FUTURE INEXPENSIVE GEOTHERMAL ENERGY AS COMPARED TO OTHER ENERGY SOURCES

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Abstract- Recent human development has been based on the use of the energy resources, especially those of fossil origin (oil, gas, coal, etc.), which are not infinite and cause damage to ecosystems. Because their burning causes the global warming, which threatens the continuity of life in the planet, it is of paramount importance to make a transition to other alternative sources of energy, that do not contribute to global warming. Based mainly on the use of a fundamental parameter called energy returned in inverted energy or energy return on investment (EROI), we can state that, except for geothermal energy, the main non-polluting alternative energy sources have low values of EROI compared to current EROI values of oil and gas. Furthermore, the main non-polluting alternative energy sources cannot contribute significantly to satisfy the global energy demand and are also adversely affected by the consequences of global warming. From these facts, we could expect in the long run a renewed emphasis on enhanced (stimulated or hot dry rock) geothermal energy sources due to technological advances in deep drilling and the availability of this kind of energy 365 days per year and 24 hours of a day.

Keywords- Energy Return On Investment (EROI), Enhanced Geothermal Energy, Fossil Fuels, Ecosystems

I. INTRODUCTION

The available free energy sources, which enable the human species to perform the fundamental tasks necessary to survive and develop, play an important role in the way we organize ourselves into complex dissipative structures. At a general level, industrial and transportation systems are mainly based on oil and gas consumption, and electricity generation, steel production, cement manufacturing are based on the use of coal. The burning of both fossil fuel types is causing pollution and global warming. While the current economic system produces and consumes more and more energy, the experimental evidence shows not only a global warming, but also a monotonically increasing number of ecosystems damaged by the pursuit of economic benefits at all costs. Hence, this human behavior must be changed to protect planetary ecosystems, and the conditions that allow the existence of life, including human life. That is, the planet is on the verge of an ecological crisis; the so called sixth mass extinction [1,2]. In the long-term, all planetary life forms are at risk of extinction due to the challenges under very rapid environmental changes like pollution, abrupt increasing on temperature and the corresponding climatic consequences.

In this light, here we briefly compare and discuss different global sources of energy and their social and environmental impact, based mainly on the use of a fundamental parameter called energy returned in inverted energy or energy return on investment (EROI) for each source of energy. EROI is a fundamental conceptual tool, which together with other criteria will allow humanity to outline a global transition to the use of other alternative sources of energy that shall not contribute to global warming, to attain a sustainable global planetary ecosystem.

II. DEFINITION OF EROI AND BIOLOGICAL EVOLUTION

EROI is a method to evaluate sources of energy per how easy energy for human use can be extracted from planet Earth based on how many energy is required to extract a determined quantity of energy of a given energy source. This concept was originally proposed by Hall et al [3,4].

The EROI is the ratio between the quantity of energy obtained from a specific source and the quantity of energy required to achieve such goal:

$$EROI \equiv {}^{E_0}/_{E_1} \qquad (1)$$

Here E_0 is the obtained energy, and E_1 is the quantity of energy required to obtain E_0. Since the production of energy is necessary for most of the human activity, it is obvious that energy sources with high EROI value are better than sources with low EROI values. And additionally, according to Hall et al [4], EROI analysis provides a useful approach for examining disadvantages and advantages of different fuels and also offers the possibility to look into the future in ways that markets seem unable to do.

The biological evolution of species has long had an interdependence between the rate of energy gain obtained from a food or energy source and the energy used to obtain it; the higher the rate of profit, the greater the chances of living and reproducing. Studies done by anthropologists about the stage of hunting and gathering indicate that human beings were acting to maximize their energetic return in relation to invested energy required to obtain food [4]. In that stage, EROI had a mean value of 10, which means that in average ten kcal were obtained, for one kcal invested to obtain food. [4]. In the current

civilization, physical energy is required to develop practically all activities such as education, medicine, art, etc. To keep a complex civilization running it is necessary to have an average energy source that covers all human needs with an EROI value close to 10 or higher. In general, any alternative source of energy that does not give an EROI value of 10 or higher is implicitly being subsidized by other higher economic or energy outputs, such as those resulting from burning fossil fuels. About the minimum value of EROI for human kind, which could give guarantee for civilization to survive, Hall [4] points out: "our guess is that we would need something like a 5:1 EROI from our main fuels to maintain anything like what we call civilization. Perhaps a future paper could undertake these difficult calculations".

III. FUTURE OF GEOTHERMAL ENERGY BASED ON EROI VALUES OF GLOBAL ALTERNATIVEENERGY RESOURCES

Next, we will present a synthesis of EROI data for various energy sources, both fossil and alternative sources together with a brief analysis of the essential aspects of Hot Dry Rock (HDR) or Enhanced Geothermal Energy (EGE), which might be in the future the main energy global alternative in view of the depletion of fossil fuels.

Most alternative energy sources to fossil fuels share several fundamental characteristics that make them incapable of replacing fossil fuels in a simple and economical way. For instance, these energy sources must satisfy at least some of these requirements; high energy density, portability, relatively high values of EROI, availability in the quantities required by mankind, accessible prices, and production 24x365. Let us recall that some sources negatively affect the ecosystems near the sites of operation. In addition, all sources, except geothermal energy, are negatively affected by the increasing consequences of global warming and therefore their reserves (even if could be technically optimized in the future) do not guarantee their supply at low prices for long periods of time. The massive substitution of fossil fuels by renewable energy sources is urgent because the time required to get such change requires around 55 years, according to Marchetti [5,6].

