ABSTRACT
The global air temperature increase is an inadequate measure of global warming, which should be considered in terms of energy. The ongoing global warming means that heat has been accumulating since 1880, in air, ground, and water. Before explaining this warming by external heat sources the net heat emissions on Earth must be considered. Such emissions, from e.g. the global use of fossil fuel and nuclear power, must contribute to global warming. The aim of this study was to compare globally accumulated and emitted heat. The heat accumulated in air corresponds to 6.6% of the global warming, while the remaining heat is stored in the ground (31.5%), melting of ice (33.4%), and sea water (28.5%). Emitted net heat corresponds to 74% of accumulated heat, during the same period. The missing heat (26%) must have other causes; e.g. the result of increasing CO₂ concentration into the atmosphere.

1. INTRODUCTION
Global mean temperatures have been compiled based on long-term air temperature measurements [NCDC-NOAA, 2007]. These temperatures (Fig 1) are separated into one monthly Sea Surface Temperature (SST) and one monthly Land Area Temperature (LAT). The global mean temperature is the area weighted mean of LAT and SST. In 1880, SST was 15.9°C and LAT was 8.6°C, with a global mean of 13.6°C. Until 2000, SST had increased by 0.5°C and the LAT 1.2°C. The corresponding global mean temperature increase 1880-2000 was 0.7°C. However, the global mean air temperature increase is inadequate measure of global warming, and independent of what causes the warming it should be considered in terms of energy [Pielke et.al., 2004; Pielke. 2005]. Here, global warming is considered as the global energy accumulation in air, ground, and water, since 1880. Before explaining the global warming by extraterrestrial heat sources, the net heat emissions on Earth should be considered. Such emissions, heat dissipation from the e.g. global use of fossil fuel and nuclear power, must contribute to global warming. In current study, accumulated and emitted heat were estimated and compared.

![Fig. 1. Global Land Area Temperature (LAT) and Sea Surface Area Temperature (SST), 1880-2000 [NCDC-NOAA].](image-url)
2. GLOBAL HEAT ACCUMULATION
Performed calculations include the period 1880-2000. The methods used to calculate heat accumulation in the air, ground and water are described in Appendix A and in [Nordell and Gervet, 2009].

2.1 Heat Accumulation in Ground
As a result of the increased air temperature also the ground surface has warmed up and heat has been conducted into the ground. The heat content of the ground increased by 23.4 kWh m\(^{-2}\) from 1880 to 2000. This heat conduction into the ground neither occurs in permafrost areas, defined as perennial ground ice, nor on glacier ice or icings [NSIDC, 2007a]. Such areas, which are affected differently by the global warming, are included in the melting of ice and its contribution to the sea level rise. Glaciated areas (0.16 \(10^{14}\) m\(^2\)) [Singh and Singh, 2001] and permafrost areas of the world (0.30 \(10^{14}\) m\(^2\)) thus reduce the total land area (1.5 \(10^{14}\) m\(^2\)) affected by the heating to 1.02 \(10^{14}\) m\(^2\). The total ground heat accumulation since 1880 then becomes 23.9 \(10^{14}\) kWh.

2.2 Heat Accumulation in Air
The heat accumulation in air (moist static energy) was estimated separately for over the sea surface and land surface. Hence, different mean air temperatures over sea and land were considered. The total heat accumulation in air is 5.0 \(10^{14}\) kWh of which 44.6% is distributed over the land area.

2.3 Heat Accumulation in Water
The heat accumulation in ocean water was estimated from the global sea level rise (GSLR), compiled by the Permanent Service for Mean Sea Level [PSMSL, 2007]. The GSLR is a result of various factors; e.g. melting land ice, thermal expansion, increasing water vapor in air, permanent removal of water from aquifers, deforestation and loss of soil moisture, reduction in the extent of wetlands, deep infiltration of irrigation water, and ocean sedimentation. [Harvey, 2000]

