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Linking Hemispheric Warming Asymmetry to Anthropogenic Waste Heat

(Waste heat)

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Abstract

This paper proposes a potential link between the observed hemispheric warming asymmetry and the distribution of population and per capita energy consumption. Nearly 87% of the world's population resides in the northern hemisphere, where per capita energy consumption has also been substantially higher than in the southern hemisphere. Consequently, anthropogenic waste heat discharged into the northern hemisphere has exceeded that discharged into the southern hemisphere, thereby contributing to the observed thermal asymmetry. Anthropogenic waste heat production in the hemispheres is primarily associated with global industrial activity and power generation, which have a thermodynamic efficiency of $43\text{--}48\% \pm 22\%$. Thermodynamic analysis of these processes over the period 2000–2025 yielded sea temperature increases of 0.53 ± 0.04 °C in the northern hemisphere and 0.21 ± 0.02 °C in the southern hemisphere. The corresponding observed increases are 0.63 °C and 0.38 °C, respectively. The differences between the calculated and observed hemispheric temperature increases are 21.9% or less. However, the calculated average sea-surface temperature trend agrees closely with the observed trend reported by the Intergovernmental Panel on Climate Change. Accordingly, the calculated hemispheric temperature increases are considered representative, suggesting that hemispheric warming asymmetry may be attributed to anthropogenic waste heat. Recent studies reveal that the intensification of the El Niño–Southern Oscillation may be attributed to hemispheric warming asymmetry. Therefore, this study may contribute to a better understanding of the causes of climatic extremes and their mitigation.

Keywords: Anthropogenic Waste Heat; Hemispheric Warming Asymmetry; Per Capita Energy Consumption; World Population; Mathematical Model

Significance statement

This study presents a thermodynamic model potentially linking the observed hemispheric warming asymmetry to the uneven global distribution of anthropogenic waste heat generated by

industrial activity and power production. The work examines how population density and per capita energy consumption produce an uneven thermal distribution at the surface, particularly between the hemispheres. Recent studies reveal that the intensification of the El Niño–Southern Oscillation may be attributed to hemispheric warming asymmetry. The findings highlight the potential role of anthropogenic waste heat in shaping large-scale climate variability and may provide an additional perspective for understanding and mitigating climatic extremes.

1. Introduction

The effort to identify the external drivers of climate anomalies has increasingly focused on energy imbalance between Earth's hemispheres (Loeb et al., 2025; Swedan, 2026). While greenhouse gas forcing is generally treated as globally diffuse, observed surface warming exhibits a distinct asymmetry, with the northern hemisphere warming significantly faster than the southern hemisphere, Fig. 1.

Uneven warming between the hemispheres has traditionally been attributed primarily to geographic characteristics of Earth's surface, including disparities in land distribution, albedo, meridional heat transport, Arctic ice melt, and aerosols (Diamond et al., 2022; Feulner et al., 2013). In addition to these established mechanisms of uneven hemispherical warming, this paper proposes anthropogenic waste heat rejected into surface water as a potential contributor to hemispheric warming asymmetry. This proposal may thus complement the current scientific understanding of uneven warming between the hemispheres.

As shown in Table 1, nearly 87% of the world's population resides in the northern hemisphere. This population imbalance is largely attributed to the unequal distribution of land area between the hemispheres. The greater land surface area in the northern hemisphere has historically supported larger populations. Furthermore, Table 1 shows that the average per capita energy consumption in the northern hemisphere for 2015 was approximately 65% greater than that in the southern hemisphere. Therefore, anthropogenic waste heat rejected into the northern hemisphere is expected to exceed that rejected into the southern hemisphere. Consequently, this uneven waste heat rejection is investigated in this manuscript to examine the extent of its contribution to the observed uneven temperature rise shown in Fig. 1.

Anthropogenic waste heat discharged into surrounding surface waters and air is largely a result of fossil-fuel burning, which represents a reverse process of ancient photosynthesis. The photosynthetic process is a chemical reaction characterized by energy conservation that remains applicable to the present time. For ongoing climate change, Swedan (2023) derived Eq. (13) based on the principles of thermodynamics, which states that “variation in the heat content of the surface is equal to the sum of energy production and heat of deforestation minus the heat of surface greening.” This also means that the sum of surface heat and chemical energy is constant. Therefore, waste heat produced by energy consumption is locked within the Earth system by an energy conservation relationship; it thus accumulates over time and contributes to sea temperature rise. The same principle applies to heat from deforestation.

