Project acronym:	**GeoHex**
Project title:	Advanced material for cost-efficient and enhanced heat exchange performance for geothermal application
Activity:	LC-CS3-RES-1-2019-2020 Developing the next generation of renewable energy technologies
Call:	H2020-LC-CS3-2019-RES-TwoStages
Funding Scheme:	RIA | **Grant Agreement No:** | 851917
WP8	**Impact assessment and compliance recommendation**

D8.2 Impact and opportunities of GeoHex on binary cycle

Due date:	31/10/2023	
Actual Submission Date:	30/10/2023	
Lead Beneficiary:	TVS	
Main authors/contributors:	Mahfuza Ahmed, M A Hye Chowdhury	
Dissemination Level[1]:	PU	
Nature:	Report	
Status of this version:		**Draft under Development**
		For Review by Coordinator
	X	**Submitted**
Version:	V3	
Abstract	The deliverable reports on the impact analysis of GeoHex materials on the binary geothermal power plant.	

REVISION HISTORY

Version	Date	Main Authors/Contributors	Description of changes
1	15/09/2023	Mahfuza Ahmed	First draft created
2	17/10/2023	M A H Chowdhury	Reviewed the whole document
3	24/10/2023	Mahfuza Ahmed	Revised the whole document and edited to the final version

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement No. 851917

[1] Dissemination level security:

PU – Public (e.g. on website, for publication etc.) / **PP** – Restricted to other programme participants (incl. Commission services) /

RE – Restricted to a group specified by the consortium (incl. Commission services) / **CO** – confidential, only for members of the consortium (incl. Commission services)

This project has received funding from the European Union's Horizon 2020 program Grant Agreement No 851917. This publication reflects the views only of the author(s), and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Document: D8.2 Impact and opportunities of GeoHex on binary cycle

Version: V3

Date: 30 October 2023

CONTENTS

EXECUTIVE SUMMARY 4

OBJECTIVES MET 4

1. INTRODUCTION 5

1.1 BINARY POWER PLANT AND THE 6

2. METHODS 7

3. RESULTS AND DISCUSSION 7

3.1 COST AND ENVIRONMENTAL PERFORMANCES 7

3.2 ECONOMIC IMPACT OF THE GEOHEX ENABLED HXS IN THE 15 MW_E REFERENCE PLANT 9

3.3 ENVIRONMENTAL IMPACTS OF THE GEOHEX ENABLED HXS 10

4. CONCLUSIONS 12

REFERENCES 13

Executive Summary

The impact analysis of GeoHex materials on the binary geothermal power plant is reported in this study. A specific scenario extracted from the literature was employed as a reference point to conduct this study. The impact analysis encompassed economic, environmental, and heat transfer performances of the GeoHex-enabled and standard heat exchangers. It is demonstrated that the cost savings for adopting GeoHex-enabled tubular types of evaporator, condenser and preheater instead of using respective standard heat exchangers in 15 MW reference binary geothermal power plant are about 12%, -17% and 5%, respectively. It is evaluated that the overall environmental footprint savings of about 13.9%, -1.3% and 13.6% for adopting GeoHex-enabled tubular evaporator, condenser, and preheater, respectively, compared with respective standard HXs. GeoHex enabled tubular type evaporator adopted in the reference plant has demonstrated a notably favourable enhancement in heat transfer performance and improving overall environmental footprint. Incorporating GeoHex technology in the reference plant's preheater has yielded a reduced environmental footprint; nevertheless, the enhancement in heat transfer performance does not appear to improve significantly. The key factors that led to the adverse outcomes with the GeoHex-enabled condenser includes the limited enhancement of the heat transfer coefficient and the significant costs and resource consumption associated with coating deposition at 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 CO_2 saving, cost saving, and efficiency enhancement for the application in different geothermal power technologies for different temperatures, enthalpy, scaling and corrosion potential of geofluid.

1. INTRODUCTION

GeoHex has innovated advanced heat exchanger (HX) materials tailored for geothermal applications, where heat exchangers play a pivotal role, particularly in ORC-based power plants. GeoHex's high-performance heat exchangers, equipped with anti-scaling, anti-fouling, and anti-corrosion properties, promise a substantial enhancement in geothermal plant performance by enabling a reduction in reinjection temperatures. This breakthrough also opens new avenues for power plant technology designers to elevate the overall thermal efficiency of these facilities.

