International Journal of
Plasma Environmental Science and Technology

Regular Paper
DOI: 10.34343/ijpest.2023.17.e02003

Electricity in the context of a new vision of global warming in which anthropogenic heat and not CO_2 is determinant

Michel Vert

Institute for Biomolecules Max Mousseron, University of Montpellier, Montpellier, France

* Corresponding author: michel.vert@umontpellier.fr (Michel Vert)

Received: 23 June 2023
Revised: 16 July 2023
Accepted: 21 July 2023
Published online: 26July 2023

Abstract

IPCC's predictions of climate deterioration include increases in temperature and in ocean level, as well as local climate events, all attributed to a surplus of carbon dioxide source of radiative forcing that has been building up in the oceans since carbon-based fossil compounds are exploited to generate energy. This mechanism is only consensual and is therefore subject to more and more criticisms without echo because of absence of an alternative mechanism. Selected unusual reasons are first presented to convince non-specialists that greenhouse effect and radiative forcing lack solid scientific basis. As according to physics and thermodynamics, the management of heat inputs in the atmosphere and in the environment must be independent of the source, a recently proposed mechanism based on ice melting and water evaporation is recalled and justified by its extension to distant pass climate fluctuations. Given the major roles attributed to anthropogenic heat releases, in particular waste heat, on the climate, the future depends on the evolution of the anthropogenic/solar heat input ratio. Three scenarios are discussed with respect to reported climate fluctuations for the last 8,000 years of the current interglacial plateau. To position the current times with respect to these scenarios, heat and waste heat generated by the different energy sources and their uses must be assessed from cradle-to-grave to complete the life cycle assessment. With regard to electricity, such assessment must include, for each source, the production mode, in particular for renewable resources, as well as the transport and uses with the aim of increasing efficiency to produce work and minimize waste heat emissions.

Keywords: Electric energy, waste heat, anthropogenic heat releases, global heat management, global warming.

1. Introduction

Global warming and climate changes are currently attributed to an increase of carbon dioxide, (CO_2), in the atmosphere. The surplus is considered at the origin of a radiative forcing according to a mechanism referred to as greenhouse effect [1]. In this domain, the International Panel of Climate Change (IPCC) is a reference body that emits predictions on future climate changes. However, these predictions are only based on compilations of a large number of averaged data exploited using calculations in different models. Earth is too large and too complex to be represented experimentally and IPCC's reports lack experimental supports. The last IPCC report indicates 0.79 [0.52 to 1.06] W m^{-2} (about 12.7 ZJ) as annual radiative forcing over the period 2006–2018 and states that "*91% of the heating in the climate system are stored in oceans, with land warming, ice loss and atmospheric warming accounting for about 5%, 3% and 1%, respectively (high confidence)*" [1].

Although IPCC's vision is universally adopted, it suffers of some flaws that are sources of skepticism among scientists who are not climatologists. For instance, waste heat released in the environment during energy production and as residue of the consumed energy that covers humanity's needs of work, comfort, techniques and activities, is currently neglected relative to the radiative forcing stored in oceans, a vision that relies on the scientifically unproved greenhouse effect. Furthermore, ice melting and water evaporation known as powerful heat absorbers in physics are also ignored in the mechanism of radiative forcing although ice loss is now certain, especially over the recent years [2]. In the context of global warming, ice melting is only considered as source of ocean rises aggravated by warming-dependent dilatation [3]. Changes assigned to CO_2-related radiative forcing on markers of climate changes and of IPCC's predictions, are listed in Fig. 1.

Anthropogenic CO2 concentration in the atmosphere:

about 420 ppmv increasing steadily for several decades

Mean global temperature :

15 °C (+0.18°C every ten years since 1981; + 1.18°C since 1880)

Disappearance of ices

Arctic, Antarctic, glaciers and permafrost (28,000 Gt between 1994-2017)

Ocean level rise:

0.2 – 0.3 cm / year or + 23 cm since 1880 (based on measurements averaged from data provided by different techniques). (liquid water increases are attributed to ice melting and dilatation due to temperature rising)

Worrying Predictions

+ 2 to 4°C more at a distance of 30 to 70 years and ocean and seas rise ~ + 0.6-1.1 m in 2100 or even more

Fig.1. Current markers and predictions related to global warming as reported by IPCC.