Previous studies (Al-Rashidi et al., 2009; Shaltout and Omstedt, 2014; Pastor et al., 2018) indicate that semi-enclosed water bodies, such as the Arabian Gulf and the Mediterranean Sea, are warming considerably faster than the global average. A common characteristic of these water bodies is that they serve as collection reservoirs of heat rejected by dense industrial activity and power generation facilities. Anthropogenic waste heat discharged into the Arabian Gulf, for example, is not excluded as a contributing factor.

These observations reveal a correlation between population density, energy consumption, and

regional surface-water temperature rise. Similarly, both population density and energy consumption are greater in the northern hemisphere than in the southern hemisphere. Accordingly, sea-surface temperature in the northern hemisphere would be expected to rise more rapidly, which is consistent with the observations discussed earlier.

This work demonstrates theoretically that the observed uneven warming between the hemispheres is attributable, at least in part, to anthropogenic waste heat rejected into the surroundings. Therefore, anthropogenic waste heat may contribute to hemispheric warming asymmetry and associated climatic extremes. The submitted paper includes sections on data and methods, results, theory, sample calculations, error analysis, and discussion. Symbols and abbreviations are also provided to indicate the meaning of symbols used in this analysis.

2. Data and methods

The world population data for each hemisphere, presented in Table 1, were obtained from the United Nations World Population Prospects database (UN, 2019). The data correspond to 2015, which represents an approximate average population for the study period 2000–2025. Per capita energy consumption data were obtained from the U.S. Energy Information Administration (EIA, 2026). The total energy consumed by the world, E , plotted in Fig. 2, is available from the International Energy Agency website, IEA (2026). By combining population distribution with per capita energy consumption, the energy consumed in each hemisphere during the study period can be calculated. This permits calculation of the sea temperature rise in each hemisphere. Sample calculations and a summary of the results are provided in Table 2.

In parallel, sea-surface temperature increases in each hemisphere during the period 2000–2025 are plotted in Fig. 1. These data were obtained from the HadSST4 sea-surface temperature dataset prepared by the Climatic Research Unit, University of East Anglia (CRU, 2026). The observed average temperature difference in each hemisphere is then presented in Table 2, Line 9, for comparison with the calculated sea temperature rises.

Energy utilization is commonly evaluated using thermodynamic efficiency, η . Industrial, power-generation, transportation, commercial, and residential sectors convert consumed energy into useful forms such as light, heat, mechanical work, and chemical energy. Thermodynamic efficiency is defined as the ratio of useful energy produced to total energy consumed. Because of the second law of thermodynamics, not all consumed energy can be converted into useful work. A portion, Q_C , is inevitably rejected as waste heat to the surrounding air and waters during the conversion process. The thermodynamic efficiency η is thus equal to $(E - Q_C)/E$.

Heat rejection is generally removed at process cooling systems using air and water. With air, or the dry form of waste heat rejection, heat is exchanged directly to the atmosphere. Process cooling water, on the other hand, discharges anthropogenic waste heat directly into surface water; this is referred to as wet form of heat rejection. This fraction of heat rejected into surface water is particularly important for sea-surface temperature rise. Unlike air, surface waters are not uniformly mixed globally. Therefore, densely populated and industrialized regions and the northern hemisphere may experience greater sea-temperature increases than the global average, as discussed in the Introduction.

Residential, commercial, and transportation sectors are not expected to contribute directly to hemispheric warming asymmetry to the same degree as industrial and power-generation sectors. Transportation systems primarily reject heat into the atmosphere, where mixing is relatively efficient. Residential and commercial energy use is largely derived from electricity generation;

therefore, their contribution to hemispheric warming asymmetry occurs mainly at power-generation sources.

Rosen (2013) estimated that the global industrial sector operates at an average energy efficiency of approximately 51%. Graus et al. (2007), on the other hand, estimated the weighted average efficiency of global power-generation systems to be approximately 35–45%. Accordingly, the combined overall efficiency of industrial and power-generation processes is expected to fall within 43–48%. The average efficiency, $\eta=0.455$, is thus used in the calculations.

