carboneras (Almeria) (Fig. 1). This SWDP provides water for human consumption and irrigation purposes and has the capacity to deliver up to 120,000 m^3 of water each day (Acciona-Agua, 2018).

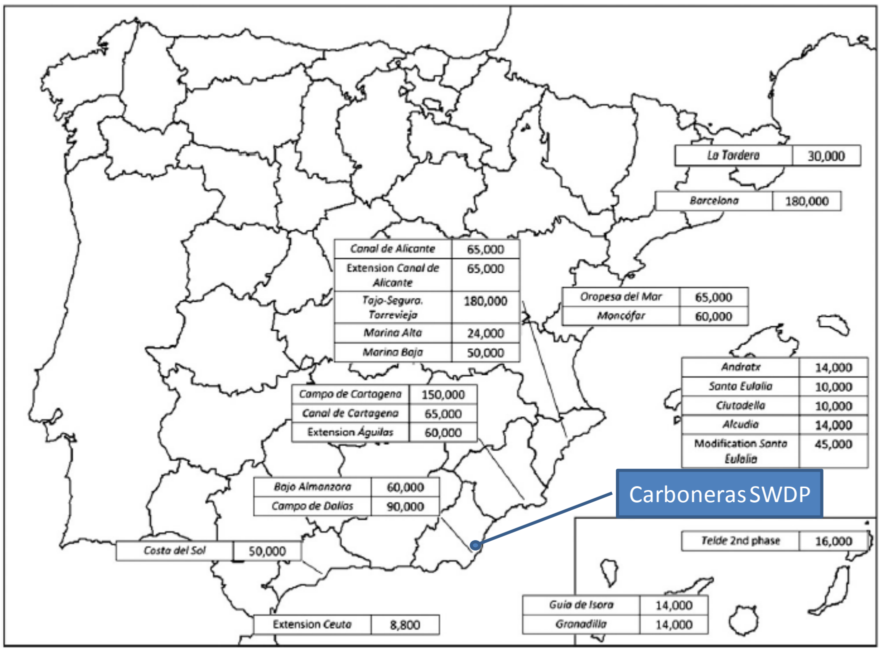


Fig. 1. Location Carboneras SWDP in geographic distribution of SWDPs in Spain (adapted to Fuentes-Bargues, 2014).

3. Brief introduction to Life Cycle Assessment

Life Cycle Assessment (LCA) is a structured, comprehensive and internationally standardised method (ISO 14040) that quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with any goods or services ("products").

Life Cycle Assessment takes into account a product's full life cycle: from the extraction of resources, through production, use, and recycling, up to the disposal of remaining waste. Critically, LCA studies thereby help to avoid resolving one environmental problem while creating others: this unwanted "shifting of burdens" is where you reduce the environmental impact at one point in the life cycle, only to increase it at another point. Therefore, LCA helps to avoid, for example, causing waste-related issues while improving production technologies, increasing land use or acid rain while reducing greenhouse gases, or increasing emissions in one country while reducing them in another.

LCA is therefore a vital and powerful decision support tool, complementing other methods, which are equally necessary to help effectively and efficiently make consumption and production more sustainable.

Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) are consecutive parts of a LCA, where:

- LCI is the collection and analysis of environmental interventions data (e.g. emissions to e.g. air and water, waste generation and resource consumption) which are associated with a product from the extraction of raw materials through production and use to final disposal, including recycling, reuse, and energy recovery.
- LCIA is the estimation of indicators of the environmental pressures in terms of e.g. climate change, summer smog, resource depletion, acidification, human health effects, etc. associated with the environmental interventions attributable to the life-cycle of a product.

The data used in LCA should be consistent and quality assured and reflects actual industrial process chains. Methodologies should reflect a best consensus based on current practice.

4. Methodology

The LCA approach used in this study assessed the greenhouse emissions (GHG emissions) from the production of desalinated water from the Carboneras SWDP powered by Spanish electricity grid.

This approach enabled the greenhouse gas emissions from the extraction, treatment and delivery of desalinated water to be calculated. The LCA follows the ISO14040-43 guidelines (ISO, 2006a, 2006b), and is divided into four steps: goal and scope definition, inventory analysis, impact assessment and interpretation. The sections that follow reflect this structure, with the first three stages described under headings of the same name. Finally interpretation and comparison with literature values are shown in results section.

4.1. Goal and scope definition

The goal is to assess the life cycle greenhouse (GHG) emissions of a SWDP powered by 100% Spanish electricity grid. This research uses a ‘cradle to gate’ approach, where the functional unit is defined as the global warming potential (GWP) of 1 m^3 of desalinated water production.

