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D8.3 Impact and opportunities of GeoHex beyond Geothermal

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CONTENTS

EXECUTIVE SUMMARY 4

OBJECTIVES MET 4

1. INTRODUCTION 5

1.1 CONCENTRATED SOLAR PLANT (CSP) COUPLED WITH ORGANIC RANKINE CYCLE (ORC) (CSP-ORC) 5

2. METHODS 6

3. RESULTS AND DISCUSSION 6

3.1 COST AND ENVIRONMENTAL PERFORMANCES 7

3.2 ECONOMIC IMPACT OF THE GEOHEX ENABLED HXS IN THE 630 KW REFERENCE CSP PLANT 8

3.3 ENVIRONMENTAL IMPACTS OF THE GEOHEX ENABLED HXS 9

4. CONCLUSIONS 11

REFERENCES 12

Executive Summary

The impact of GeoHex materials in heat exchangers (HXs) adopted for Concentrated Solar Power (CSP) plant is analysed in this report. A specific scenario taken from current literature was used as a reference point to conduct this study. The impact analysis encompasses economic, environmental and heat transfer performance of the GeoHex-enabled and standard HXs.

It has been demonstrated that the cost savings made byadopting the GeoHex-enabled tubular types of evaporator, condenser and preheater instead of using standard heat exchangers in 630 kW reference CSP plant are about € 16,920, - € 103,800 and € 19,600 respectively. Carbon footprint savings of about 6,120, -3000 and 20,000 kg CO_2 eq for adopting GeoHex-enabled HX components were achieved compared with standard HXs in 630 kW reference CSP plant. The adverse outcomes of the GeoHex-enabled condenser were primarily due to two key factors. These factors include the limited improvement in the heat transfer coefficient within the GeoHex-enabled condenser and the costs and resource utilisation required for coating deposition on a laboratory scale.

Objectives Met

The deliverable contributed towards the work package WP8 objective:

- To assess the impact of GeoHex-enabled heat exchanger in terms of CO2 saving, cost saving, and efficiency enhancement for the application in different geothermal power technologies for different temperatures, enthalpy, scaling and corrosion potential of geofluid; b) To assess the same impact for the application in conventional power technologies, renewable power technologies, waste heat recovery etc.

1. INTRODUCTION

GeoHex's primary objective revolves around developing advanced coating materials tailored for geothermal-based heat exchangers (HXs). These materials are designed to facilitate higher heat transfer rates, mitigate corrosion, fouling, and scaling issues, and optimise the heat transfer surfaces' performances, which are vital for efficient boiling and condensation processes, ultimately resulting in enhanced heat transfer performances in HXs. HXs are versatile in various industrial applications, serving as crucial components in heating and cooling processes within large-scale industrial fluid systems.

This report goes beyond the scope of the geothermal industry to evaluate the broader impacts of GeoHex materials. As indicated in the report's title, besides assessing the implications, there's an apparent focus on exploring potential opportunities for adopting GeoHex materials outside the geothermal power plant industry. The deliverable report D1.7 has comprehensively delved into the possibilities and prospects of integrating innovative GeoHex materials into HXs in diverse applications beyond geothermal, including concentrated solar plants (CSP), waste heat recovery systems (WHR), etc.

In this report, we investigate the impacts of GeoHex materials on Concentrated Solar Power (CSP) plants, with a particular focus on a CSP coupled with ORC (CSP-ORC) setup. It aims to analyse the impacts of cost and environmental performances of GeoHex-enabled HXs adopted in the CSP-ORC plant instead of standard HXs.

1.1 Concentrated Solar Plant (CSP) coupled with Organic Rankine Cycle (ORC) (CSP-ORC)

CSP technologies utilise mirrors to reflect and concentrate sunlight onto a receiver. The concentrated sunlight's energy heats a high-temperature fluid in the receiver. This heat, also known as thermal energy, can be used to spin a turbine or power an engine, producing electricity. It can also be utilised in industrial applications such as water desalination, improved oil recovery, food processing, chemical production, and mineral processing [1].