As discussed in Swedan (2023), fossil fuels have been the dominant form of energy consumption worldwide. In addition to heat, carbon dioxide is emitted into the atmosphere. The subsequent thermodynamic interaction of atmospheric carbon dioxide and water vapor contributes to the transfer of heat from the atmosphere back toward the surface through water-vapor condensation. This process involves a water-vapor phase change from vapor to liquid and a heat-transfer process with a high coefficient of heat transfer (Knudsen et al., 1984). The anthropogenic waste heat transferred from the atmosphere to the surface distribute approximately evenly between sea-surface water and melting glaciers.

When useful energy is consumed, it is ultimately converted into waste heat in the surrounding atmosphere. For example, when light emitted from a bulb is absorbed by the ground, or when a vehicle reaches its destination, the useful energy is eventually dissipated as sensible heat into the atmosphere. Because atmospheric air is reasonably well mixed, the sensible heat balance to the atmosphere—the total energy consumed minus the heat rejected to the hydrosphere—distributes between the hemispheres. Even though the atmosphere mixes waste heat relatively uniformly, the southern hemisphere gains more anthropogenic waste heat because it has larger surface area.

Conversely, anthropogenic waste discharged directly into the hydrosphere has a negligible heat transfer coefficient with the surrounding environment. This is because sea temperature rise is small and the associated heat-transfer coefficient is negligible (Knudsen et al., 1984). The discharged heat by wet cooling can therefore increase the heat content of the surrounding surface water and glaciers melting is negligible. This understanding of heat transfer phenomena is utilized to calculate sea surface temperature rise.

3. Results

Table 1 indicates that approximately 87.1% of the world's population resided in the northern hemisphere in 2015. The per capita energy-consumption ratio between the hemispheres was approximately 1.65, with the northern hemisphere exhibiting the greater share. The Theory section presents the heat and mass balance of anthropogenic waste heat rejected into the surrounding air and water, as described in the methods section. As shown in the sample calculations, at 45.5% thermodynamic efficiency of industrial and power generation processes, nearly 91.8% of anthropogenic waste to the hydrosphere accumulates in the northern hemisphere. This is the major contributor to the heat asymmetry between the hemispheres.

Sample calculations results are summarized in Table 2. The table shows that for the period 2000–2025, anthropogenic waste heat discharged into the surrounding air contributed temperature increases of 0.15 and 0.11 °C in the southern and northern hemispheres, respectively, Line 5. However, waste heat discharges into surface water by wet cooling added an additional 0.03 °C and 0.31 °C to the southern and northern hemispheres, respectively, Line 6. The calculated total temperature rises are 0.18 ± 0.01 °C and 0.42 ± 0.03 °C for the southern and northern hemispheres, respectively, Line 7.

As Fig. 1 shows, for the study period, the observed sea temperature increases were 0.38 °C

and 0.63 °C for the southern and northern hemispheres, respectively, Line 9 of Table 2. The calculated temperature increase for the northern hemisphere is within 33.3% of the observed temperature increase. The deviation, however, is greater for the southern hemisphere, at nearly 52.6%.

Not considered in these sample calculations are the heat added by deforestation and that removed by surface greening. These are nearly equal to 22.85% and 12.84%, respectively, of the total heat associated with carbon conversion to carbon dioxide (Swedan, 2023).

In the error analysis section, thermodynamic efficiency has a relative error margin of 22%, while energy consumption has a relative error margin of nearly 9%. Within these allowable margins and the addition of the net heat of deforestation and surface greening, the calculated sea temperature rise can assume 0.21 ± 0.02 °C and 0.53 ± 0.04 °C for the southern and northern hemispheres, respectively, Line 8 of Table 2. This reduces the deviation between calculated and observed values to 15.9% and 44.7% for the northern and southern hemispheres, respectively.

However, the calculated difference in sea temperature rise between the hemispheres, 0.24 °C, agrees closely with the observed difference 0.25 °C, Lines 7 and 9 of Table 2. Even at the higher energy values permitted within the error margins and the addition of the net heat of deforestation and surface greening, the difference remains within 21.9%., Lines 8 and 9 of Table 2.

4. Theory

Following the method description above, the mass and heat balance of anthropogenic waste heat for the study period 2000–2025 is analyzed in this theory section. The main parameters are the total energy consumed worldwide, the thermodynamic efficiency of industrial and power generation processes, the human population in the northern and southern hemispheres, and the average per capita energy consumption in each hemisphere. These parameters determine the share of energy consumption ultimately discharged into the atmospheric air and surface water.

