Energy 36 (2011) 694–707

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

The crepuscular planet. A model for the exhausted continental crust

Alicia Valero [a,*], Antonio Valero [a], Javier B. Gómez [b]

[a] CIRCE Centre of Research for Energy Resources and Consumption, Mariano Esquillor Gómez, 15, 50018 Zaragoza, Spain
[b] Department of Earth Sciences, Universidad de Zaragoza.C/Pedro Cerbuna 12, 50.009 Zaragoza, Spain

ARTICLE INFO

Article history:
Received 20 July 2010
Accepted 22 September 2010
Available online 26 November 2010

Keywords:
Exergy
Upper continental crust
Crepuscular planet
Reference environment
Minerals

ABSTRACT

We propose a model for an exhausted upper continental crust. The Crepuscular Earth represents a degraded planet where all resources have been extracted and dispersed, and all fossil fuels have been burned. The starting point of the model of crepuscular crust is the composition given by the geochemist Grigor'ev, which is constrained by the conservation of mass statement between the chemical composition of the crust in terms of elements and in terms of minerals. Additionally, the model is given geological consistence, by introducing a series of assumptions based on geological observations. As a result, the obtained crepuscular crust is composed of the 294 most abundant minerals. Together with the model of exhausted atmosphere and hydrosphere developed in a previous paper, the study will serve as a reference for calculating the exergy of the current mineral capital on Earth and its degradation velocity.

1. Introduction

Economic development is tightly linked to the extraction and use of mineral resources. In the time span of a few generations, man has exhausted a large part of the mineral capital that Nature had produced during millions of years. As a result, the world has undergone a rapid industrialization and the quality of life of especially those living in developed countries has reached unsuspected limits. However, the Second Law of Thermodynamics imposes a cost on any transformation in Nature. The counterpart of the industrial revolution is the loss of biodiversity, the greenhouse effect, the pollution of soils and rivers, etc.

The irreversibility concept tells us that sooner or later everything will be degraded with the maximum possible generated entropy. Fortunately, the energy coming everyday from the Sun has avoided this end to come. In fact, it has allowed the existence of life and an ecological equilibrium on Earth. But industrial processes are altering the natural equilibrium and are accelerating the approach to the "commercial end of the planet".

In [27], we defined the "Crepuscular Earth" as one where all materials would have reacted, dispersed and mixed until an entropic soup, corresponding to the current composition with all of its elements that compose the crust, hydrosphere and atmosphere at ambient temperature and pressure. In short, a planet with the absence of concentrated mineral resources.

The advantage of knowing this commercial end of the planet is clear: from this reference, every substance that is more concentrated or diluted, warmer or colder, with a greater or a lower chemical potential, pressure, height, velocity, etc., will have more exergy than the Crepuscular Earth. That will allow to assess which is the natural capital on Earth and at what rate it is being degraded. Moreover, knowing the "commercial end of the planet" and what it means to degrade it, will help us to manage more efficiently our resources.

In [27] we obtained a model of the crepuscular atmosphere and hydrosphere. For that purpose, we assessed the effect on the atmosphere and hydrosphere of releasing all the carbon contained in the conventional and non-conventional fossil fuel reserves. The result was a warmer atmosphere and hydrosphere, with a higher CO_2 content. The dynamics of the atmosphere and its interaction with our society behavior in the next centuries entails many uncertainties. Thermodynamically speaking, the impact of the estimated temperature and composition of the resulting crepuscular atmosphere or hydrosphere on the bulk of the mineral capital on Earth is practically insignificant. Only the exergy of fossil fuels decreases when the temperature and the carbon dioxide concentration of the atmosphere increases.

The valuation of the mineral wealth is tightly connected to the definition of the crepuscular continental crust, which is the source of the main minerals and metals useful for mankind. The crust, however, is the most complex problem. The number of substances that form the crust is very high (there are more than 4500 minerals registered. See for instance http://www.webmineral.com/). Almost the entire periodic table of elements is contained in it. Moreover, its composition is not homogeneous at all and it is still being explored.

* Corresponding author. Tel.: +34 976 76 18 63; fax: +34 976 73 20 78.
E-mail address: aliciavd@unizar.es (A. Valero).

0360-5442/$ – see front matter
doi:10.1016/j.energy.2010.09.034

Nonetheless, in this paper we will present a model of the mineralogical composition of the upper continental crust. Thanks to this model, we will be able to assess the mineral capital on Earth in a more realistic way than it was done before, when only the chemical exergy of the minerals, calculated from a Reference Environment was taken into account [6].