There are various data regarding the contribution of thermal expansion to the 20\(^{th}\) century sea level rise. The most commonly suggested thermal volume expansion rate is presently 0.5 mm per year [Church et.al., 2001, Antonov et.al., 2002]. Recent studies show considerably lower values [Ishii et.al. 2003] and it is reported that the ocean water has been cooled for several years [Lyman et.al. 2006]. Satellite measurements show that large-scale El Nino like ocean temperature fluctuations occurred between 1955 and 1995 [Ishii et.al. 2003]. Such fluctuations and the recently reported ocean temperature decrease is a result of large-scale and long-cycled (~15 years) ocean circulation, leading to melting of sea ice and subsequent cooling of the water. Based on the temperature fluctuations between 1955 and 1995 a thermal expansion rate of 0.02 mm year\(^{-1}\) was estimated [Ishii et.al. 2003]. Since this expansion, i.e. 1 mm over the last 50 years, is a result of global warming the expansion until 1955 is neglected. Assuming that the sea water heating occurred in the top 1,000 m of water, this 1 mm thermal expansion corresponds to 21.6 \(10^{14}\) kWh of heat.

Recent estimates of the total sea level rise due to the melting of small glaciers and Greenland is about 60 mm. Here, this contribution was estimated to about 50 mm until 2000. The main uncertainty is whether the ice mass of Antarctica is decreasing or increasing, i.e. causes the sea level to rise or not [Harvey, 2000]. If the mass of ice on Antarctica increases, the total melt heat will be correspondingly less. The energy required to melt glaciers and permafrost, totaling 50 mm sea level rise, is 16.8 \(10^{14}\) kWh.

The total area of sea ice is \(19.9 \times 10^{12}\) m\(^2\) of which \(14.8 \times 10^{12}\) m\(^2\) is floating on the northern hemisphere. The estimated annual melting 1980-2000 was 0.38%±0.02% on the northern
hemisphere and 0.02%±0.48% [NSIDC, 2007b] on the southern. During the same period the total thinning of the 3 m thick ice was estimated to 4% [Johannessen et.al. 2003]. Here, values for the northern hemisphere are used, while the very uncertain values for the southern hemisphere are disregarded. The resulting annual melting of 258 km³ sea ice requires 0.22·10¹⁴ kWh year⁻¹, during 1980-2000. The total sea ice melting during the last 120 years is considered proportional to the energy consumption during the same period, see Fig 3, resulting in the melting of 10⁷ km³ of sea ice and a corresponding heat absorption of 8.5·10¹⁴ kWh. The total heat accumulation in ocean water during 1880-2000, i.e. by heating of sea water and melting of land and sea ice, then adds up to 46.9·10¹⁴ kWh.

The global heat accumulation in the air, ground and water during 1880-2000 is thus 75.8·10¹⁴ kWh (27.3·10²¹ J). This heat is distributed in air (6.6%), ground (31.5%), water (28.5%), and melting of land and sea ice (33.3%) according to Fig 2. It is noticeable that the heat content in air only corresponds to 6.6% of the global warming.

4. GLOBAL NET HEAT GENERATION

The major natural heat source is the geothermal heat flow but heat is also generated by, e.g. volcanic eruptions, earthquakes, and meteorites. Non-natural heat sources include the global use of fossil fuel, nuclear power, and deforestation. Heat emissions from nuclear bomb tests and conventional bombs also add to the net heat generation.

4.1 Commercial Energy

The world’s consumption of commercial non-renewable energy from 1880 to 2000 [CDIAC, 2007; EIA, 2007] is shown in Fig 3. The total commercial energy consumption 1880-2000 is 38.5·10¹⁴ kWh (13.9·10²¹ J). All this energy dissipates into heat. A useful key value is that the global energy consumption in 2000 was approximately 10¹⁴ kWh (0.36·10²¹ J).
4.2 Volcanoes and Earth Quakes
An average of 1.4 million earthquakes occurs each year on Earth. Almost all of these are considered part of natural net heating. The thermal energy released from a few large volcanic eruptions during the last 120 years was estimated based on [Simkin and Siebert, 1994].

4.2 Nuclear Bomb Tests and Conventional Bombs
More than 2,000 nuclear tests, atmospheric and underground, were carried out, 1945-1998. Though nuclear explosions have a great power, released energy was small because of its short duration. Energy released by conventional bombs was also investigated. It was found that bomb explosions do not mean any significant net heating.