Water emerges as the ideal working fluid of choice in large-scale power plants operating at high temperatures (greater than 370 °C). Nevertheless, when it comes to harnessing energy from low-temperature sources or generating lower power outputs, using steam becomes an inefficient and unprofitable approach due to its thermodynamic properties. Conversely, ORC power plants, which employ organic working fluids with lower boiling points, offer a more efficient and economically appealing solution for power generation from low-temperature sources. Using a highly efficient thermodynamic cycle, ORC converts the thermal energy received from the solar panel receiver into electricity. As such, ORC power systems for low-grade solar heat energy are the most suitable choice for converting solar thermal energy into electricity on a distributed scale with power outputs ranging from a few kW to MW range [2].

In this report, we have considered the CSP-ORC plant to assess the impact of GeoHex material on the heat exchangers of the ORC system, which has a plant capacity of 630 kW [3]. In this 630 kW CSP-ORC plant, the solar heat is produced by Linear Fresnel Collectors (LFC). Linear Fresnel Solar Collector produces solar heat energy by concentrating solar energy with mirrors that track the sun. This heat energy is concentrated in a receiver, an isolated vacuum tube absorber – where the heat transfer fluids, such as steam, hot oil or hot air, are produced after the solar thermal energy is absorbed. The heat transfer fluid then transfers the solar heat to the working fluid in the ORC.

The heat exchanger's surface areas of the evaporator, condenser and preheater were unavailable in the reference [3]; hence, these heat exchanged surface areas were obtained from the representative plant of 1 MW capacity [4].

The GeoHex materials applications areas in the CSP-ORC plant are evaporator, condenser and preheater which are shell and tube type heat exchangers; therefore, the results of GeoHex-enabled tubular type will be used to evaluate the impacts of GeoHex materials in this 630 kW CSP plant coupled with ORC.

The GeoHex-enabled HXs were developed using the best-ranked coating materials. The best coating materials were selected using the results of heat transfer coefficients and mechanical & and tribological properties through the ranking methodology described in detail in the deliverable report D5.5. Table 1 provides an overview of the selected top coatings, their corresponding substrates, application area of HXs and their technology options. The GeoHex mini-ORC plant with an installed capacity of 10 kW was then built at CEA facilities, with GeoHex-enabled and standard HXs for testing the heat transfer coefficients and other performances of these HXs.

Table 1 - Best performance coating materials selected through ranking for GeoHex-enabled HXs.

Application area	Technology options	Substrate materials	Coating materials	
			ORC side	Brine side
Evaporator	Plate	SS	Fe-doped Al2O3–TiO2 composite coatings -	None
	Tubular	CS	Fe-doped Al2O3–TiO2 composite coatings -	None
Condenser	Plate	SS	Superhydrophobic, superoleophobic surface with CuO nanostructures	None
	Tubular	CS	Superhydrophobic, superoleophobic surface with CuO nanostructures	None
Preheater	Plate	SS	None	Amorphous
	Tubular	CS	None	Ni-P/Ni-P-PTFE

2. METHODS

The standard and GeoHex-enabled HXs' cost and environmental performances, along with the heat transfer coefficient results, are considered to analyse the impacts of GeoHex materials in the CSP coupled with ORC of capacity 630 kW [3]. The results of cost and environmental impacts for the GeoHex-enabled and standard HXs per m^2 heat exchanged surface area have been reported in the deliverables D7.7 and D7.8, respectively. These results have been used to evaluate the impacts of GeoHex-enabled HXs instead of standard HXs employed in the reference CSP plant. In addition, the heat transfer coefficients for the GeoHex-enabled and standard HXs have been obtained from the performance evaluation of a 10 kW$_e$ electricity-generating mini ORC plant at CEA facilities. The heat transfer performance results for the standard and GeoHex-enabled HXs are reported in the deliverables D7.5 and D7.6, respectively. A model has been developed to evaluate the impacts of GeoHex materials on the CSP-ORC plant. Since the heat exchangers used in the 630 kW reference CSP plants are shell and tube types, the heat transfer performance results of tubular types HXs are used to analyse the economic and environmental impacts of GeoHex-enabled tubular types HXs in the 630 CSP plant.