If E represents the total energy consumed in the study period, and η represents the thermodynamic efficiency of industrial process, then, ηE , represents the energy converted into useful product. The difference, $Q_C = E - \eta E$, is waste heat rejected to the surrounding hydrosphere and atmospheric air. In this work, this waste is assumed to be divided equally between the atmosphere and hydrosphere. This assumption is based on the widespread and competitive use of both air-and water-cooling systems. Therefore, the heat to the hydrosphere will be equal to $Q_C/2 = (1 - \eta) E/2$.

$$Q_H = (1 - \eta) E/2 \quad (1)$$

$$Q_A = E - Q_H \quad (2)$$

Where

Q_H = Total waste heat rejected to surface water by wet cooling, J.

η = Thermodynamic efficiency of anthropogenic processes, dimensionless.

E = Total energy consumed worldwide, J.

Q_A = Total heat gained by the atmospheric air, J.

The heat gained by the atmosphere, Q_A , mixes relatively uniformly by air circulation; however, the heat to surface water, Q_H , accumulates unevenly, depending on population density distribution and per capita energy consumption. This heat, Q_H , thus divides between the hemispheres as follows:

$$Q_{HN}=Q_H \times N_{NH} PC_{NH}/(N_{NH} PC_{NH}+N_{SH} PC_{SH}) \quad (3)$$

$$Q_{HS}=Q_H \times N_{SH} PC_{SH}/(N_{NH} PC_{NH}+N_{SH} PC_{SH}) \quad (4)$$

Where

Q_{HN} =Waste heat rejected to the northern hydrosphere by wet cooling, J.

Q_{HS} =Waste heat rejected to the southern hydrosphere by wet cooling, J.

N_{NH} =Population in the northern hemisphere.

PC_{NH} =Average per capita energy consumption in the northern hemisphere, J person⁻¹.

N_{SH} =Population in the southern hemisphere.

PC_{SH} =Average per capita energy consumption in the southern hemisphere, J person⁻¹.

Equations (17) of the reference Swedan (2023) may be used to calculate sea temperature rise, which will be quoted in this section as follows:

$$dT_s=(dQ_s/2) \times W_s/(\Gamma \times C_{PA}) \quad (5)$$

Where

dT_s =Sea surface temperature rise, °C.

dQ_s =Heat to Earth's surface water, J.

W_s =Air humidity at saturation with sea water, kg water per kg dry air, dimensionless.

C_{PA} =Air specific heat, 1 000 J kg⁻¹ °C⁻¹.

Γ =Annual precipitation, 4.86 x 10¹⁷ kg yr⁻¹."

5. Sample calculations

Equation (5) will be used to calculate the average sea-surface temperature increase in each hemisphere attributed to anthropogenic waste heat discharged into the atmosphere and hydrosphere. Anthropogenic waste heat to the atmosphere heats land, surface water, and melt glaciers; therefore, the global average value of sea surface air humidity is used. The value of W_s for Eq. (5) used by Swedan (2023) is nearly equal to 0.012 kg water vapor per kg dry air.

Conversely, waste heat rejected to the hydrosphere by wet cooling increases surface water temperature as discussed in the method section. Referring to the temperature map provided by NOAA (2026), the oceans extend from the equator to approximately 55–60° latitude. The geographic center of this ocean surface area lies near 25.2° latitude, where the average temperature is nearly 25.3 °C. At saturation, air above the sea surface holds about 0.021 kg of water vapor per kg of dry air. This is the value of W_s to be used in Eq. (5) for anthropogenic waste discharged by wet cooling processes.

The Visual Encyclopedia of Earth (Allaby, 2008) reveals nearly 57.1% of the total water surface is in the southern hemisphere and the remaining 42.9% is in the northern hemisphere. Therefore, dry waste heat exchanged is greater in the southern hemisphere by a factor of 1.33, which should be accounted for in the calculations.