Earth was formed about 4.5 billion years ago. Since then, the atmosphere and the environment have been heated by natural sources of heat (Sun, volcanoes, forest fires). The atmosphere and water appeared about 4 billion years ago followed by life. During these billions of years, the climate oscillated between warm and cold periods but there was no dramatic accumulation of heat that would have precluded the appearance of life and its persistence. The absence of dramatic drift related to heat buildup was in force until the middle of the 19th century from which point radiative forcing is now said cumulatively stored in oceans, leading to frightening predictions of temperature and ocean level rises for the end of the 21st century or before [1]. There is a clear contradiction here between absence of heat accumulation in the case of natural heating over billions of years and accumulation of heat in the case of less than two hundred years of radiative forcing. This contradiction suggests that there are two kinds of heat managed differently on Earth. Fundamental principles of physics and thermodynamics strongly oppose such a differentiation since heat is a physical phenomenon independent of the source. To respect these sciences, a new mechanism has been proposed that relies on the management of heat by the water present on Earth, keeping radiative emission, another well-defined physical process, as the only possible means to eliminate heat from the planet [4]. According to this new mechanism, replacing carbon-based fossil fuels with electricity to avoid the formation of climate-perturbing anthropogenic CO_2 as recommended by the IPCC, can only be profitable if electricity can meet energy needs with less anthropogenic heat releases (AHR) in the environment. Anthropogenic heat (AH) includes heat for heating and residual or waste heat during uses, not forgetting heat from humans and hot blood animals.

The aim of this contribution to the 2023 ISNPEDADM meeting held in La Rochelle, France, was to convince electricity specialists that their expertise is needed to show whether carbon-free electricity can replace beneficially carbon-based energy if anthropogenic heat releases are climate determinant. As participants were not necessarily well aware of the relation between atmospheric CO_2 and global warming, and of why some scientists are strongly against greenhouse effects, arguments to question the role of CO_2 are first presented. Then, the management of heat by water and water interphase equilibria is briefly recalled and validated by the possibility of extending the mechanism to climate changes in distant past. Finally, the recommended transition from carbon-based fossil energy to a decarbonized energy is discussed in the light of the new mechanism to show the lack of justification and the need of estimates of direct heating and waste heat.

2. Questioning the role of CO_2 in global warming

In the context of greenhouse effects, the role of CO_2 is based on an average global atmospheric concentration determined from data collected at an international laboratory located at about 3,400 m on the slopes of the

Hawaiian Mauna Loa volcano and mathematically harmonized to take into account secondary factors. The resulting concentration assumed to be applicable to the whole planet, evolves regularly with seasonal fluctuations (Fig. 2) [5−6]. However, NASA showed rather recently that carbon dioxide is primarily located in the Northern hemisphere [7]. Furthermore, Mauna Loa data are collected in the middle of the Pacific Ocean in a zone where turbulent winds blow occasionally from the West where China, the principal producer of anthropogenic CO_2 in the world is located. Whether increasing Chinese CO_2 releases may affect Hawaiian data has not been considered yet.