3. RESULTS AND DISCUSSION

The cost and environmental impact of GeoHex-enabled HXs instead of using standard HXs employed in the reference CSP power plant coupled to an ORC of an installed capacity of 630 kW have been discussed. The GeoHex-enabled and standard preheaters, evaporators and condensers have been employed in a mini ORC binary power plant for obtaining the heat transfer coefficients' results of those HXs (D7.5 and D7.6). The costs, carbon and environmental footprints results of those HXs have been determined per m^2 heat exchanged surface area (D7.7 and D7.8). The main findings of the deliverables D7.5, D7.6, D7.7 and D7.8 are summarised and given in subsection 3.1. The results of cost and environmental impacts for adopting GeoHex-enabled HXs instead of using the respective standard HXs in 630 kW reference CSP plant have been evaluated and presented in subsections 3.2 and 3.3, respectively.

3.1 Cost and Environmental Performances

In the deliverable report D7.7, a cost model was developed to estimate the total cost (CAPEX) associated with standard and GeoHex-enabled HXs per m² heat exchanged surface area. The model considered the inverse relationship between the heat exchanger's surface area and its heat transfer coefficient, indicating that an improvement in the heat transfer performances of GeoHex-enabled HXs would result in a reduced surface area requirement and subsequently lower the reference CSP plant costs. The heat transfer coefficient (HTC) results for standard and GeoHex-enabled HXs were reported in the deliverables D7.5 and D7.6. Table 2 presents the estimated CAPEX of standard and GeoHex-enabled HXs and the cost reduction or increase of GeoHex-enabled HXs due to changes in the heat transfer coefficients. In the last two columns of Table 2, the cost impacts for adopting GeoHex-enabled HXs have been evaluated in terms of € / m^2 and the percentage savings as compared with the respective standard HXs. The costs and heat transfer performances data in Table 2 are sourced from D7.7, D7.5, and D7.6.

Table 2 – Cost performances of plate and tubular types GeoHex enabled and standard evaporators, condensers, and preheaters

Application area	Technology options	Stanadard HX Costs	GeoHex enabled HX costs		HTC enhancement or degradation in GeoHex enabled HX as compared with Standard HX	Evaluated GeoHex enabled HX costs considering HTC performances	Cost benefits due to adoption of GeoHex enabled HXs instead of using Standard HXs	
			Coating Deposition	Total				
		(€/m^2)	(€/m^2)	(€/m^2)	(%)	(€/m^2)	(€/m^2)	(%)
Evaporator	Plate	561	73	634	53.8	412	148.8	+26.5
	Tubular	780	73	853	24.2	686	93.4	+12.0
Condenser	Plate	516	193	709	3.5	685	-169.0	-24.7
	Tubular	844	193	1037	2.0	1017	-173.1	-17.0
Preheater	Plate	1863	356	2219	-3.6	2301	-438.2	-23.5
	Tubular	1064	120	1184	16.7	1015	49.0	+4.6

The carbon and the overall environmental footprint results of 6 GeoHex enabled and 6 standard HXs have been gathered from the deliverable D7.8 and are listed in Tables 3 and 4, respectively. The carbon footprint savings and the overall environmental footprint savings for adopting GeoHex-enabled HXs instead of standard HXs have been calculated and listed in last two columns of Tables 3 and 4, respectively.