As Fig. 2 reveals, the cumulative energy for the study period 2000–2025 is nearly equal to 1.41 x 10²² J. Using the average value (η =0.455) for industrial and power generation thermodynamic efficiency, the following applies:

$$Q_H=(1-\eta) E/2=(1-0.455) \times 1.41 \times 10^{22}/2=3.84 \times 10^{21} \text{ J, Eq. (1).}$$

$$Q_A = E - Q_H = 1.41 \times 10^{22} - 3.84 \times 10^{21} = 1.03 \times 10^{22} \text{ J, Eq. (2).}$$

$$dT_S = (Q_A/2) \times W_S / (\Gamma \times C_{PA}) = (1.02 \times 10^{22}/2) \times 0.012 / (4.86 \times 10^{17} \times 1000) = 0.13 \text{ }^\circ\text{C, Eq. (5).}$$

Here, Eq. (5) is applied to the entire Earth with Q_A contributes equally to melting glaciers and raising sea temperature. As a result, Q_A is divided by 2. However, the entire annual precipitation value ($4.86 \times 10^{17} \text{ kg yr}^{-1}$) is used in the equation.

In Table 1, the world population and average per capita energy consumption in the hemispheres are tabulated. The average per capita energy consumption for the northern and southern hemispheres are $PC_{NH} = 8.49 \times 10^{10}$ and $PC_{SH} = 5.15 \times 10^{10} \text{ J yr}^{-1}$, respectively. The populations in the northern and southern hemispheres are $N_{NH} = 6.41 \times 10^9$ and $N_{SH} = 9.48 \times 10^8$, respectively. Therefore

$$Q_{HN} = Q_H \times N_{NH} PC_{NH} / (N_{NH} PC_{NH} + N_{SH} PC_{SH}) = Q_H \times 6.41 \times 10^9 \times 8.49 \times 10^{10} / (6.41 \times 10^9 \times 8.49 \times 10^{10} + 9.48 \times 10^8 \times 5.15 \times 10^{10}) = Q_H \times 0.918 = 3.84 \times 10^{21} \times 0.918 = 3.53 \times 10^{21} \text{ J, Eq. (3)}$$

$$dT_S = Q_{HN} \times W_S / (\Gamma/2 \times C_{PA}) = 3.53 \times 10^{21} \times 0.021 / (4.86 \times 10^{17}/2 \times 1000) = 0.31 \text{ }^\circ\text{C, Eq. (5).}$$

Again, Eq. (5) is used to calculate average sea temperature rise in the northern hemisphere by wet cooling. Q_{HN} , being warm water discharged directly into the hydrosphere, does not melt glaciers as discussed in the method section, and, therefore, Q_{HN} is not divided by 2. Because half of the total annual precipitation is in the northern hemisphere, Γ is divided by 2.

Similarly

$$Q_{HS} = Q_H \times N_{SH} PC_{SH} / (N_{NH} PC_{NH} + N_{SH} PC_{SH}) = Q_H \times 9.48 \times 10^8 \times 5.15 \times 10^{10} / (6.41 \times 10^9 \times 8.49 \times 10^{10} + 9.48 \times 10^8 \times 5.15 \times 10^{10}) = Q_H \times 0.082 = 3.84 \times 10^{21} \times 0.082 = 3.15 \times 10^{20} \text{ J, Eq. (4).}$$

$$dT_S = (Q_{HS}) \times W_S / (\Gamma/2 \times C_{PA}) = 3.15 \times 10^{20} \times 0.021 / (4.86 \times 10^{17}/2 \times 1000) = 0.03 \text{ }^\circ\text{C, Eq. (5).}$$

The increase in sea surface temperature in the northern hemisphere due to waste heat discharge to the atmosphere is $dT_S = (42.9/50) \times 0.13 = 0.11 \text{ }^\circ\text{C}$.

The total sea surface temperature rise in the northern hemisphere is $dT_S = 0.11 + 0.31 = 0.42 \text{ }^\circ\text{C}$.

The increase in sea surface temperature in the southern hemisphere due to waste heat discharge to the atmosphere is $dT_S = (57.1/50) \times 0.13 = 0.15 \text{ }^\circ\text{C}$.

The total sea surface temperature rise in the southern hemisphere is $dT_S = 0.15 + 0.03 = 0.18 \text{ }^\circ\text{C}$.

6. Error analysis

The intent of this section is to evaluate calculation errors of the thermodynamic efficiency and sea temperature increase. A variable x has an absolute error Δx and a relative error $\varepsilon x = \Delta x/x$.