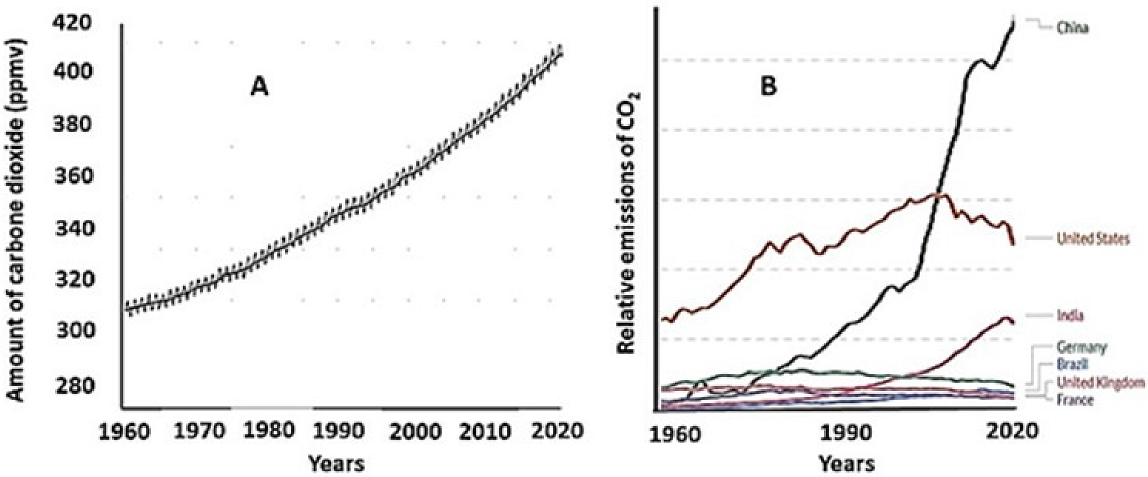

Fig. 2. A) Evolution of the average concentration in carbon dioxide around the Mauna Loa volcano [5] permission from "NOAA Climate.gov"; B) Variation of the emission of CO_2 by China and other countries during the last decades compared to other producing countries [6] : Source: Global Carbon Budget (2022); OurWorldInData.org/co2-and-greenhouse-gas-emissions • CC BY.

As for ocean level rise, the annual rate is presently 0.2-0.3 cm, an estimate now inferred from averaged satellite data. The overall rise since 1880 was estimated not greater than 23 cm based on data collected from different techniques. The increases are linked to the disappeared ice supplemented by the dilatation of ocean waters due to ocean warming. This vision does not take into account the fact that heating the water is a source of evaporation that tends to limit dilatation. In addition, the disappearance of ice is often assessed from the reduction of surface areas of glaciers and polar ices whereas in terms of thermodynamics, the melting of ice depends on mass or volume and not on surface. The global ice imbalance was estimated at 28,000 gigatons between 1998 and 2017 [8]. This mass of ice required about 9.34 ZJ to melt at about 0°C whereas the global anthropogenic heat release was estimated at about 7.30 ZJ [9]. During the same period, the cumulated radiative forcing was about 170 ZJ [1]. Accordingly, the huge amount of heat (about 155 ZJ) stored in oceans should have caused much larger ices disappearance than observed. To our knowledge, the thermodynamic properties of ice melting, of evaporation and of water interphase equilibria, well-known for their ability to control temperature, have not yet been taken into account in the context of climate changes. The last AR6 IPCC report mentions that: "*it is virtually certain that evaporation will increase over the oceans*", without any relation to thermodynamics-based consequences.

The concepts of greenhouse effect and of radiative forcing are also subjects of debate. In physics, the greenhouse effect is observed when solar thermic infrared radiations cross the transparent wall of a close space like the glazed interior of a car, for example. Some of these radiations are absorbed and heat the interior. The enclosure of the space acts against heat elimination by convection and thus the interior temperature increases. The greenhouse effect exploited by climatologists is different. Atmospheric CO_2 absorbs specific IR waves emitted from the warmed surface of the planet previously heated by solar radiations. The excited CO_2 molecules return to ground state by reemitting the absorbed radiative energy in all directions. Half of the reemitted radiative energy returns to the surface, a process at the origin of radiative forcing. This mechanism respects neither the fundamentals of modern physics nor the Beer's law:

$$A = \log (I_0/I) = \varepsilon_\lambda LC \quad (1)$$

in which I_0 is the intensity of a radiation with wavelength λ; I is the intensity of the absorbed radiation at a distance L from the origin, A is the absorbance, ε_λ is the absorptivity at the wavelength λ specific of the absorbing substance, and C the concentration in absorbing substance.

In terms of physics, CO_2 is not a greenhouse gas. It is only an IR-absorbing gas that warms the atmosphere after a process of transferring the absorbed specific radiative energy to kinetic energy that increases the agitation of atmosphere molecules and thus raises the temperature regardless the origin of radiations. CO_2 is not by far the most efficient gas that absorbs specific IR waves. Water vapor absorbs more IR energy but it was nevertheless dropped by IPCC in recent reports because of a fast turnover of water in the atmosphere. This reason is inconsistent because it is the concentration (humidity) that must be considered according to Beer's law.

Lastly, let us consider the inputs of IR-derived heat by which Earth is heated. In the climate literature, heat is sometimes confused with temperature. Temperature is a physical parameter that reflects an equilibrium reached after heat transfer from a hot medium to a cold one. For the same transferred amount of heat in joules, the equilibrium temperature depends on the heat capacity of the heated medium in J Kg^{-1}. To the main contributions of heat brought discontinuously by natural sources (Sun, volcanoes, forest fires, etc.) are now added anthropogenic contributions, many continuously, due to the undeniable anthropogenic heat released at the production stage of the various energies and when fossil fuels combustion and electricity are used by trains and cars, thermic and nuclear plants, boats, planes and space rockets, missiles and bombs, computers, data storage centers, arsons, phones, garbage burning, etc. Humans, cattle, and hot blood animals are also contributors. Anthropogenic heat is increasingly regarded as sources of environmental heating [10-15]. Recently, a quantitative correlation between waste heat and global warming was attempted that included waste heat dispatched between land, ocean, and air. However, estimates did not take into account heat absorption by water during evaporation [14−15]. Waste heat was said accounting for 80% of the consumed world energy, i.e about 0.48 ZJ of 0.595 ZJ [16], a value to be compared to the 0.34 ZJ absorbed by the 1200 Gt loss of ice in 2021 estimated from [8].