This report outlines the potential impact of GeoHex materials in the Geothermal Binary power plant.

As mentioned in this report's title, in addition to assessing the impacts, there is also a requirement to investigate the potential opportunities associated with utilising GeoHex material within the binary geothermal power plant. Deliverable D1.7 thoroughly explored the possibilities and opportunities of implementing innovative GeoHex materials within the HXs for the binary geothermal power plant. Therefore, this report investigates how these materials can impact binary geothermal power plants' overall cost and environmental performances without iterating the possibilities and opportunities for adopting these innovative GeoHex materials.

As outlined in the Grant Agreement, it was suggested to analyse the impact of GeoHex materials considering a use case scenario, e.g., a Turkish binary power plant. Since the Turkish plant owner/operator is not a member of the GeoHex project's consortium, the necessary data on its HXs and plant was not obtainable. Nonetheless, the report completed the GeoHex materials impact analysis using the reference heat exchangers in the geothermal binary power plant [1].

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 details 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 Al_2O_3–TiO_2 composite coatings	None
	Tubular	CS	Fe-doped Al_2O_3–TiO_2 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	Nano porous	Amorphous metal

	Tubular	CS	Nanoporous	Composite Ni-P/Ni-P-PTFE duplex-HPHP

1.1 Binary Power plant

In the last few decades, the binary power cycle, utilising the Organic Rankine Cycle (ORC), has become a preferred means for exploiting low to moderate enthalpy geothermal resources. Over the years, the basic ORC has been improved and modified better to adapt the cycle to various heat source conditions. The name 'binary' derives from the fact that two fluids are used in the power cycle. The primary fluid is the geofluid (brine) and the secondary fluid is the organic working or power fluid. The primary cycle starts at the production wells and ends in the reinjection wells. The reservoir's field properties in the primary cycle determine the geothermal fluid's temperature and desired flow rates. The geothermal fluid can be either water or steam. When the geothermal fluid is water or brine, it is kept at a pressure above its flash point at fluid temperature along the primary cycle to avoid the flash of geothermal fluid in the HXs. At the end of the primary cycle, the geothermal fluid temperature cannot drop to the silica scaling point. The working fluid, chosen for its appropriate thermodynamic properties, receives heat from the geofluid, evaporates and produces mechanical work in the turbine while expanding. The fluid is then discharged to the condenser, where condensing heat is transferred to a cooling medium, either water or air. The liquid condensate is then pumped at elevated pressure into the evaporator, completing the cycle.

The main components of a basic geothermal binary cycle power plant are the preheater, evaporator, turbine, condenser and working fluid pump. The block diagram of a basic binary power plant with the main components is shown in Figure 1. The fundamental thermodynamic process of binary cycles is the Rankine cycle, where the vapour reaches a dry saturated condition in the evaporator and is condensed in the condenser. Some of the benefits derived from a binary cycle system include using a lower-temperature resource and a closed loop such that the geofluid is not lost and all geofluid is injected back into the ground. Therefore, the geothermal fluid used to run binary plants does not come into direct contact with the turbine or the condenser; it is generally only sent through HXs and then reinjected to the reinjection well.

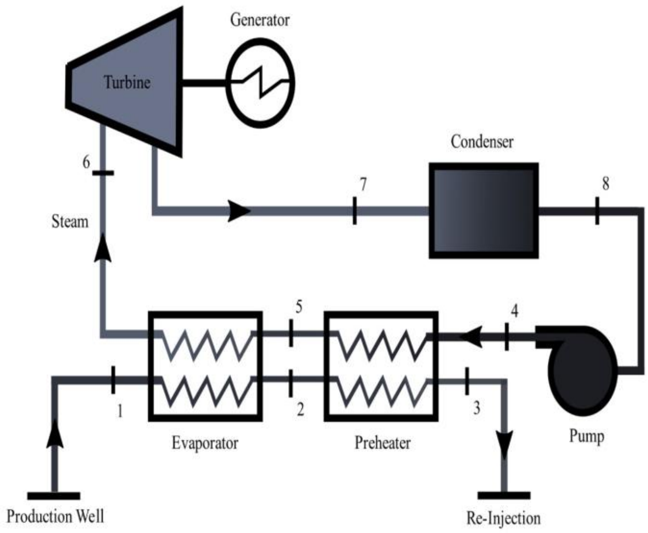

Figure 1 - A schematic diagram of a basic binary power cycle [2]