Table 3 - Carbon footprint results of plate and tubular types of 6 GeoHex enabled and 6 standards HXs

Technology options	HX types	HTC enhancement in GeoHex enabled HXs	Carbon footprint (kg CO2 eq /m^2)		Carbon footprint savings	
			GeoHex enabled HXs	Standard HXs	(kg CO2 eq / m^2)	(%)
Plate	Preheater	-3.6	182	166	-16	-9.6
	Evaporator	53.8	66.0	70.6	4.6	+6.5
	Condenser	3.5	77.0	71.5	-5.5	-7.7

Tubular	Preheater	16.7	320	370	50	+13.5
	Evaporator	24.2	245	279	34	+12.2
	Condenser	2.0	304	299	-5.0	-1.7

Table 4 - Overall environmental footprint results of plate and tubular types of 6 GeoHex enabled and 6 standard HXs

Technology options	**HX types**	**HTC enhancement in GeoHex enabled HXs**	**Environmental footprint (mPt/m^2)**		**Environmental footprint savings**	
			GeoHex enabled HXs	**Standard HXs**	**(mPt / m^2)**	**(%)**
Plate	Preheater	-3.6	105.00	96.97	-8.03	-8.3
	Evaporator	53.8	33.38	44.41	11.03	+24.8
	Condenser	3.5	46.38	46.58	0.20	+0.4
Tubular	Preheater	16.7	140.24	162.29	22.05	+13.6
	Evaporator	24.2	107.26	124.54	17.28	+13.9
	Condenser	2.0	134.90	133.12	-1.78	-1.3

3.2 Economic Impact of the GeoHex enabled HXs in the 630 kW reference CSP plant

The cost impacts of GeoHex materials developed for the preheater, evaporator, and condenser have been evaluated using the reference CSP plant coupled to ORC [3] of 630 kW installed capacity. Since the reference plant's HXs are shell and tubular types, the cost impacts of tubular type GeoHex enabled HXs are considered and analysed with respect to respective tubular standard HXs. Table 5 shows the cost calculations and cost savings in € and € per MW for adopting GeoHex materials in the reference plant's preheater, evaporator and condenser (HXs).

Table 5 - Cost Impacts of GeoHex enabled evaporator, condenser and preheater adopted in 630 kW CSP- ORC plant.

Items	**Unit**	**Evaporator**	**Condenser**	**Preheater**
Total heat exchanged surface area of tubular type HXs in 630 kW plant	m^2	180	600	400
Estimated costs of standard tubular type HXs	€/m^2	780	844	1,064
Evaluated costs of GeoHex enabled tubular types HXs	€/m^2	686	1,017	1,015
Total costs of standard tubular type HXs installed in 630 kW plant	€	140,400	506,400	425,600
Total costs of GeoHex enabled tubular type HXs installed in 630 kW plant	€	123,480	610,200	406,000
Cost savings for adopting GeoHex enabled tubular type HXs instead of using respective standard HXs	€	16,920	-103,800	19,600
	(%)	12	-17	5
	(€/MW)	26,857	-164,762	31,111

It is evident from Table 5 that the reference plant owner could save about € 16,920 or € 26,857 per MW on tubular-type evaporator costs for adopting GeoHex enabled instead of standard evaporators in the 630 kW CSP plant. However, the cost of tubular type condenser increased by about 17% for adopting GeoHex enabled instead of the standard tubular type of condenser in the 630 kW CSP power plant. For the preheater, the reference plant owner could save € 19,600 or € 31,111 per MW on tubular type preheater cost for adopting an GeoHex enabled preheater instead of the standard preheater in the 630 kW CSP plant. The cost savings for adopting a tubular-type GeoHex-enabled evaporator, condenser, and preheater in place of respective standard HXs are shown in Figure 1.