The critics of the greenhouse effect and of the radiative forcing due to atmospheric CO_2 are still ignored today, in particular because they have not been replaced so far by a credible alternative mechanism to the radiative forcing.

3. An alternative mechanism to radiative forcing

Any alternative to the greenhouse effect and the radiative forcing must take into account and respect the fundamentals imposed by chemistry, physics and thermodynamics prior to be applied to climate.

The proposed alternative to greenhouse effect consists of a unique mechanism of management of heat supplies independently of their origin, a condition imposed by physics, with the physical phases of water to absorb, transfer and release heat. Water on Earth was given a role comparable to that of the refrigerant that allows to control the temperature in the interior of a refrigerator [9]. The whole mechanism has been detailed in [4] and is summarized schematically in Fig. 3. Among the factors that determine the climate in the low troposphere, the formation of clouds is important because it condenses the moist air raised from the surface by evaporation and releases the heat withdrawn from the surface in a cooler zone in the atmosphere. Condensation greatly decreases the IR-absorbing moisture above the cloud layer, a decrease that acts in favor of radiative elimination though the spectral windows between 8 and 13 µm specific to water vapor. Furthermore, the atmosphere and the environment below the clouds are cooled because of solar IR radiations screening.

When there was no anthropogenic heat release, this mechanism managed solar heating for billions of years without any continuous accumulation and dramatic drifts due to inner control by combined ice melting, evaporation, heat diffusion and exchanges by convection and conduction and radiative elimination. Fundamentally and ideally, ice melting and evaporation of water are physical phenomena that should keep global temperature and ocean level constant. Actually, the size of the planet, ocean streams, fluctuations of winds, and local variations of albedo, for example, preclude constancy and create local climate balanced at the global level.

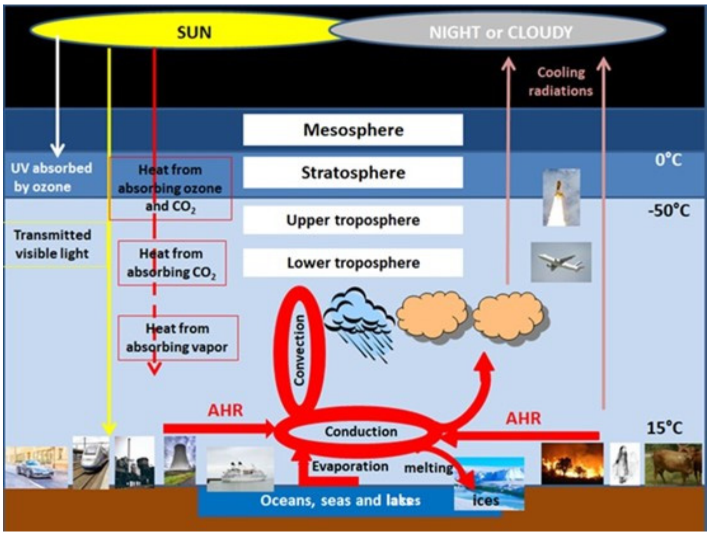

Fig. 3. Schematic representation of the mechanism that manages solar and anthropogenic heat supplies [4].

Since the beginning of the industrial age, more and more anthropogenic heat is injected in the low atmosphere. The controlling process that includes ice melting, evaporation and convection must be enhanced to manage the increase in heat. In other words, climatic events involved in heat dissipation such as winds, hurricanes, tornadoes, should become more frequent and more intense, an evolution mostly dependent on whether AHR remain negligible or not relative to solar gain. Despite imperfect control, taking into account heat absorption by melting of ice and evaporation leads to the conclusion that global temperature and ocean level can change but less than in case of radiative forcing. Therefore, the alternative mechanism justifies the still small rises of temperature and ocean level and the fairly large ice loss. If AHR continue to increase in the future as population and standard of living grow, the loss of ice, the best marker of global warming, will increase whereas evaporation will lead to more and more clouds in the sky. In average, more water in the form of clouds means less water on the surface, a shift that should lead to water scarcity and even droughts.