The system boundary of LCA mainly consists of three stages: seawater extraction, treatment in plant (included post-treatment) and distribution to irrigators community "*Comunidad de Usuarios de Aguas de la Comarca de Níjar*". The specific energy consumption (kWh/m^3) of Carboneras SWDP by stages was obtained from AcuaMed (2016). The emissions from the construction phase are not included in the system boundary of the LCA analysis due to its long term span (RMIT, 2007). Frequently consumed items such as chemicals used, short life-time components or components requiring frequent replacements, such as membranes, have been included in the system boundary. Since there is no available information of these items for Carboneras SWDP, such an information was taken from Ecoinvent databases.

The seawater extraction stage includes the greenhouse gas emissions from electricity generation for pumping seawater into the water treatment plant. The seawater treatment stage consists of three stages: pre-treatment, reverse osmosis system and post treatment. Each of these stages includes greenhouse gas emissions from the production and transportation of chemicals and membranes for water treatment and from the generation of electricity for pumping. Post-treatment includes greenhouse gas emissions from electricity generation for water delivery to irrigators community (Fig. 2). The seawater distribution included the distribution by pressurised pipe system to reservoir of irrigators community.

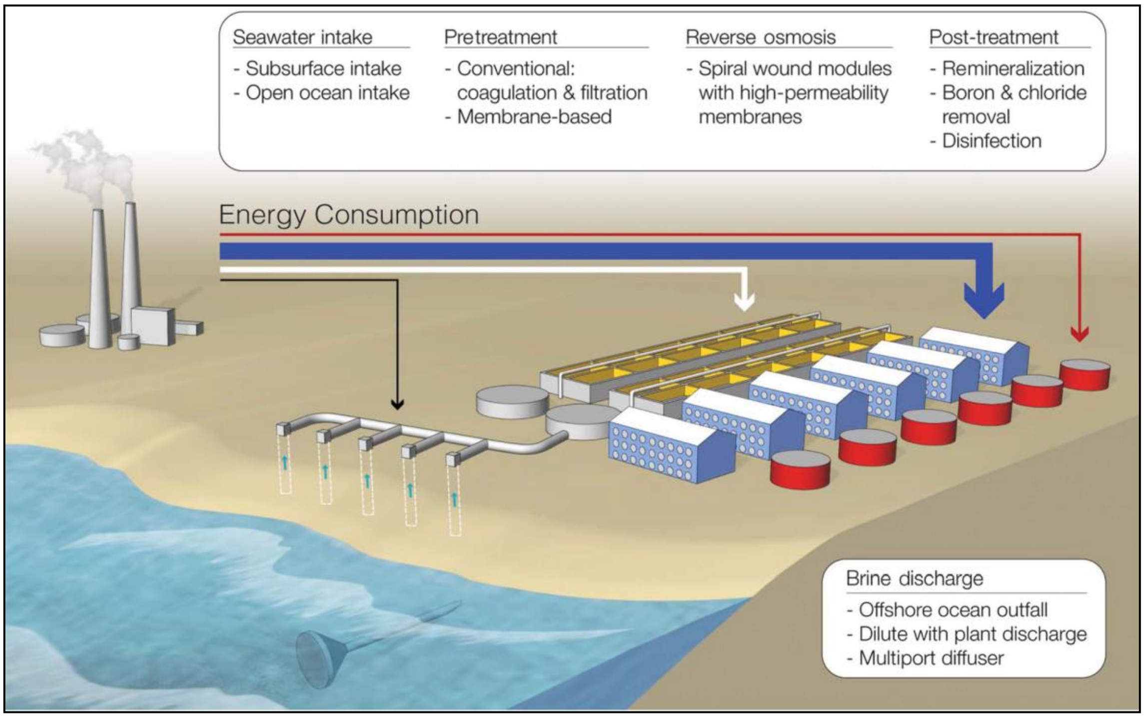


Fig. 2. Conceptual drawing of an SWRO desalination plant showing the various stages—seawater intake, pre-treatment, reverse osmosis, post-treatment, and brine discharge—and their interactions with the environment. The thickness of the arrows for the energy consumption represents the relative amount of energy consumed at the various stages (Elimelech and Phillip, 2011).

4.2. Inventory analysis

A LCI is the phase of LCA aimed at compiling all output emissions and wastes and also input resources as environmental flows.