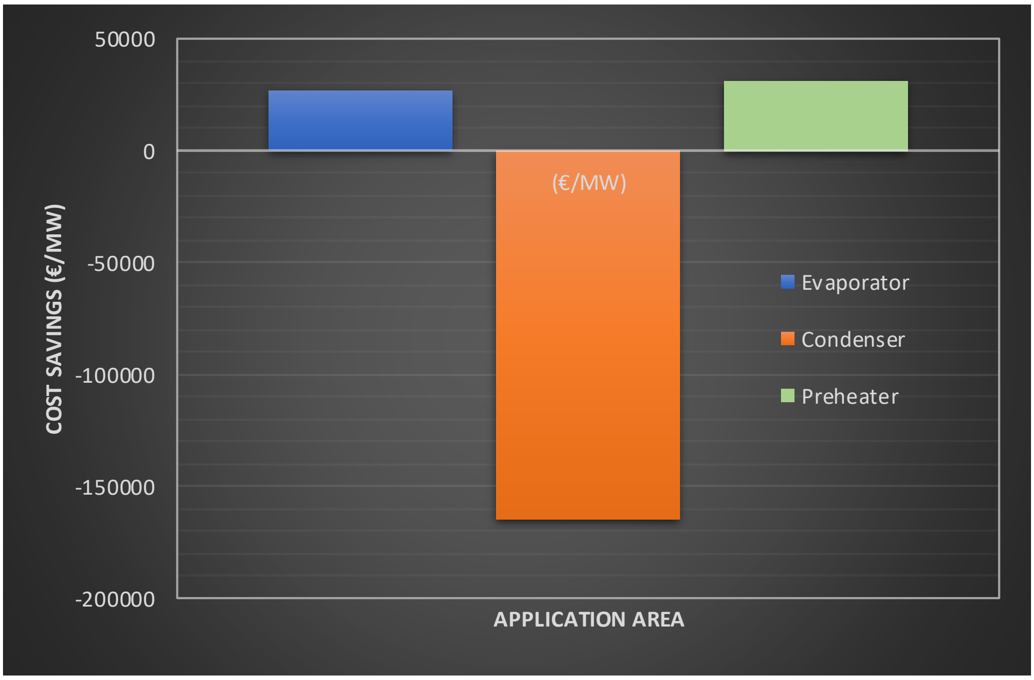

Figure 1 - Cost savings (€/MW) for adopting GeoHex-enabled HXs in place of standard HXs in 630 kW CSP-ORC plant.

3.3 Environmental Impacts of the GeoHex enabled HXs

The carbon and overall environmental footprint results of 3 GeoHex enabled and 3 standard tubular types HXs (preheater, condenser, and evaporator) adopted in 630 kW CSP-ORC have been calculated and analysed using the evaluated data per m^2 heat exchanged surface area given in Tables 3 and 4 and listed in Table 6.

Table 6 – Carbon and overall environmental footprint results of 3 GeoHex enabled and 3 standards tubular HXs adopted in 630 kW CSP.

Items	Units	Evaporator	Condenser	Preheater
Total heat exchanged surface area	(m^2)	180	600	400
Total carbon footprint of standard HXs	(kg CO_2 eq)	50,220	17,9400	14,8000
Total carbon footprint of GeoHex enabled HXs	(kg CO_2 eq)	44,100	182,400	128,000
Total environmental footprint of standard HXs	(mPt)	22,417	79,872	64,916
Total environmental footprint of GeoHex enabled HXs	(mPt)	19,307	80,940	56,096
Carbon footprint savings	(kg CO_2 eq)	6,120	-3,000	20,000
	(kg CO_2 eq / MW)	408	-200	1333

Environmental footprint savings	(mPt)	3,110	-1,068	8,820
	(mPt / MW)	207	-71	588

It is seen from Table 6 that the plant owner could save total carbon footprints of about 6,120 and 20,000 kg CO_2 eq due to the adoption of GeoHex enabled evaporator and preheater in place of respective standard HXs, respectively, in 630 kW CSP-ORC plant. However, using a GeoHex-enabled condenser will increase the carbon footprint by about 3,000 kg CO_2 eq. The total carbon footprint savings in units of kg CO_2 eq per MW for adopting GeoHex-enabled tubular preheater, evaporator and condenser instead of respective standard HXs are plotted in Figure 2.