This mechanism is qualitative due a lack of quantitative data on the sources and uses of the global energy produced and consumed by humanity, and on evaporation that depends on temperature and on atmospheric and oceanic dynamics. Therefore, to be credible, indirect validation was necessary. A way was found that consists in a comparison with climate changes in distant past.

4 Distant past climate variations

Distant past relates billions of years during which cycles composed of glaciation and deglaciation periods with intercalated plateau periods occurred more or less regularly as illustrated by paleoclimatologists in the last 420,000 years [17-18].

The evolutions of temperature and of ocean level changes during the last 150,000 years are presented in Fig. 4 with temperature fluctuations during the current Holocene period. The comparison with the climate regulation mechanism based on heat and water is schematically shown in Fig. 5. Let us start the comparison 150,000 years ago. At that time, glaciation was maximal (Fig. 5 bottom). Much of the water was under the form of ice whereas temperature and ocean level were very low and atmospheric humidity almost absent (Fig. 4). Solar radiation was not screened by clouds and thus the temperature rise was quite fast, that is to say within about 10,000 years (Fig. 5, left). When deglaciation was well advanced, it levelled off because humidity was back (Fig. 5 top). The pseudo plateau lasted for about 10 to 15,000 years during which the Sun continued to supply heat controlled by ice melting, evaporation and formation of clouds (Fig. 5 top). When the cloud layer was important enough to screen the Sun, cooling become dominant.

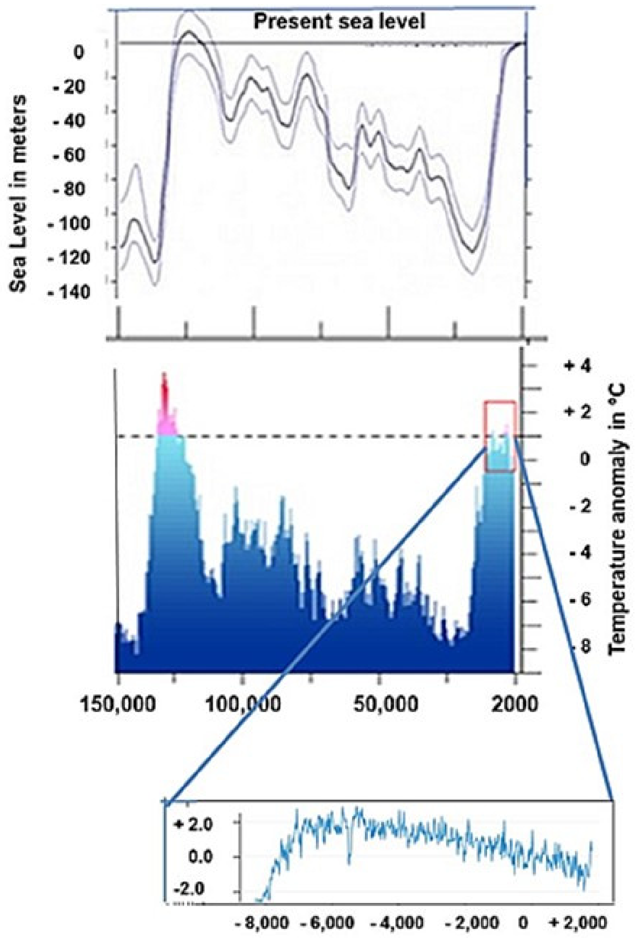

Fig. 4. Reconstructed global temperature over the last 420,000 years based on the Vostok ice core from the Antarctica (from [17]; permission from "Nature") associated with the sea level variations reconstructed from [18], permission from "Nature", for the sake of comparison over the last 150,000 years, and the rather small atmospheric temperature changes over the last 8,000 years of Holocene according to [19]; permission from "Nature".