For operational phase, LCI was obtained by process based LCI method. Operational phase background data was obtained from available libraries in Ecoinvent databases. In order to make the LCA results more representative for Spain, European databases and libraries have been used and the grid electricity were selected for Spanish electricity mix factor.

The following process for tap water production by seawater reverse osmosis with conventional pretreatment has been used (Ecoinvent databases) due to lack of data about the technical specifications of Carboneras SWDP. This database represents the production of 1 m^3 of drinking water (potable water) water from seawater reverse osmosis with conventional pretreatment using enhance membrane modules and a single stage configuration. Enhance membrane is a polyamide membrane of 40.9 m^2 of active membrane surface and maximum operating pressure of 83 bars. The LCI of 1 m^3 of desalinated water production are listed in Table 2.

Table 2. Life cycle inventory (LCI) of 1 m^3 of desalinated water production.

Inputs	Amount	Unit	Source
Electricity			
• Seawater extraction	0.62	kWh/m^3	AcuaMed, 2016
• Treatment and post-treatment	3.38	kWh/m^3	AcuaMed, 2016
• Distribution to irrigators community	0.98	kWh/m^3	AcuaMed, 2016
Chemical products		-	
• Iron (III) chloride	2.06E-02	Kg/m^3	Ecoinvent 3
• Lime, hydrated	4.35E-02	Kg/m^3	Ecoinvent 3
• Sodium hydrogen sulfite	2.37E-02	Kg/m^3	Ecoinvent 3
• Sulfuric acid	9.53E-02	Kg/m^3	Ecoinvent 3
• Polyvinylidenchloride, granulate	4.70E-01	Kg/m^3	Ecoinvent 3
• Chlorine, liquid	1.00E-04	Kg/m^3	Ecoinvent 3
• Sodium hypochlorite	1.38E-03	Kg/m^3	Ecoinvent 3
• Polyacrylamide	1.05E-03	Kg/m^3	Ecoinvent 3
• Polycarboxylates, 40%	4.49E-03	Kg/m^3	Ecoinvent 3

Reverse osmosis system was modeled using typical seawater characterisation, single stage enhance module membrane system with recovery rate of 40%. It includes water intake of seawater, conventional pretreatment, reverse osmosis filtration, recarbonisation and emissions of brine to sea. The modeling of the reverse osmosis treatment was done using the ROSA (Reverse Osmosis System Analysis) system design software from Dow Chemical. Recarbonation and post-treatment of permeate water are modeled with the Rothberg, Tamburini and Winsor (RTW) Model for Corrosion Control and Process Chemistry 4.0 by Tetra Tech. Typical seawater characterisation for salinity of 3.5% (w/w) was used for modeling. This database includes material inputs for the different water treatment stages: chlorination, coagulation, flocculation, clarification, sedimentation of sludge, dual media filtration, cartridge filtration, membrane filtration and post-treatment. It includes material for the membrane module and pressure vessel assuming lifetimes of 5 and 15 years, respectively.

4.3. Impact assessment

LCIA is the final phase of LCA in which inventory data are converted into impact results through the use of appropriate algorithms or indicators, to simplify understanding and assessing the environmental impact of a product system. Two impact categories have been considered in the present study; an energy flow indicator and a GWP indicator. The first, Cumulative Energy Demand (CED) has been used as energy flow indicator that analyses energy use throughout the life cycle of a product, including the energy consumed during the extraction, manufacturing and disposal of the raw and auxiliary materials (Frischknecht et al., 2005, 2007); and the second, GHG emissions has been used as GWP indicator. GHG emissions were calculated based on the IPPC 2013 method for the timeframe of 100 years (IPCC, 2006). Both indicators were calculated with SimaPro 8.5 software (Pre Consultants, 2018).

5. Results

5.1. Carbon dioxide emissions of one cubic meter of desalinated seawater

The analysis found that the equivalent of 4.82 kg of CO_{2eq} could be emitted from the production of 1 m^3 of desalinated water, included distribution process to irrigators community, and the cumulative energy demand (CED) required for the process was 88.62 MJ/m^3, 79.58% of non-renewable sources (Table 3).

Table 3. Impact category by cubic meter of DSW.