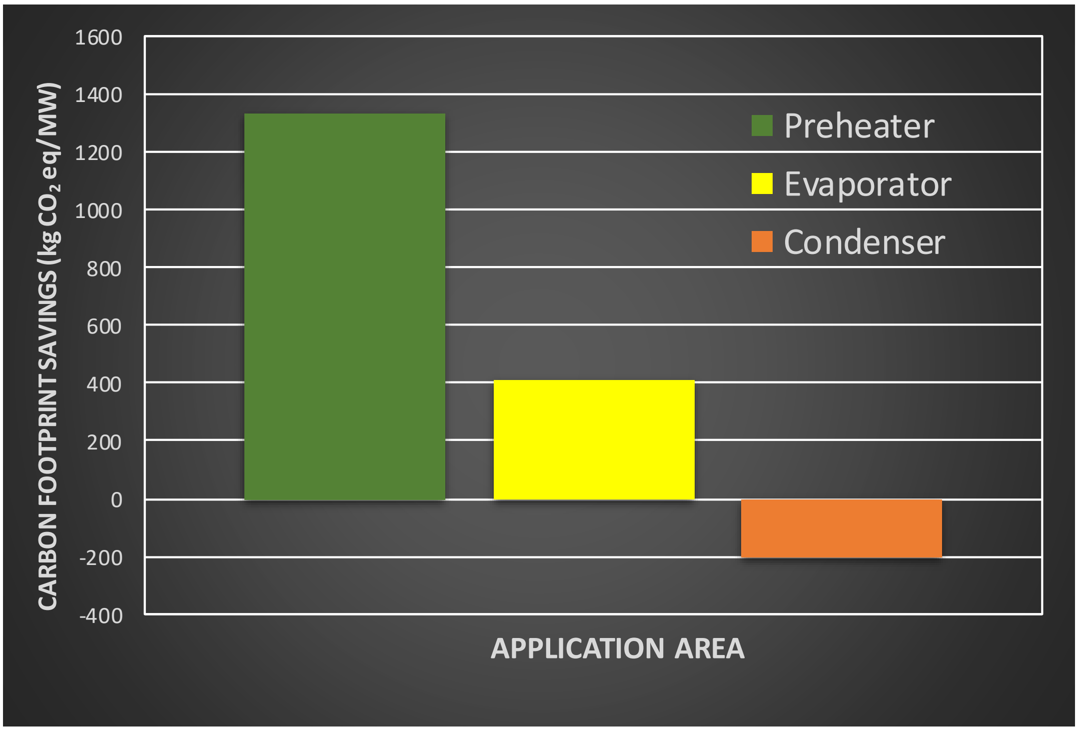

Figure 2 - Carbon footprint savings (kg CO_2 eq / MW) for adopting GeoHex-enabled tubular HXs compared to respective standard HXs in a CSP of 630 kW.

The quantified scores of 4 endpoint damage categories (carbon footprint, human health footprint, ecosystem quality footprint, and resources footprint) for the HXs in their respective units have been converted to a common scale of measurements, termed as 'single score' in units of eco-point (Pt). The overall environmental footprint is the sum of all four footprints in a common unit of Pt. The overall environmental footprint results of GeoHex-enabled HXs adopted in the 630 kW CSP are given in Table 6. The overall environmental footprint savings in units of mPt / MW for adopting GeoHex-enabled tubular HXs instead of using respective standard HXs have been calculated, and the results are plotted in Figure 3.