Let us enumerate EROI data for various energy sources, both fossil and alternative sources, and its contribution to global consumption of energy. Oil: Its contribution to global consumption is 32.6 percent [7] and its average EROI value is 18 [8]. Coal: Contributes 30 percent to world energy consumption [7] and its EROI has an average value of 40 [8]. Gas: Contributes 23.7 percent [7] to world energy consumption and its EROI value for gas is 10 [8]. Nuclear: Its contribution to world energy consumption is 2.0 percent, [9] and its global average value of EROI is 6.5 [9]. Hydropower: This energy source represents 2.3 percent of the world energy consumption [9] and its global average value for EROI is 84 [9]. Wind power: Its contribution to world energy consumption is around 0.2 percent [9] and its average value for EROI is 6 [9]. Photovoltaic solar energy: Its contribution to world energy consumption is around 0.06 percent [9] and its average value of EROI is 6 [9]. Biomass: Its contribution to world energy consumption is a little more than 7.5 percent [10]. First data of a very careful study shows preliminary and incomplete values which could indicates that the use of wood for burning in small thermoelectric plants could give a possible value of 25 for EROI, if the facility is less than 50 kilometers from the forest which provides the fuel [11]. Bioethanol and biodiesel: Represents 0.5 percent of the total world energy consumption. EROI for corn based ethanol, gives a value for EROI of 1.73:1, according to Kim and Dale [12], or 0.82:1 according to Pimentel and Patzek [13]. Cellulosic Ethanol: Due to the inherent problems with corn ethanol, there is a growing interest in using cellulosic biomass from non-food biological material to produce ethanol. This industry is just beginning to emerge and no large-scale plants are available from which to extract performance data to calculate EROI values [14]. While David Pimentel certainly hopes that the proposal to convert cellulosic biomass into liquid fuel will achieve the goal of generating a significant amount of net energy, he is not optimistic that even if this process were possible it could make a sufficient difference. This because the green plants collect and convert less than 0.1% of the incident sunlight into plant matter, while photovoltaics at 15% efficiency collect 150 times the solar energy per square meter than green plants do per year and would be, in his opinion, a better use of the land. Actions in such way would not compromise much of the biomass of United States since there all green plants collectively produce biomass equivalent to about 53 exajoules of energy per year from sunlight, which is only about half of our total fossil energy use [14]. Energy from tides and waves: This type of power it is geographically limited. The total contribution of ocean energy is about 0.002 percent [9]; EROI is 6 for tides, while the energy of waves has an EROI of 15. There are few places on the planet where the tides are high and can be dammed [9]. Tar Sands: The average value for EROI of tar sands is 4, [15]. Shale Oil and Gas: Its EROI value is roughly 1.5:1 for the final fuel product [16]. The last two energy sources are not considered economically relevant in any serious scheme, because of their low EROI value, and because, as in the case of bio ethanol obtained from maize, they correspond to geo-political decisions of the governments that promote and impulse that promote and impulse these types of energy sources [17].

Geothermal energy: This comes from primordial energy of planetary accretion and radioactive decay

of materials that exist in regions near the center of the Earth. Depending on the process of production, it can be divided in two types,; WHR and HDR:

a) Wet Hot Rock (WHR): This energy source consists of steam sources, which arise naturally from Earth to the surface in exploitable quantities. This type of geothermal power is geographically limited. The total contribution of wet geothermal energy is about 0.1 percent of energy world consumption [9].

b) Hot Dry Rock (HDR) or Enhanced Geothermal Energy (EGE): This energy source does not arise naturally from Earth to the surface. However, as we will discuss below, most of the geothermal energy could be obtained within conventional techniques almost from anywhere from dry and impermeable rock from 6 to 10 kilometers deep in the Earth. Therefore, this type of geothermal power it is not geographically limited, in contrast to WHR sources. To extract geothermal energy from hot dry rocks deposits, first a well is drilled to the area of hot rocks, which lies several kilometers below the surface of the Earth. Later a stationary flow of cold water is injected through this well. This requires the operation of a hydraulic system, which passes the water through natural and induced fractures that exist in the area of hot rocks. And then, hot water is carried to the surface through another well. From this last stage the installation operates more or less as a wet rock geothermal plant, where the only difference between a wet geothermal plant and the enhanced geothermal plant is that in the last case the water used to transport heat energy from inside the Earth is recirculated in a continuous circuit. EROI for WHR energy source is around 9 [18], and in the case of HDR or EGS goes from 1.9 to 13 or from 5.7 to 39, according to Hall [19]. Hall attributed these differences to the lack of a unified methodology to consider the border effect of thermodynamic systems, and to the future implications of technological improvements. Enhanced Geothermal Energy or Hot Dry Rock Geothermal Energy is available 365 days a year, 24 hours a day. Such type of energy source is destined to grow in an accelerated way because it does not contribute carbon to the atmosphere, it is renewable, and its cost is close to that of fossil fuels. Large-scale production worldwide is technically and economically affordable soon. The breaking of rocks into large fragments requires much less energy as compared to the traditional drilling process that transforms the rocks into dust during the drilling processes. With these new techniques, the cost of drilling increases almost linearly with depth, unlike conventional techniques for which the drilling cost grows exponentially with depth. It is expected that these techniques will reduce in 90 percent the perforation costs, which for any geothermal energy facility represents the main portion of the total investment, according to Augustine [20] and work in Refs. 21-25. So, fortunately, one of the main obstacles to the development of HDR or EGS is in the process of being solved.

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