The cost and environmental impacts of HXs with and without the adoption of GeoHex materials employed in a reference binary geothermal power plant [1] have been analysed. In this analysis, the heat transfer performances of GeoHex-enabled (with adoption of GeoHex materials) and standard (without adoption of GeoHex materials) preheaters, evaporators, and condensers have been considered for calculating the costs and resource consumption of those HXs. The heat transfer performances of those HXs have been measured using the mini ORC plant at CEA facilities of installed capacity 10 kW where GeoHex enabled and standard HXs were employed.

A model has been developed to evaluate the cost and environmental impacts of GeoHex-enabled and standard HXs employed in the reference binary geothermal power plant with an installed capacity of 15 MW_e.

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 reference binary geothermal power plant [1]. 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 using standard HXs employed in the reference binary geothermal power 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. To analyse the impacts of GeoHex materials a model has been developed to evaluate the impacts of GeoHex materials on the binary cycle geothermal power plant. Since the heat exchangers in the 15 MW_e reference binary power plants are shell and tube type, the heat transfer performance results of GeoHex-enabled tubular types are used to analyse the economic and environmental impact of GeoHex materials in the 15 MW_e binary power plant.

3. RESULTS AND DISCUSSION

The cost and environmental impacts of GeoHex materials on the HXs employed in the reference binary geothermal power plant of an installed capacity of 15 MW_e 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 footprint 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 GeroHex-enabled HXs instead of using the respective standard HXs in 15 MW_e reference binary plant is evaluated and presented in subsections 3.2 and 3.3, respectively.

3.1 Cost and Environmental Performances

In report D7.7, a cost model was developed to estimate the total cost (CAPEX) associated with standard and GeoHex-enabled HXs per m² heat exchanger 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 performance of GeoHex-enabled heat exchangers would result in a reduced surface area requirement and subsequently lower the geothermal binary power 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 costs of standard and GeoHex-enabled heat exchangers 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 of adopting GeoHex-enabled HXs have been evaluated in terms of € / m^2 and the percentage savings compared with the respective standard HXs. The cost and heat transfer performance 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	Standard 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 the adoption of GeoHex-enabled HXs instead of using Standard HXs	
			Coating Deposition	Total				
		(€/m²)	(€/m²)	(€/m²)	(%)	(€)	(€/m²)	(%)
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 and the overall environmental footprint savings for adopting GeoHex-enabled HXs instead of standard HXs have been calculated and listed in Tables 3 and 4, respectively.

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

Technology options	HX types	HTC enhancement in GeoHex enabled HXs	Carbon footprint (kg CO2 eq /m²)		Carbon footprint savings	
			GeoHex enabled HXs	Standard HXs	(kg CO2 eq / m²)	(%)
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 6 GeoHex enabled and 6 standard HXs

Technology options	HX types	HTC enhancement in GeoHex enabled HXs	Environmental footprint (mPt /m²)		Environmental footprint savings	
			GeoHex enabled HXs	Standard HXs	(mPt / m²)	(%)
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 15 MW_e reference plant

The cost impacts of GeoHex materials developed for the preheater, evaporator, and condenser have been evaluated using the reference binary power plant [1] of 15 MW_e installed capacity. Since the reference plant's HXs are shell and tubular types, the cost impacts of tubular type GeoHex enabled HXs are 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 in 15 MW_e binary geothermal power plant.

Items	Unit	Evaporator	Condenser	Preheater
Total heat exchanged surface area of tubular type HXs in 15 MW plant	m^2	6,200	73,575	1,681
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 15 MW plant	€	4,836,000	62,097,300	1,788,584
Total costs of GeoHex enabled tubular type HXs installed in 15 MW plant	€	4,253,200	74,825,775	1,706,215
Cost savings for adopting GeoHex enabled tubular type HXs instead of using respective standard HXs	€	582,800	-12,728,475	82,369
	(%)	12	-17	5
	(€/MW)	38,853	-848,565	5,491

It is evident from Table 5 that the reference plant owner could save about **€ 582,800** or **€ 38,853 per MW** on tubular-type evaporator costs for adopting GeoHex enabled instead of standard evaporators in the 15 MW binary 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 15 MW plant. For the preheater, the reference plant owner could save **€ 82,369 or € 5,491 per MW** on tubular type preheater cost for adopting GeoHex enabled instead of the standard preheater in the 15 MW binary plant. The cost savings in percentages for adopting tubular-type GeoHex-enabled evaporator, condenser and preheater in place of respective standard HXs are shown in the bar chart in Figure 2.