From the first paragraph of the theory section $\eta = 1 - Q_C/E$, where Q_C is the total heat rejected to the surrounding air and water by anthropogenic processes. Therefore

$$\text{Max } \Delta\eta = |\partial\eta/\partial Q_C| \Delta Q_C + |\partial\eta/\partial E| \Delta E \quad (6)$$

$$\text{Max } \Delta\eta = \Delta Q_C/E + \Delta E Q_C/E^2 \quad (7)$$

$$\text{Max } \Delta\eta = (Q_C/E) (\Delta Q_C/Q_C + \Delta E/E) \quad (8)$$

$$\text{Max } \varepsilon\eta = \text{Max } \Delta\eta/\eta = [Q_C/(\eta E)] (\varepsilon Q_C + \varepsilon E) \quad (9)$$

$$\text{Max } \varepsilon\eta = [(1-\eta)/\eta] (\varepsilon Q_C + \varepsilon E) \quad (10)$$

Referring to Eq. (10), for the lowest observed efficiency value, $\eta = 0.35$, and maximum relative errors $\varepsilon Q_C = \varepsilon E = 0.09$ (Hoesly and smith, 2023), the maximum efficiency relative error $\text{Max } \varepsilon\eta \approx 0.334$, or 33.4%. For the highest observed efficiency, $\eta = 0.51$, and minimum relative errors

$\varepsilon Q_C = \varepsilon E = 0.05$ (Hoesly and Smith, 2023), the minimum efficiency relative error $\text{Min } \varepsilon \eta \approx 0.10$, or 10%. The average relative error in the calculated thermodynamic efficiency of anthropogenic processes, $\varepsilon \eta$, is nearly 0.22 or 22%.

The error in the calculated sea surface temperature rise, εdT_s , by Eq. (5) is mainly a function of the error in energy data εE and the error in precipitation $\varepsilon \Gamma$. The latter is negligible, nearly equal to 1.1% (Gruber and Levizzani, 2008). Therefore, the maximum value of the relative error in the calculated sea temperature rise, $\text{Max } \varepsilon dT_s \approx 0.09$, and the minimum error, $\text{Min } \varepsilon dT_s \approx 0.05$. The average error in the calculated sea temperature rise is 0.07, or 7%.

7. Discussion

Referring to Chapter 2 of the IPCC Sixth Assessment Report (Gulev et al., 2021), Table 2.4 presents sea-surface temperature rise between 1980 and 2020. The average sea-surface temperature increase over this period is 0.59°C , or nearly 0.15°C per decade (d^{-1}). From Table 2 of this manuscript, the observed average increase over the last 25 years is $0.20^\circ\text{C d}^{-1}$, Line 9, while the calculated increase is nearly $0.11^\circ\text{C d}^{-1}$ when considering energy consumption alone, Line 7. When, however, deforestation and surface greening are considered, and the allowable error ranges for thermodynamic efficiency and energy consumption are applied, the trend in average sea-surface temperature rise approaches $0.14^\circ\text{C d}^{-1}$, Line 8, which is reasonably close to the observed $0.15^\circ\text{C d}^{-1}$ in IPCC report. This conclusion, along with the agreement in sea-temperature difference between the hemispheres discussed in the results section, potentially suggest that the observed hemispheric temperature rise may contain some background climate variability. The physical model proposed here may thus be representative, and anthropogenic waste heat is likely to be a major contributor to the observed hemispheric warming asymmetry.

Clearly, this work suggests that anthropogenic waste heat is not merely a localized and negligible byproduct of energy consumption, but may contribute significantly to the observed sea temperature rise. With combined industrial and power-generation efficiencies estimated at 43–48%, humanity unintentionally transfers nearly 27% of the energy consumed into surrounding surface waters, mostly in the northern hemisphere. This point-source thermal forcing may provide a physically and mathematically consistent mechanism for the hemispheric warming asymmetry.

Recent atmospheric and meteorological literature, particularly Swedan (2026), proposes a direct causal relationship between hemispheric warming asymmetry and the intensification of El Niño–Southern Oscillation (ENSO). Accordingly, climatic extremes associated with ENSO may be linked, at least in part, to anthropogenic waste heat. Similar processes may also operate at regional scales in semi-enclosed water bodies such as the Mediterranean Sea, the Black Sea, and the Arabian Gulf, where industrial and power-generation activities are concentrated. The resulting “hot spots” may potentially act as thermodynamic engines that drive local and regional weather extremes. Therefore, climate mitigation strategies should consider the thermodynamic limits and environmental impacts of industrial and power-generation heat dissipation into the surrounding surface waters.