Mineral deposits are a rarity in the Earth. Throughout geological ages, mines have been covered by strata and soil layers on which vegetation has prospered. Each time man extracts substances from concentrated deposits, the mineral stock on Earth decreases. This has associated another effect: the remaining ores have a lower grade (concentration). The result is that in subsequent extraction steps, more energy and materials are required and more waste-rock is produced per unit of mineral obtained. In the limit, the grade of the deposits equals that of the exhausted crust, or what is the same, the mineral exergy bonus that Nature provides us for granted is irreversibly lost. In practical terms, it becomes then unsurmountable costly to extract minerals from a dispersed crust, since it may be demonstrated from the Second Law that as the ore grade tends to zero, the energy required to separate a substance from the deposit, tends to infinity. The calculation of the mineral exergy bonus is explained in detail in [28]. Basically, the exergy bonus of a mineral deposit is defined as the exergy that would be expended in recovering the deposit from the crepuscular planet with the available technology. Thus, it provides a measure of the replacement cost of a natural good. This concept, which sounds somewhat strange in the thermodynamic field, is commonly used in Economics. Furthermore, it constitutes a physical and objective way to associate a value to non-marketed goods.

The crepuscular crust represents a hypothetical picture of our planet without mineral deposits, oil or gas fields and with all minerals dispersed on its surface. This fictitious crust has been so exploited and dug up, that the "bare-rock" of which it is composed is well visible.

According to [26], the amount of world non-fuel industrial mineral resources is in the order of 10^{15} kg. When the remaining minerals are considered, the total quantity of concentrated minerals might increase in one or two orders of magnitude, hence to around 10^{17} kg. On the other hand, according to [29], the amount of possible available conventional and unconventional fossil fuels, is around 10^{16} kg. This means that all concentrated mineral resources of fuel and non-fuel origin only represent 0.001% of the total mass of the Earth's upper continental crust (around 10^{22} kg [31]). Therefore, we can state with no significant error, that the upper continental crust of the crepuscular planet can be approximated to the average mineralogical composition of the current Earth's crust.

In the next sections, an estimation of the mineralogical composition of the crepuscular upper continental crust is carried out. But we should clarify first the conceptual differences between the Crepuscular Earth and the Reference Environment.

2. Crepuscular Earth versus Reference Environment

The concept of Crepuscular Earth can be easily mixed up with that of Reference Environment (RE) for several reasons. In fact, both concepts constitute a reference for calculating exergies, but there are determinant differences.

The problem of establishing a RE for exergy calculations has received the attention of a good amount of authors [1,2,7,21,23]. The different RE conceptions can be divided into two main groups: Partial RE and Global RE.

Some authors such as [2,7,21] claim that the RE should be established according to the specific characteristics of the analyzed process. Hence, there is not a unique RE, but as many as the conditions of the analyzed processes require. The conception of these partial RE are therefore very far removed from the idea of degraded Earth. But for computing exergy changes of variable composition or chemically reactive steady flow processes, a global RE is generally unnecessary generally unnecessary.

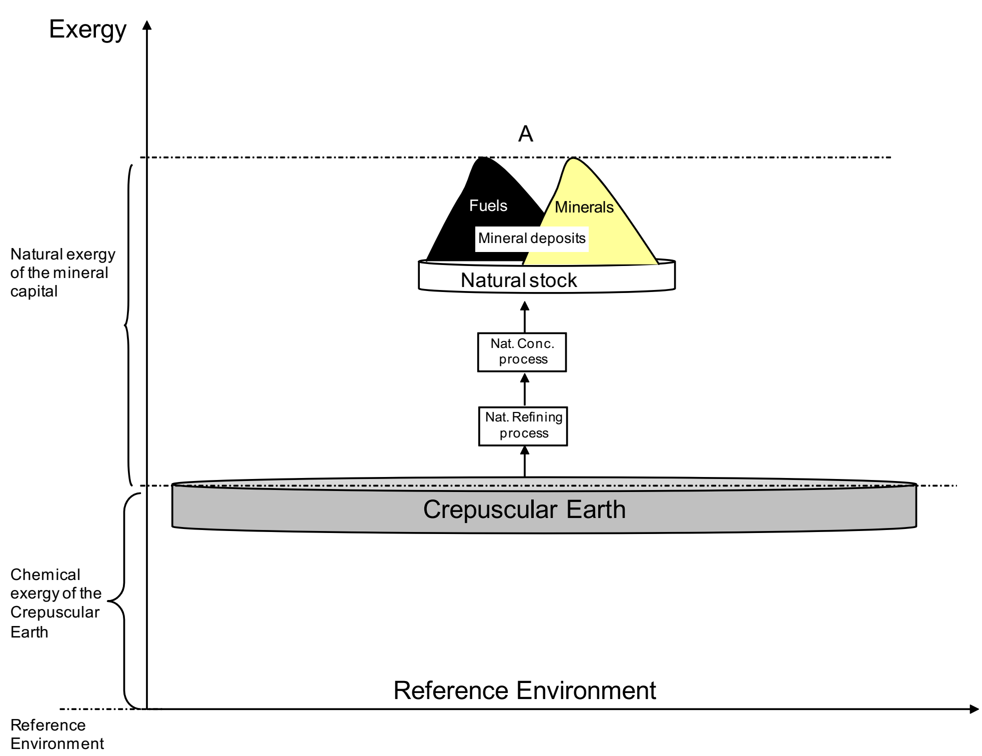

Fig. 1. Conceptual diagram of the difference between RE and Crepuscular Earth for the evaluation of the mineral capital.