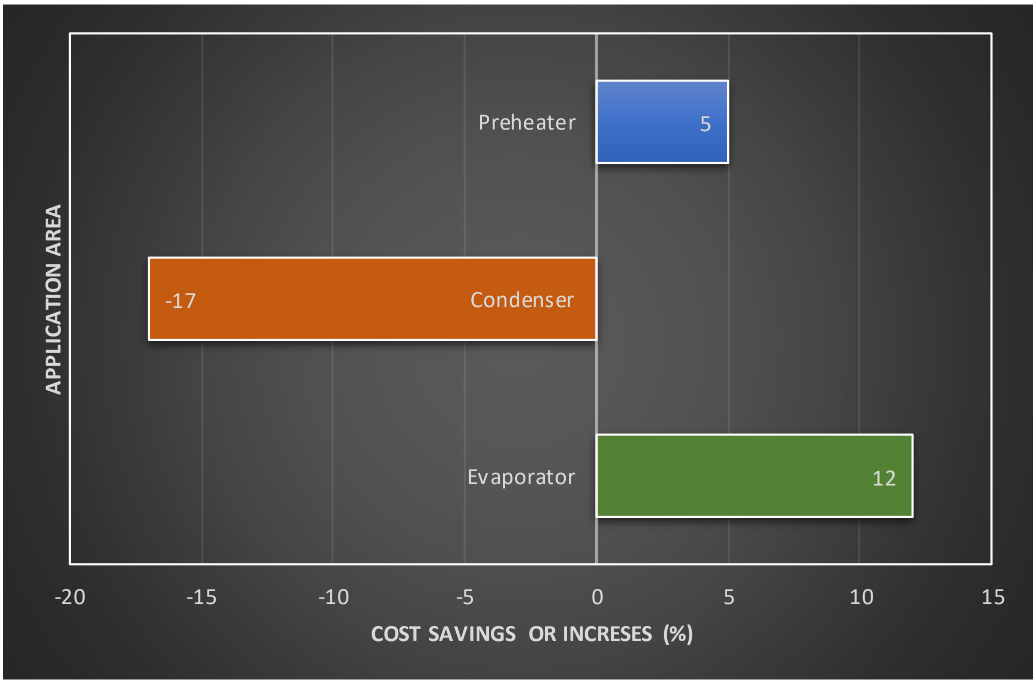

Figure 2 - Cost savings (%) for adopting GeoHex-enabled HXs in place of standard HXs in 15 MW binary power plant.

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 15 MW binary power plant 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 15 MW binary power plant.

Items	Units	Evaporator	Condenser	Preheater
Total heat exchanged surface area	(m^2)	6200	73575	1681
Total carbon footprint of standard HXs	(kg CO_2 eq)	1,729,800	21,998,925	621,970
Total carbon footprint of GeoHex enabled HXs	(kg CO_2 eq)	1,519,000	22,366,800	537,920
Total environmental footprint of standard HXs	(mPt)	772,148	9,794,304	272,809
Total environmental footprint of GeoHex enabled HXs	(mPt)	665,012	9,925,268	235,743
Carbon footprint savings	(kg CO_2 eq)	210,800	-367,875	84,050
	(kg CO_2 eq / MW)	14,053	-24,525	5,603
Environmental footprint savings	(mPt)	107,136	-130,964	37,066
	(mPt / MW)	7,142	-8,731	2,471

It is seen from Table 6 that the plant owner could save total carbon footprints of about 210,800 and 84,050 kg CO_2 eq due to the adoption of GeoHex enabled evaporator and preheater in place of respective standard HXs, respectively, in 15 MW binary power plant. However, using a GeoHex-enabled condenser will increase the carbon footprint by about 367,875 kg CO_2 eq. The total carbon footprint savings in units of kg CO_2 eq per MW for adopting GeoHex-enabled tubular HXs instead of respective standard HXs are plotted in Figure 3.