Unlike carbon dioxide, waste heat has an intrinsic economic value because it represents recoverable energy. Its mitigation or limitation can therefore involve engineering projects that provide a return on investment rather than relying solely on the cost of emissions reduction. Such projects can utilize proven technologies that are already operating in the field to recover and reuse waste heat. Consequently, waste-heat recovery projects have the potential to be financially self-sustaining and, in some applications, profitable.

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12. Author contributions

The author, Nabil Swedan, produced the entire work including text, table, and figure.

13. Data availability:

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15. Tables

Table 1. Annual per capita energy consumption and population per geographic regions in 2015. The hemispheric per capita energy consumptions are population-weighted average values. Data sources are (UN, 2019; EIA, 2026).

Geographic region	Northern hemisphere			Southern hemisphere		
	Population	Per capita J/year	Average J/year	Population	Per Capita J/year	Average J/year
Africa	8.76E+08	3.80E+10	8.49E+10	3.06E+08	3.64E+10	5.15E+10
Asia	4.17E+09	6.28E+10		2.80E+08	2.60E+10	
Europe	7.43E+08	1.69E+11		0.00E+00	1.69E+11	
South America and the Caribbean north of the equator	2.91E+08	4.40E+10		0.00E+00	4.40E+10	
North America	3.33E+08	3.32E+11		0.00E+00	3.32E+11	
Australia and New Zealand	0.00E+00	2.47E+11		2.85E+07	2.47E+11	
South America south of equator	0.00E+00	7.01E+10		3.33E+08	7.01E+10	
Total	6.41E+09	---	---	9.48E+08	---	---

Table 2. Calculated and observed sea temperature rise in the hemispheres for the period 2000–2025. Energy consumption is obtained from IEA (2026) presented in Fig. 2.

Line	Description/Hemispheres	Southern hemisphere	Northern hemisphere	Total/Average
1	Industrial and power efficiency, η	0.455	0.455	0.455
2	Energy consumption, J	1.16E+21	1.29E+22	1.41E+22
3	Heat to the hydrosphere, J	3.15 E+20	3.52 E+21	3.84E+21
4	Heat to the atmosphere (mixed air), J			1.02E+22
5	Contribution of dry waste heat to sea temperature rise for $\eta=0.5$, °C	0.15	0.11	0.13
6	Contribution of wet waste heat to sea Temperature rise, °C	0.03	0.31	
7	Total sea-surface temperature rise using energy production alone, °C	0.18	0.42	0.28
8	Total sea-surface temperature rise, including deforestation, surface greening, and allowable error margins for E and η , °C	0.21	0.53	0.35
9	Observed sea temperature rise, degrees C	0.38	0.63	0.49