4.3 Non-commercial Fossil Fuel Consumption
Fossil fuel consumed outside the energy market is not included in global energy statistics. Examples of such non-commercial energy are, for example, flares at gas and oil fields, fires at coal fields and in underground coal mines, and petroleum products that are not used in energy production e.g. in the production of plastics. Also deforestation contributes to net heating.

4.4 Gas Flaring
Flaring of associated gas was a common industry practice in the early "decades" of oil production, when there were virtually no gas markets, or concerns regarding the environment or rational use of hydrocarbon resources. The gas flaring in Africa alone is presently equivalent to half of that continent’s power consumption. Fewer than 20 countries account for more than 85 percent of gas flaring and venting. The magnitude of this problem is underlined by the World Bank’s The News Flare [GGFR, 2007; WB, 2007], which is devoted to reducing the global gas flaring.

4.5 Underground Coal Fires
Hundreds of coal fields are burning out of control around the world. Some of the oldest and largest coal fires occur in China, the United States, and India [Stracher and Taylor, 2004]. Those burning underground can be difficult to locate and are not included in this net heat estimation.

4.6 Deforestation
The deforestation since 2000 is 200 km²/day and the global forest area has been reduced by 11.1 Mkm² since 1850. Here, it was assumed that this wood was burnt or decomposed.

4.7 Nuclear Power
Since the mean efficiency nuclear electricity is 33% the resulting heat emission is twice as high at generated electricity. Waste heat from nuclear power plants means a small share of the global heat emissions but has a large impact locally. Sweden’s nuclear power plants e.g. generate 70 TWh. Thus, 140 TWh of waste heat is emitted into the sea water. This amount of heat is 40% greater than the annual space heating demand of all buildings in Sweden.

A summary of the net heat generation is given in Table 1. The main part (~70%) of the net heat emissions (38.5 $10^{14}$ kWh) results from the commercial consumption of oil, gas, coal and nuclear power, while other non-renewable heat sources totals 10.4 $10^{14}$ kWh and miscellaneous heat sources (volcanoes, earth quakes etc.) means 6.8 $10^{14}$ kWh. The global net heat generation between 1880 and 2000 was 55.7 $10^{14}$ kWh (20.1 $10^{21}$ J).
Table 1: Global Net Heat Generation, 1880-2000.

<table>
<thead>
<tr>
<th>Heat Generation Ratio</th>
<th>Commercial Non-Renewable Energy Consumption</th>
<th>Other Non-Renewable Heat Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heat Generation</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>(10^{14} kWh) (10^{18} kJ) (%)</td>
<td></td>
</tr>
<tr>
<td>Crude oil</td>
<td>15.2 (5.48) 20.1 (%)</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>6.9 (2.49) 9.1 (%)</td>
<td></td>
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<tr>
<td>Coal</td>
<td>16.0 (5.76) 21.1 (%)</td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.4 (0.14) 0.5 (%)</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>38.5 (13.87) 50.8 (%)</td>
<td></td>
</tr>
<tr>
<td>Other Non-Renewable Heat Sources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas flaring</td>
<td>0.9 (0.32) 1.2 (%)</td>
<td></td>
</tr>
<tr>
<td>Coal fires</td>
<td>0.1 (0.03) 0.1 (%)</td>
<td></td>
</tr>
<tr>
<td>Deforestation</td>
<td>8.2 (2.95) 10.8 (%)</td>
<td></td>
</tr>
<tr>
<td>Production of plastics</td>
<td>0.4 (0.14) 0.5 (%)</td>
<td></td>
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<tr>
<td>Waste Heat from Nuclear Power</td>
<td>0.8 (0.29) 1.1 (%)</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>10.4 (3.42) 13.7 (%)</td>
<td></td>
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<tr>
<td>Miscellaneous Heat Sources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volcanoes</td>
<td>4.0 (1.42) 5.2 (%)</td>
<td></td>
</tr>
<tr>
<td>Earthquakes</td>
<td>2.7 (0.97) 3.6 (%)</td>
<td></td>
</tr>
<tr>
<td>Nuclear tests</td>
<td>0.1 (0.03) 0.1 (%)</td>
<td></td>
</tr>
<tr>
<td>Wars (bombs)</td>
<td>0.1 (0.04) 0.1 (%)</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>6.8 (2.46) 9.0 (%)</td>
<td></td>
</tr>
<tr>
<td>TOTAL: NET HEAT EMISSION</td>
<td>55.7 (20.1) 73.5 (%)</td>
<td></td>
</tr>
<tr>
<td>TOTAL: ACCUMULATED HEAT</td>
<td>75.8 (27.3) 100.0 (%)</td>
<td></td>
</tr>
<tr>
<td>MISSING HEAT</td>
<td>20.1 (7.2) 26.5 (%)</td>
<td></td>
</tr>
</tbody>
</table>