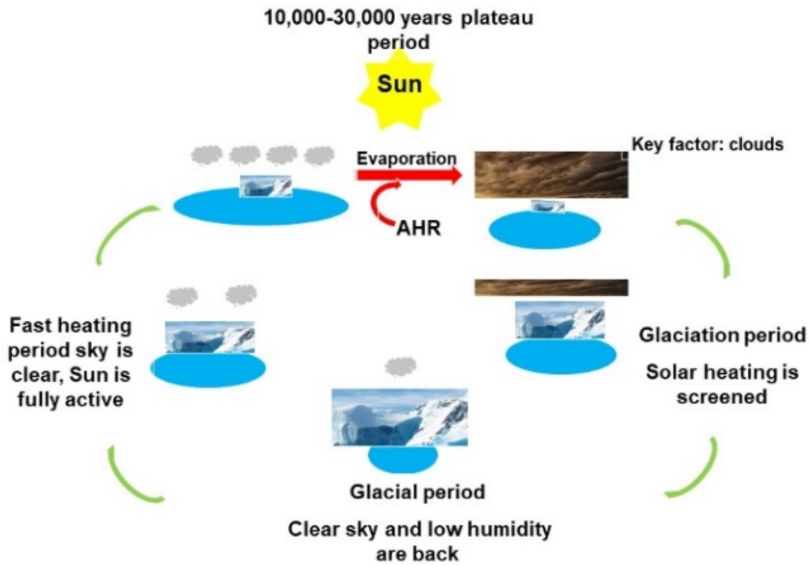

Fig. 5. Schematic representation of the comparison of evolution of the last deglaciation-glaciation-deglaciation period shown in Fig. 4 with the mechanism shown in Fig. 3 without any AH releases.

The pseudo-plateau ended and glaciation started. The temperature started to drop but the change from water, liquid or as clouds, to ice took longer than from ice to water during deglaciation because several dynamic exchanges were involved, at namely, coalescence of cloud water droplets to liquid water, raining or snowing, glaciation at about 0°C and further cooling (Fig. 5, right). At the end of the glaciation period, the cycle was completed and much of the water present on Earth, including that of the past cloud layer, was frozen again. Decreases in global temperature and ocean level were as large as − 10°C and − 120 m, respectively, compared to present times (Fig. 4). A new period of rather rapid deglaciation took about 10,000 years to complete at the start of the current Holocene era during which temperature fluctuations have remained within ± 2°C. (Fig. 4 bottom). However, about 200 years ago, HA started being injected in the atmosphere and in the environment, a major difference with the previous interglacial plateau 125,000 years ago. So far, the estimated 1.1 °C never exceeded the Holocene upper limit and is still far from it.

Although the presence of thick clouds as the source of past glaciation periods has not been proven to our knowledge, changes shown in Fig. 4 are well explained by the water management of heat inputs. Furthermore, glaciation due to the occultation of the Sun by a thick layer of clouds can be compared to the glaciation currently observed in each winter on half of the planet when the duration of solar heating in shortened. These two reasons can be considered as solid to validate the roles of heat managing given to heat, water, and clouds and schematized in Fig. 3.

5. Consequences when AH is determinant of climate changes

In terms of climate, the future depends on the anthropogenic/solar inputs ratio in terms of heat energy. Three scenarios look possible. According to the first one, the ratio remains negligible as it is claimed today. Climate continues to fluctuate as it has since the beginning of Holocene. On the other hand, if the ratio is no longer negligible due to the growth of the human population and its standard of living, the +2 °C Holocene upper limit can remain relatively respected but with aggravated climatic events, in particular increased ice imbalance, more local rain and more local drought, and more clouds. In the last scenario, the ratio becomes so large that, sooner or later, the ice stock, the evaporation and the heat dispatching by atmospheric winds and ocean streams no longer manage to avoid dramatic drifts with respect to Holocene. The formation of a thick cloud layer is accelerated to finally lead to shortening the time until he next glaciation. The challenge is to position the current period in relation to one of these scenarios. The increase of global ice imbalance when drifts of global temperature and ocean level are still very mall suggests that the second scenario is already in effect and consequences could worsen in the future according to scenario 3. Therefore, control and assessment of the growth of waste heat and AHR appear essential to keep global climate under control.