Impact category	Unit	Total	Stage		
			Seawater extraction	Treatment and post-treatment	Water distribution
Cumulative Energy Demand	MJ/m^3	87.62	6.08	71.91	9.62
• Non-renewable	MJ/m^3	79.58	5.21	66.13	8.24
• Renewable	MJ/m^3	8.04	0.87	5.79	1.38
GHG emissions	kg CO_{2eq}/m^3	4.82	0.26	4.15	0.41

Fig. 3 showed the dendrogram of the main contributions to GHG emissions per cubic meter of DSW. It should be noted that the main contributor to GHG emissions was treatment and post-treatment stage (Table 3, Fig. 4). By inputs, electricity was the key input contributor to the GHG emissions in DSW process with 58.52% of the total (Fig. 3). In addition, it is of highlight the strong link between energy and emissions in this process, as show in Fig. 5. GHG emissions are directly proportional to CED, that is in agreement with the strong link between energy and GHG emissions. A lineal regression has been calculated to relate GHG emissions and CED in the three stages (Fig. 5), where it can be noticed that GHG emissions increases when CED rises, with a high value of determination coefficient (R^2 = 0.99).

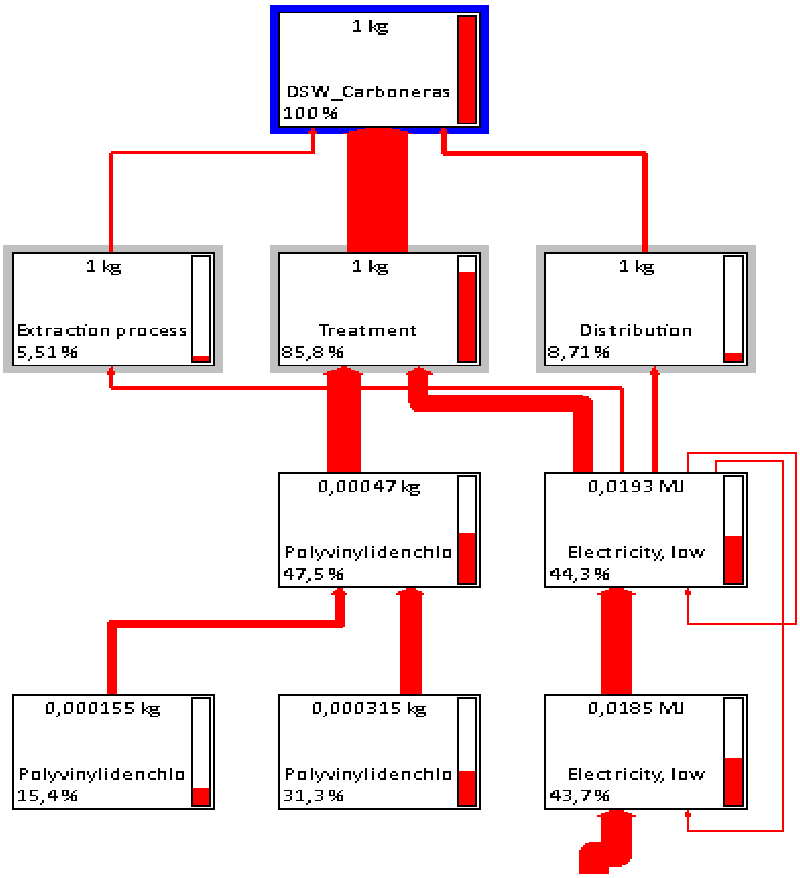


Fig. 3. Dendrogram of the main contributions to GHG emissions per cubic meter of DSW.