5. CONCLUDING REMARKS

Independent of what causes the global warming it should be considered as energy accumulation on Earth. Performed estimations of global heat accumulation in air, ground, and global net heat emissions include the years from 1880 to 2000.

It was found that the air only contains 6.6% of globally accumulated heat. The remaining heat (Figure 4) is accumulated in ground (31.5%), sea water (28.5%), sea ice melt (11.2%) and land ice melt (22.2%).

The net heat emissions contributes to 74% of the global warming. The missing heat (26%) must have other causes, e.g. the greenhouse effect, natural variation of the climate, and/or underestimation of net heat emissions.

Performed calculations are conservative i.e. both the global heat accumulation and the heat emissions are underestimated. The underestimated heat accumulation means that the missing heat in Fig. 4 is too high. Also the underestimation of net heat emission gives the same result.

Most measures already taken to combat global warming are beneficial also for current explanation. Renewable energy should be promoted instead of using fossil fuels. However, CO₂ sequestration and subsequent storage will have very little effect on the global warming. It is also concluded that nuclear power is not a solution to global warming but part of the problem.
Methods used

Heat accumulation in ground: It was assumed that the temperature of the ground surface was equal to the global land area temperature (LAT), see Fig. 1, and that the mean thermal properties of the ground and geothermal heat flow are known. Because of the increasing ground surface temperature heat is conducted from the ground surface into the ground.

The ground temperature change was determined by one-dimensional heat conduction:

\[
\frac{\partial^2 T}{\partial z^2} - \frac{1}{\alpha} \frac{\partial T}{\partial t} = 0
\]

where \( T \) is the ground temperature, \( t \) time, \( \lambda \) the thermal conductivity of the ground, \( \alpha = \lambda / C_v \) the thermal diffusivity, \( C_v \) the volumetric heat capacity of the ground, and \( z \) the vertical direction. Eq. (1) was numerically solved for \( T(z=0) = \text{LAT}(t) \) and \( T(z=400) = C \), a time step of 0.5 h during 120 years, and a length step of 0.1 m. A ground thermal conductivity of 2.5 W m\(^{-1}\) K\(^{-1}\), volumetric heat capacity of 0.6 kWh m\(^{-3}\) K\(^{-1}\), and a geothermal heat flow of 0.065 W m\(^{-2}\) were assumed.

The resulting heat accumulation in the ground (\( Q \)) caused by the temperature change \( \Delta T(z) \) after 120 years of global warming was calculated by:

\[
Q_g = \int_0^D C_v \cdot \Delta T(z) \, \partial z
\]

D is any depth at which the ground temperature is undisturbed by the global warming. Eq. (2) was solved for the boundary conditions used above. In performed calculations, a sufficient \( D = 400 \) m was used since the temperature disturbance did not reach below a depth of 270 m.

Heat accumulation in air: In calculating the heat accumulation in air, its temperature profile was assumed linear from the ground surface to a height of 5,500 m, where the Earth’s effective temperature occurs (-18.8°C) [Salby, 1996]. The mean relative humidity was assumed unchanged from 1880 to 2000. It was estimated to be 62%, after area weighting of data for different latitudes [CDC, 2007]. The calculations were separated into two air volumes, i.e. air over sea and land surface. The heat content of air (moist static energy) over sea surface and land surface, \( Q_s + Q_l \), is expressed by:

\[
Q_h = A_s \int_0^H C_p \cdot \rho_a (z) \cdot \Delta T_s(z) \, \partial z + A_l \int_0^H C_p \cdot \rho_a (z) \cdot \Delta T_l(z) \, \partial z + L \cdot \Delta m_l (z) \, \partial z
\]

where \( C \) is the specific heat of dry air (J/kg °C), \( \Delta T \) (°C) is the air temperature change, \( L \) is the latent heat of vaporization (J/kg), \( \Delta m_l \) the absolute humidity (kg/m\(^3\)). \( A_s \) and \( A_l \) represent the sea surface area and land surface area.