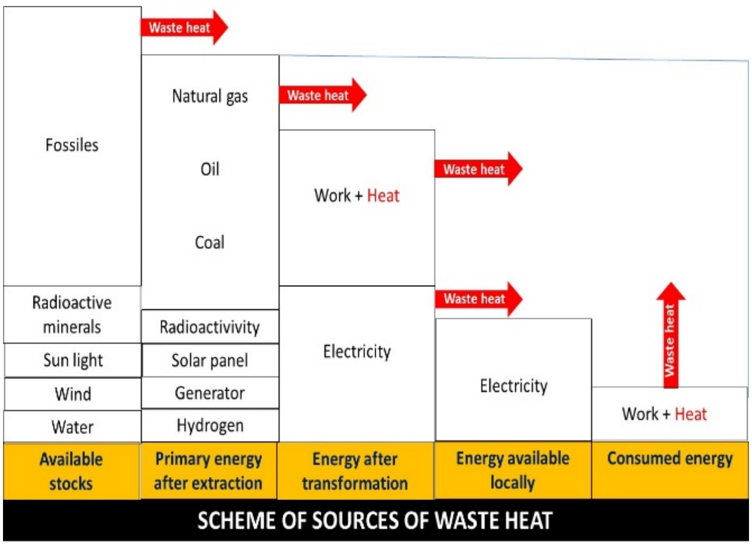

Fig. 6. Waste heat from combustion and from electricity to be assessed from cradle to grave.

Currently, the main argument for recommending electricity as a climate-friendly energy is the need to combat atmospheric CO_2. I hope the previous sections were demonstrative enough to convince that CO_2 is not the right target to control the climate. On the other hand, when they were formed, radioactive minerals, like fossils much later, stored enormous quantities of dormant energy potentially sources of electricity and, therefore, of waste heat during their treatment and exploitation in power plants. The overall amounts of consumed energy are available [20] but the amounts of waste heat that depend on yields at the production and consumption stages are not (Fig. 6).

With regard to environmental protection, the process of life cycle assessment is common use [21]. Life cycle assessment (LCA) is a methodology for assessing the environmental impacts associated with all the stages of the life of a commercial product, process, or service. Environmental impacts are assessed from raw material extraction and processing (cradle), through the product's manufacture, distribution, and use, to the recycling or final disposal of the materials that compose it (grave). The method involves a thorough inventory of the energy and materials that are required and calculates the corresponding emissions to the environment but not yet released waste heat in terms of climate.

5. Conclusion

The role of climate determinant granted to heat in the new management by water validated by its extension to distant past strongly suggests that the fight against the production of CO_2 is an inappropriate policy that may have dramatic economic and social consequences in the future if anthropogenic heat releases continue to grow while remaining neglected in favor of radiative forcing. Today, the transition to electricity, especially carbon-free electricity produced by nuclear plants, hydroelectric power stations, wind turbines, photovoltaic panels, and hydrogen fuel cells, is recommended, in particular to politicians. The lack of information about the surplus of heat injected into the environment relative to historical solar raises the question of evaluation in terms of heat cycle assessment to complete the life cycle assessment used to respect the environment, this applies to carbon fuels as well. Specialists of the production, distribution and exploitation of electricity should therefore be the right scientists to estimate heat and waste heat at the production and operation stages of electricity, this for the various sources and uses. For instance, electric cars are said, much better in terms of the impact on the climate in comparison to internal combustion vehicles, but is this still true if heat and waste heat releases to produce batteries are included? The unique reasonable policy to combat anthropogenic heat releases and to minimize ice losses and climatic drifts is to improve yields in work and/or decrease the need of global energy. As early as 1972 when the depletion of fossil resources was a prospect, Sicco Manshfolt, a former vice-president for agriculture of the European Commission underlined in "Letter Manshfolt 1972": "*it is evident that the society of tomorrow cannot be based on growth*" [22], a statement applicable today in the context of climate changes dependent on anthropogenic heat releases.

Acknowledgment

The author is indebted to the University of Montpellier for allowing the use of documentation facilities.

References

[1] Masson-Delmotte, V., Zhai P., Pirani A., Connors S.L., Péan C., Chen Y., Goldfarb L., Gomis M.I., Matthews J.B.R., Berger S., Huang M., Yelekçi O., Yu R., and Zhou B., Lonnoy E., Maycock T.K., Waterfield T., Leitzell K., Caud N., IPCC summary for policymakers. in: climate change 2021: the physical science basis. contribution of working group I to the sixth assessment report of the Intergovernmental Panel on Climate Change, 2022.

[2] Rignot E., Mouginot J., Scheuchl B., van den Broeke M., van Wessem M.J., Morlighem M., Four decades of antarctic ice sheet mass balance from 1979–2017, *PNAS.*, Vol. 116, pp. 1095−1103, 2019.

[3] R.P. Allan, B. Liepert, Anticipated changes in the global atmospheric water cycle, *Environ. Res. Lett.*, Vol. 5, 025201, 2010.