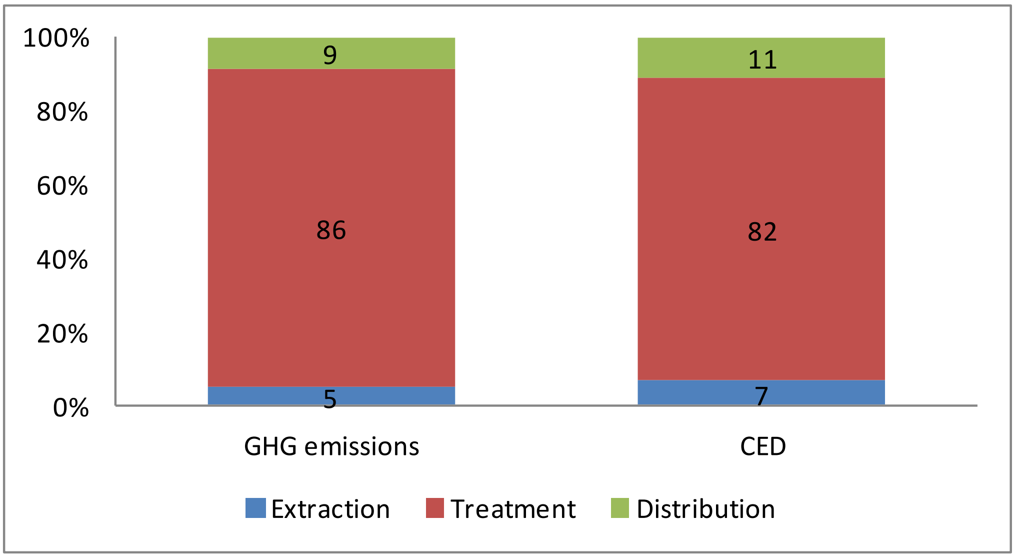


Fig. 4. Relative contribution by stages to GHG emissions and CED by cubic meter of DSW.

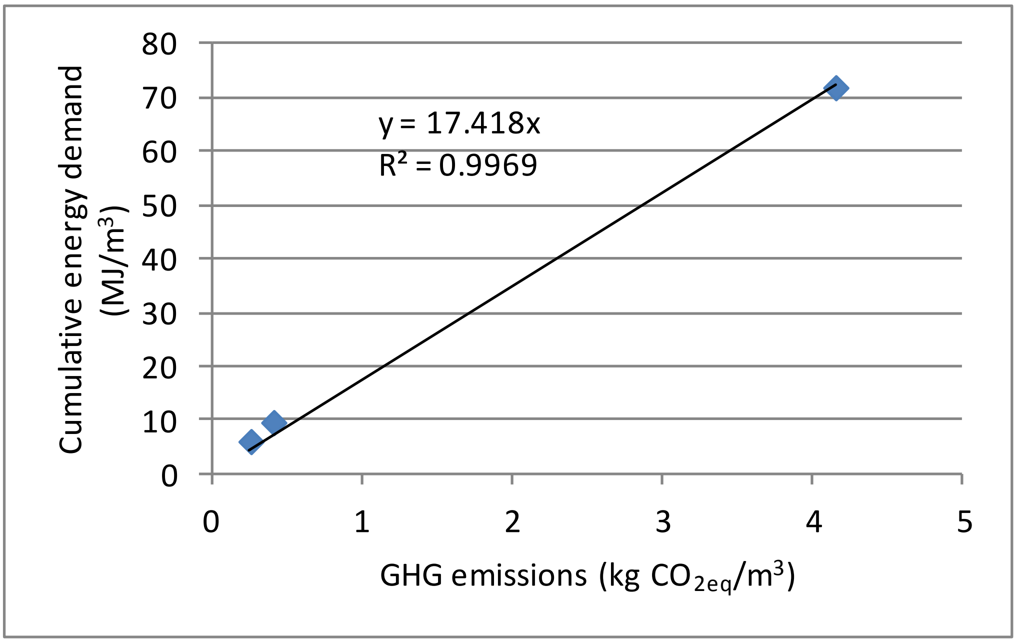


Fig. 5. Relationship between GHG emissions and CED in the three stages.

5.2. Comparison with literature values

Although seawater desalination is one of the most climate resilient water sources, there are concerns over its potentially high environmental impact. LCA provides a comprehensive, ISO standardised method for evaluating such impacts (Muñoz and Fernández-Alba, 2008). Despite this, in certain cases, it is difficult to compare between studies due to the fact that the process stages are different. Stokes and Horvath (2009) reported 3.95 kg CO_{2eq}/m^3 considering construction and operational phase of a SWDP powered by electricity grid in California (USA).

Biswas (2009) assess GHG emissions of a SWDP in Perth, Western Australia, and obtained 3.8 kg CO_{2eq}/m^3 for operation phase (extraction, pre-treatment and reverse osmosis) using Western Australia grid electricity. In this case, the emissions from the production of capital equipment, including building and infrastructures and machinery were not considered. A similar study carried out by Shahabi et al., (2014) compared a SWDP in Perth, Western Australia in three electricity production scenarios i) 100% Western Australia grid electricity, ii) 100% wind energy, and iii) 92% wind energy plus 8% solar PV; and concluded that the infrastructure construction phase of the a SWDP powered by electricity grid is accounted for 2% contribution of the total life cycle GHG emissions, however increased to 15-17% in SWDP powered by renewable energies. The GHG emissions produced with 100% Western Australia grid electricity was 3.77 kg CO_{2eq}/m^3.The value of GHG emissions obtained in our study are higher than the others authors mentioned above. Part of this difference can be due to use the specific electricity grid of each country; because the electricity use in treatment process was 3.5 kWh/m^3 in the study of Shahabi et al., (2014) and 5.1 kWh/m^3 in the study of Stokes and Horvath (2009).