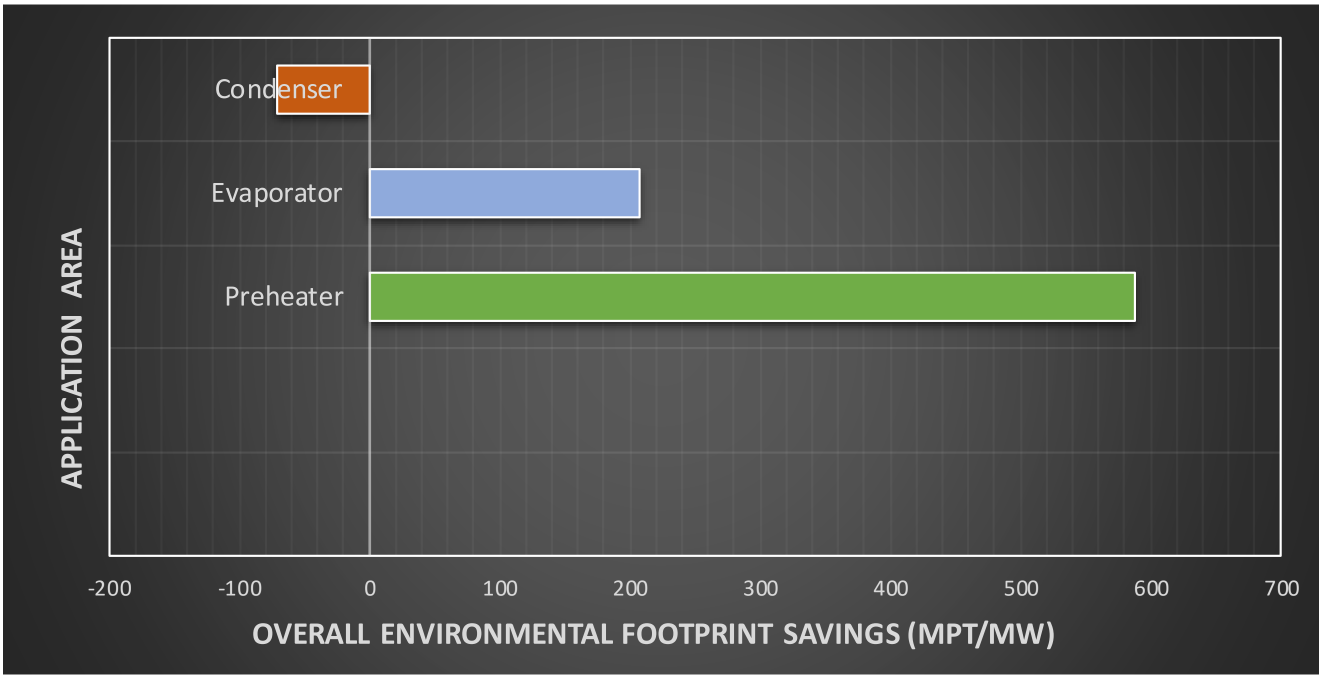

Figure 3 - Overall environmental footprint savings (mPt / MW) for adopting GeoHex-enabled tubular HXs compared with standard HXs in a 630 kW CSP.

Through literature searches, no plant data were available for the CSP plant that uses plate & gasket type HXs; therefore, this study did not analyse the impact of GeoHex materials on the plants that use plate & gasket type HXs.

4. CONCLUSIONS

This study analysed the cost and environmental impact of adopting a GeoHex-enabled preheater, evaporator and condenser instead of standard HXs in a 630 kW CSP plant. The principal findings from this analysis are that :

- Adoption of a GeoHex-enabled tubular evaporator and preheater instead of using the standard evaporator and preheater in a 630 kW CSP-ORC plant, would save about € 26,857 and € 31,111 per MW of the installed capacity of the plant.
- The cost savings for adopting GeoHex-enabled tubular types of evaporator, condenser and preheater instead of standard HXs in 630 kW CSP plant are about 12%, -17% and 5%, respectively.
- Carbon footprint savings of about 408 and 1,333 kg CO_2 eq per MW installed capacity of the plant for adopting GeoHex enabled tubular evaporator and preheater in place of the respective standard HXs in a 630 kW CSP plant, respectively.
- The overall environmental footprint savings of about 207, -71 and 588 mPt per MW installed capacity of the plant for adopting GeoHex-enabled tubular evaporator, condenser, and preheater, respectively, as compared with respective standard HXs in 630 kW CSP plant.

It is noted that the heat exchanger areas for the CSP-ORC plant under consideration [3] were unavailable. As a result, they were obtained from a 1 MW representative binary power plant [4]. Therefore, the estimations of the GeoHex materials' impact on the 630 kW CSP-ORC plant are approximations.

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