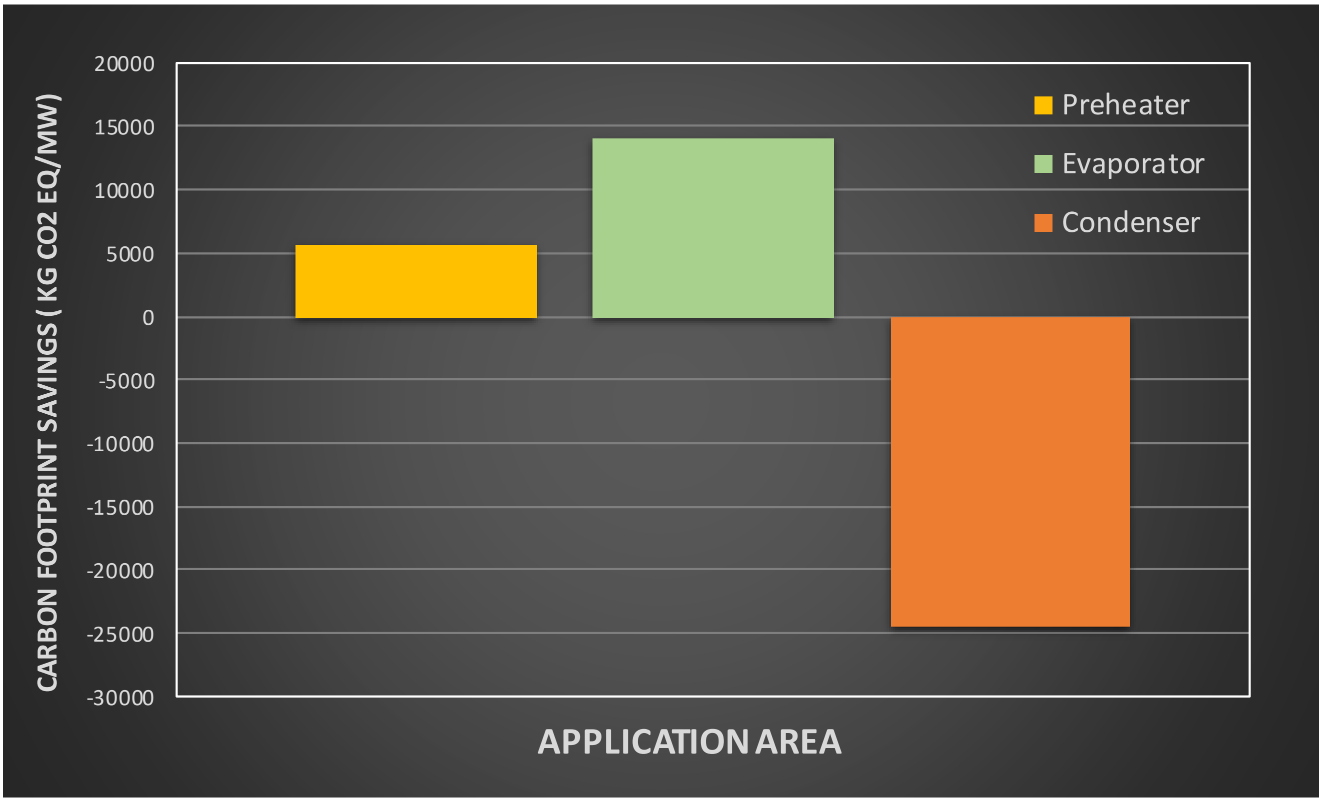

Figure 3 - Carbon footprint savings (kgCO2e q / MW) for adopting GeoHex-enabled tubular HXs compared to respective standard HXs in a 15 MW binary power plant.

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 15 MW binary plant 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 4.