16. Figures

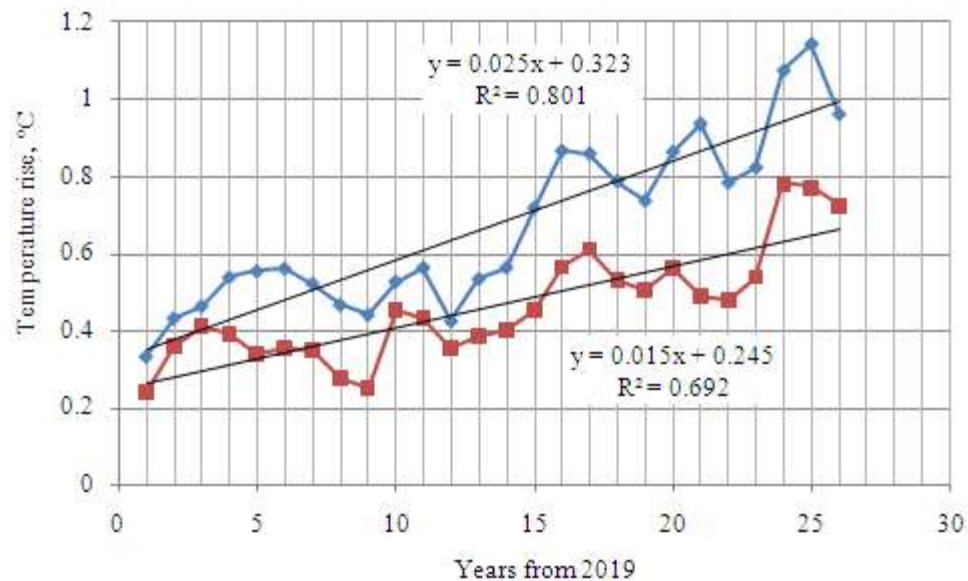


Fig. 1. Observed sea surface temperature trends for the Earth's hemispheres in degrees Celsius between 2000 and 2025. Blue lines for the northern hemisphere and red lines for the southern hemisphere. Data source is HadSST4 file, Climate Research Unit, University of East Anglia, CRU (2026).

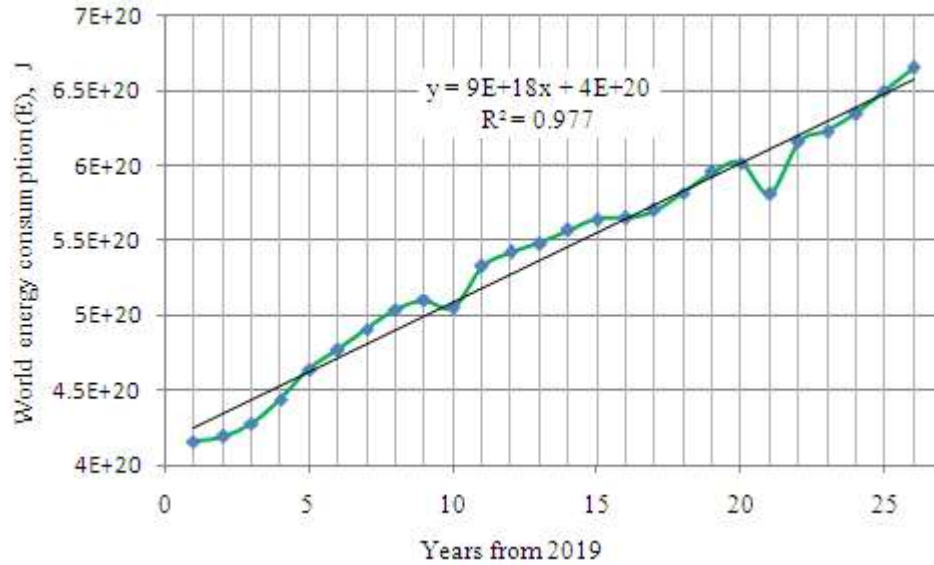


Fig. 2. World energy consumption (E) in joules between 2000 and 2025. Data source IEA (2026).

17. Symbols and abbreviations

C_{PA}	Specific heat of the air mixture, $J\ kg^{-1}\ ^\circ C^{-1}$
d	A symbols that denotes an infinitesimal variation
dT_s	Sea temperature rise, $^\circ C$
dQ_s	Heat gained by surface water, J
Dry cooling	Waste heat rejection to the surroundings using air as a cooling medium
ε	Relative error of a measurement or a calculated parameter
Δ	Small variation or absolute error in a measurement or a calculation
d^{-1}	Per decade
E	Total energy consumed by the world, J
Γ	Annual precipitation, kg
η	Thermodynamic efficiency of industrial and power generation, dimensionless
N_{NH}	Population in the northern hemisphere
N_{SH}	Population in the southern hemisphere
PC_{NH}	Annual per capita energy consumption in the northern hemisphere, $J\ person^{-1}$
PC_{SH}	Annual per capita energy consumption in the southern hemisphere, $J\ person^{-1}$
Q_A	Waste heat rejected directly to the atmosphere, J
Q_C	Total waste heat rejected by industrial and power generation, J
Q_H	Waste heat rejected to the hydrosphere by wet cooling, J
Q_{HN}	Waste heat rejected to the northern hydrosphere by wet cooling, J
Q_{HS}	Waste heat rejected to the southern hydrosphere by wet cooling, J
s	Second
t	Time
T_{NH}	Average sea-surface temperature in the northern hemisphere, $^\circ C$
T_{SH}	Average sea-surface temperature in the southern hemisphere, $^\circ C$

W_s	Air humidity at saturation, kg water per kg dry air
yr	Year
Wet cooling	Waste heat rejection to surface water using water as a cooling medium