Heat required for ice melting: The heat required to melt ice is also seen as a kind of heat accumulation. Performed calculations are based on estimated volumes of melted land ice, sea ice, and permafrost from 1880-2000. It was also assumed that melted ice is black ice, i.e. transparent ice with a density of \( \rho_{\text{ice}} = 917.3 \) kg/m\(^3\) with a latent heat (melt heat) of \( L_{\text{ice}} = 334 \) kJ/kg. The total amount of energy required to melt \( V \) (m\(^3\)) of ice is then given by:

\[
Q_{\text{ice}} = V \cdot \rho_{\text{ice}} \cdot L_{\text{ice}}
\]

Heat accumulation in sea water: The heat accumulation in sea water is the total change in sensible heat i.e. the heat required to warm up the water. This heating is indirectly estimated from estimations of the volume expansion of heated water. The volume expansion \( \Delta V \) is given by:

\[
\Delta V = \alpha V_0 \Delta T
\]
Where \( \alpha \) is the thermal coefficient of ocean with a salinity of 35 ppm. Since \( \alpha \) is relatively linear the estimated sea level increase as a result of thermal expansion (\( \Delta V \)) Eq.(5) gives the temperature increase (\( \Delta T \)) of the sea water. The corresponding sensible heat accumulation in sea water (\( Q_{sw} \)) is thus given by;

\[
Q_{sw} = \int_{0}^{1000} C \cdot \Delta T(z) \, \partial z
\]

(6)

and the total heat accumulation in the ocean water is thus \( Q_w \) becomes;

\[
Q_w = Q_{sw} + Q_{ice}
\]

(7)

**Total heat accumulation:** The total global heat accumulation is given by the sum of heat accumulation in air, ground, and seawater;

\[
Q_{total} = Q_a + Q_g + Q_s
\]

(8)

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**APPENDIX B**

**Error estimation**

**Net Heat Generation:** Included net heat generation is reliable i.e. all net heat included is really emitted, see Table 1. The major part “Commercial Energy Consumption” is as good as international energy statistics. “Other non-renewable heat” is underestimated since e.g. underground coal fires were excluded and that deforestation does not include reduced biomass in normal forestland. The main uncertainty is in “Miscellaneous Heat Sources” or rather heat emissions from earthquakes and volcanoes. Even though only a few such rare events were included it could be questioned if some of these should be seen as part of background heating, which means that they should not be included. All together it is estimated that the global heat emissions are underestimated by less than 10%.

**Global Heat Accumulation:** Heat accumulation in air is a reliable as the global temperature change reported by NCDC. The heat accumulation into the ground is underestimated since the global mean value for the ground thermal conductivity was assumed at 2.5 W/m,K, which corresponds to crystalline bedrock from the ground surface and downwards. In areas with 10 m soil cover (~1 W/m,K) or sedimentary bedrock the resulting thermal conductivity would rather be 2.0 W/m,K which would reduce the total heat accumulation in the ground by 6.3% of the total heat accumulation. Heat absorbed my sea ice melting until 2000 was overestimated since the melted ice area was assumed to have the mean thickness of 3 m. In more recent studies it was assumed that the thickness of melted ice area was linearly thinner to 0 at the edge of the ice field. For that reason the calculated mass of sea ice was too high, which reduces the total heat accumulation by 5.6% (Figure 2). The main uncertainty in this estimation is the sensible heat accumulation in sea water because of the various estimations and measurements of sea water temperature. In current study, measurements (estimations) that give the sea water temperature over the longest period (~50 years) were chosen. Even though the warming of sea water is the main uncertainty in performed calculations I see no reliable way to estimate this error and this part is therefore left unchanged.

Assuming that this estimation of the uncertainty of used data is correct the net heat generation would maximally be increased by 10% and the global heat accumulation decreased by 11.9%. These maximum errors all together reduce the amount of missing heat (unexplained heating) from 26% to 5.5%, which means that almost all of the global warming would be explained by net heat emissions.
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