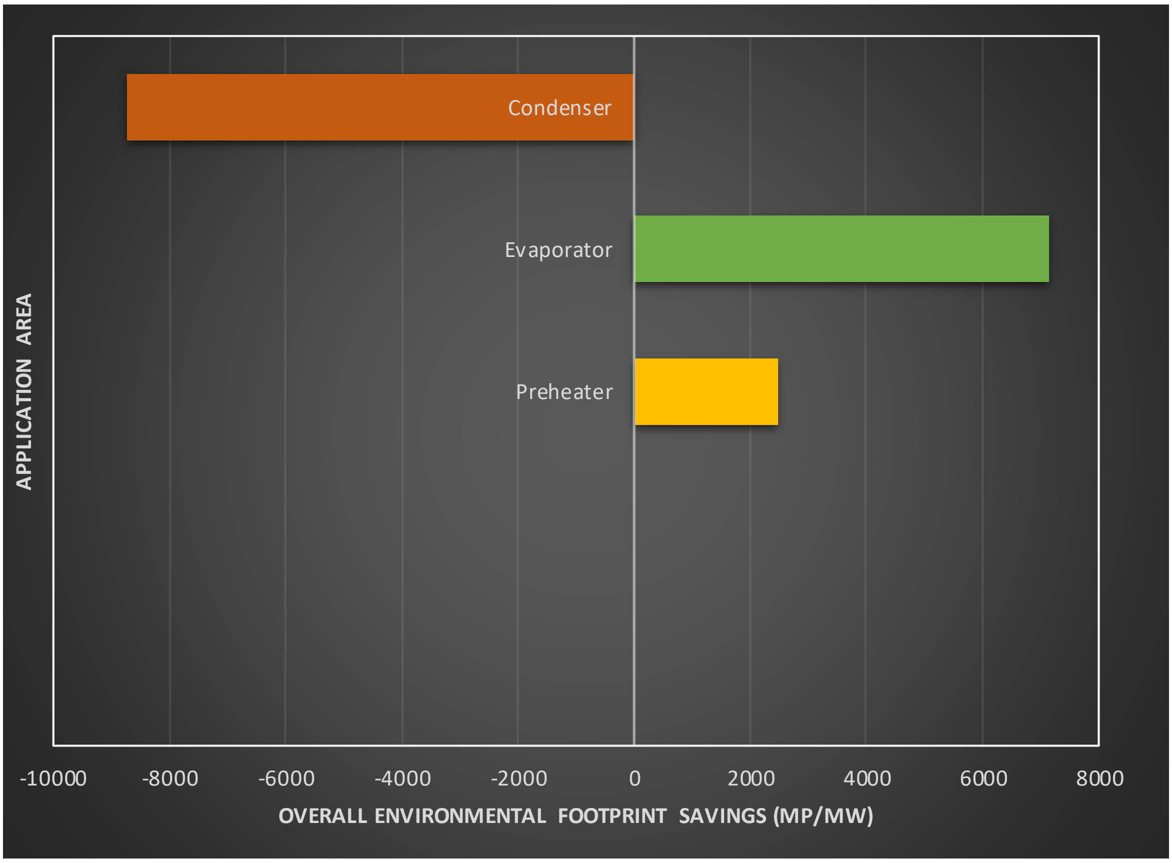

Figure 4 - Overall environmental footprint savings (mPt / MW) for adopting GeoHex-enabled tubular HXs compared with standard HXs in a 15 MW binary power plant.

Through literature searches, no plant data were available for the Binary power 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 heat exchangers.

4. CONCLUSIONS

This study analysed the cost and environmental impacts for adopting GeoHex-enabled HXs in place of respective standard HXs in a 15 MW binary geothermal power plant. The important findings from this analysis are as follows:

- Adopting a GeoHex-enabled tubular evaporator and preheater in a 15 MW binary plant would save about €582,800 and €82,369 instead of using the standard evaporator and preheater.
- The cost savings for adopting GeoHex-enabled tubular types of evaporator, condenser and preheater instead of using respective standard HXs in 15 MW binary plant are about 12%, -17% and 5%, respectively.
- Carbon footprint savings is about 210,800 kg CO_2 eq for adopting a GeoHex-enabled tubular evaporator in place of the respective standard evaporator in a 15 MW binary plant.
- Carbon footprint savings of about 84,050 kg CO_2 eq for adopting GeoHex enabled tubular preheater in place of respective preheater in 15 MW binary plant.
- The overall environmental footprint savings are about 13.6%, 13.9% and -1.3% for adopting GeoHex-enabled tubular preheater, evaporator, and condenser, respectively, compared with respective standard HXs.

References

1. <http://jkspdc.nic.in/publication_files/geothermal_puga.pdf> accessed 18 April 2023