[4] Vert M., A different vision of the global warming based on chemistry, physics and thermodynamics., *Int. J. Energy Environ. Sci.*, Vol. 7, pp. 74–79, 2022.

[5] Lindsey R., Climate change: atmospheric carbon dioxide, NOAA, https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide, 2022.

[6] Richie H., Who emits the most CO_2 today? Our World of Data, 2019? https://ourworldindata.org/annual-co2-emissions

[7] NASA Center for Climate Simulation, Carbone dioxide in 3D, https://www.nccs.nasa.gov/news-events/nccs-highlights/carbon-visualization, 2017.

[8] Slater T., Lawrence I.R., Otosaka I.N., Shepherd A., Gourmelen N., Jakob L., Tepes P., Gilbert L., Nienow P., Review article: Earth's ice imbalance, *The Cryosphere*, Vol. 15, pp. 233–246, 2021.

[9] Vert M., Refrigerator as model of how earth's water manages solar and anthropogenic heats and controls global warming, *ESS Open Archive*, 2021.

[10] Vert M., Earth's ices melting: and if the greenhouse effect of anthropogenic CO_2 is not the (only) cause?, Hal-02418659v1, 2019.; Vert M., Anthropogenic heat estimate from world energy production: effects on ice loss, global warming and humanity, Hal-02418659v3, 2020.

[11] Jin K., Wang F., Chen D., Liu H., Ding W., Shi S., A new global gridded anthropogenic heat flux dataset with high spatial resolution and long-term time series, *Scientific Data*, Vol. 6, 139, 2019.

[12] Karamanev D., Impact of anthropogenic heat emissions on global atmospheric temperature, Preprints, preprints 202104.0729.v1, https://www.preprints.org/manuscript/202104.0729/v1, 2021.

[13] Pan Z., He Y., Song Y., Long B., Huang N., Zhang N., Wang J., Ma S., Han G., Pan Y., Impact of the anthropogenic heat release on the energy balance of land–atmosphere system, *Geophys. Res. Let.*, *ESS Open Archive*, 2019.

[14] Bian Q., The nature of climate change- equivalent climate change model's application in decoding the root cause of global warming. *Int. J. Environ. Climate Change*, Vol. 9 (12), pp. 801–822, 2019.

[15] Bian Q.H., Global warming thermodynamics. *Open Access Library J.*, Vol. 9 (7), e8945, 2022.

[16] BP Statistical Review of World Energy, 71th Edition, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf, 2022.

[17] Petit J.R., Jouzel J., Raynaud D., Barkov N.I., Barnola J.M., Basile I., Bender M., Chappellaz J., Davis M., Delaygue G., Delmotte M., Kotyakov V.M., Legrand M., Lipenkov V.Y., Lorius C., Pépin L., Ritz C., Saltzman E., and Stievenard M.., Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica, *Nature*, Vol. 399, pp. 429–436, 1999.

[18] Waelbroeck C., Labeyrie L., Michel E., Duplessy J.C., Mc Manusc J.F., Lambeck K., Balbon E., and Labracherie M., Sea-level and deepwater temperature changes derived from benthic foraminifera isotopic records, *Quaternary Sci. Rev.*, Vol. 21 (1–3), pp. 295–305, 2002.

[19] Vinther B.M., Buchardt S.L., Clausen H.B., Dahl-Jensen D., Johnsen S.J., Fisher D.A., Koerner R., Raynaud D., Lipenkov V., Andersen K.K., Blunier T., Rasmussen S.O., Steffensen J.P., and Svensson A.M., Holocene thinning of the Greenland ice sheet, *Nature*, Vol. 461, pp. 385–388, 2009.

[20] Statistical Review of World Energy, 72th edition, https://www.energyinst.org/__data/assets/pdf_file/0004/1055542/EI_Stat_Review_PDF_single_3.pdf, 2023.

[21] Finnveden G., Hauschild M.Z., Ekvall T., Guinée J., Heijungs R., Hellweg S., Koehler A., Pennington D., Suh S., Recent developments in life cycle assessment, *J. Environ. Manag*., Vol. 91, pp. 1–21, 2009.

[22] Internationaal Instituut voor Sociale Geschiedenis, Amsterdam. Sicco L. Mansholt (1945-1995). Teksten van lezingen van J. Linthorst Homan. In manuscript en gedrukt., Vol. 528, pp. 1951–1953, 1972.