Several of these studies identified the significant role of electricity consumption in the total life cycle impact of SWDPs powered by fossil fuels based electricity grid. Results showed that the high contribution of the GHG emissions from Western Australia grid electricity is associated with coal burning activities in power plants. The electricity uses in the treatment and distribution processes for a SWDP powered by electricity grid is responsible for more than 92% of the GHG emissions contribution in the study of Shahabi et al. (2014), and 90% in the study of Stokes and Horvath (2009).

Other key indicator interesting to compare SWDPs is specific energy consumption (kWh/m^3). Reverse osmosis desalination consumes more energy than the theoretical minimum energy required for desalination. Theoretical minimum energy for desalination as a function of percent recovery for common seawater (35 g/liter salt and a typical recovery of 50%) is 1.06 kWh/m^3(Elimelech and Phillip, 2011). At present, current state-of-the-art SWDPs in operation phase consume between 3.5 and 4.3 kWh/m^3 (Biswas,2009; Martinez-Alvarez et al., 2017; Raluy et al., 2005; Shahabi et al., 2014; Stokes and Horvath, 2009). However, as a result of continual technological improvements, including higher-permeability membranes, installation of energy recovery devices, and the use of more efficient pumps, can be reduce the amount energy consumption rate as low as 1.8 kWh/m^3 (Elimelech and Phillip, 2011).

Regarding the specific energy consumption directly related to produce desalinated water in commercial SWDPs. Martinez-Alvarez et al. (2017) analysed seven large-size coastal SWDPs in the Segura River Basin (south-eastern Spain). In view of the proximity of the coastal areas of Almería and the Segura River Basin, both in the Mediterranean basin, it is interest to compare values of specific energy consumption by cubic meter of DSW. The average value of four SWDP for agricultural use in Segura River Basin was 5.09 kWh/m^3, similar to obtained in Carboneras SWDP (4.98 kWh/m^3). GHG emissions values are not comparables between both studies because the study of Martinez-Alvarez et al. (2017) only analyzed the GHG emissions directly related with electricity grid company, so the value was lower.

6. Strategies to reduce the environmental impact in desalinated seawater

The strategies to reduce GHG emissions associated to DSW are extremely limited in the frame of this project, since the potential of decreasing the environmental impact of desalination involve the energy production model or energy policy by country. In this context, it would be very interesting to analyze the potential of reduction of the environmental loads depending on the origin of the energy consumed by the SWDP. Biswas (2009) showed that life cycle greenhouse gas emissions can be reduced by 68% if electricity is generated from wind turbines to power the reverse osmosis system only. Shahabi et al. (2014) concluded that powering desalination plants with renewable energy instead of the fossil based grid electricity will be reduces 90% the GHG emissions.

The EU 2030 Framework for Climate and Energy also sets a further binding target that at least 27% of the energy used in the EU by 2030 should be renewable (EC, 2018). In Spain, by the end of 2015 a level of 15.6% of all its energy needs came from renewable energy sources (EEA, 2018) and the contribution from renewable energy to the electric generation mix already reached 38.9% in 2016 (IDAE, 2017). It should be necessary a hypothetical "green" mix of energy sources to reduce the overall environmental impact of DSW in Spain. According Galbete (2013) could be that in Spain 100% of electricity generation achieved with renewable energy towards the year 2050.

7. Conclusions

The carbon dioxide emission of Carboneras seawater desalination plant (SWDP) has been analyzed in this deliverable. Life Cycle Assessment (LCA) approach has been used in this study. Cumulative Energy Demand (CED) and Green House Gas (GHG) emissions has been used as indicators of climate change impact of Carboneras SWDP.

The GHG emissions calculated for the production of 1 m^3 of desalinated water were 4.82 kg of CO_{2eq} including distribution process to irrigators community. The CED required for the process was 88.62 MJ/m^3. The most relevant processes for the production of desalinated water was treatment stage (86%), being the electricity the key input contributor to the GHG emissions (58.52%).

The value of GHG emissions obtained in Carboneras SWDP is higher compared to other SWDPs. Part of this difference can be due to the use of the specific electricity grid of Spain, because the specific energy consumption directly related to produce desalinated water was similar to obtained in others commercial SWDPs for agricultural use in Segura River Basin.

The strategies to reduce GHG emissions associated to DSW are extremely limited in the frame of this project, since the potential of decreasing the environmental impact of desalination involve to change the model of energy policy in Spain.

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