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PERSPECTIVES ON GLOBAL DEVELOPMENT AND TECHNOLOGY 14 (2016) 290-299

PERSPECTIVES ON GLOBAL DEVELOPMENT AND TECHNOLOGY
brill.com/pgdt

Impact of Global Energy Resources Based on Energy Return on their Investment (EROI) Parameters

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Abstract

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 damage ecosystems; it is of paramount importance to make a transition to other alternative sources of energy. We compare and discuss many global sources of energy and their impact, based on the useful parameter called energy returned on energy invested or energy return on investment (*EROI*). In the long run we could expect 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.

 | DOI 10.1163/15691497-12341389

Keywords

Ecosystems – energy sources – energy return on investment (EROI) – enhanced geothermal energy – fossil fuels

1 Introduction

The available energy for the human species plays a fundamental role in the way in which humans organize themselves according to complex social and technical structures. For instance, in the modern world, the quality and duration of human life is proportional to the daily quantity of energy per capita.

At the same time that people produce and consume more energy, many experiences with damaged ecosystems show the search for economic profits must be changed to protect the ecosystem. At a general level, industrial and transportation systems are mainly based on oil and gas consumption, causing pollution and global warming. Furthermore, humanity is on the verge of an ecological crisis. In this light, here we briefly compare and discuss different global sources of energy and their social and environmental impact, based on a useful parameter called energy returned on energy invested or energy return on investment (*EROI*) for each source of energy. *EROI* is an extremely important conceptual tool to outline a future economy based on energy sources different from fossil fuels in order to attain a sustainable global planetary ecosystem.

2 Oil and Minerals Depletion in a Finite Planet

Naturally some very important questions arise. What is the amount of global oil and gas reserves? Which is the maximum amount of such reserves that could be profitable? At what rate it is possible to produce oil and gas?

We know that the running of all the industrial processes requires an energy flow in a direct or indirect way. But it wasn't until the energy crisis of 1974 that many people began to realize the central role that energy plays in maintaining and developing the current life style of human civilization. In 1999, when former US vice-president Dick Cheney was CEO of the petroleum company Halliburton, he gave a speech before the London Institute of Petroleum. The essential message given by Cheney was that there were some estimates that give a yearly growth of oil demand around two percent, and that a conservative decline in the world production of three percent in the next years was to be expected. At the same conference he also stated that oil is unique since it is a relatively cheap strategic energy resource in natural form. Since in the Middle East there exists approximately two-thirds of all of the world's oil with a cheap cost of exploitation, then important events such as US interventions, internal conflicts, and wars were a clear result of this reality.

There exist three forms of fossil fuels: coal, oil, and gas, which were part of living prehistoric vegetal and animal life. Now they are being consumed or spent at a rate millions times faster than they were formed. By burning them, our human activity returns carbon to the planetary ecosystem (in the form of atmospheric carbon dioxide and other molecules) and other minerals. In 1896, Svante Arrhenius, Chemistry-Nobel Prize winner in 1903, predicted that the industrial revolution eventually would be produce global warming.

Bertrand Russell said more than 50 years ago, that humanity had not realized that it was squandering fossil fuels by dissipating in a couple of hundred years non renewable energy sources that took more than 100 million years to produce naturally (McLamb 2011).

Regarding the extraction of minerals, there exist rising limitations to obtain all types of minerals that are being used for different economic activities. There is research that indicates that for many minerals, their extraction exhibits a peak in the future, as for instance in the cases of phosphorus and iron (Déry and Anderson 2007). In summary, we live in a finite-size planet, and it is a principle of the economy to exploit first the deposits of higher concentration. Low-mineral concentration fields are left for later exploitation. Therefore, it is possible that these deposits could be eventually rejected for their explotation because of their high energy consumption, water pollution or other deep disturbances caused to the ecosystems.

3 Definition of EROI and Biological Evolution

EROI is a method to evaluate sources of energy according to a criteria of how easy energy can be extracted. This concept was originally proposed by Hall (2008; Hall et al. 2009). 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:

$$EROI = E_0 \,/\, E_1.$$

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.

The existing interdependence between energy profit and biological evolution is very general. Plants and animals are subjected to tremendous evolutionary pressure to get energy under conditions of competition in order to survive. 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. 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. The same value is approximately found valid for many predators, such as lions and tigers.

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.

4 EROI for the Most Popular Source of Energy: Fossil Fuels

Throughout history, humanity has exploited different energy sources. Nowadays, the world average value EROI for hydrocarbons in the world has gone from a value of 35 to a value of 15 between 1960 and 1980 (Dale et al. 2011). The EROI values for oil and gas worldwide lie between 11 and 20, and for coal it is 40. In other words, for every barrel of oil or its equivalent invested to producing more oil, between 11 and 20 barrels of oil are delivered to human society.

The EROI parameters must consider the energy used in all the actions socially realized to achieve the studied source of energy. For example, to produce oil there is energy invested in different processes such as building infrastructure, exploration and extraction, transportation, etc. As an example, let us give some average costs in the last process, transportation. Considering that oil is moved only by truck an average distance of 600 miles, then the cost is 3.58 MJ per ton-mile, considering that the oil weighs approximately 136 kilograms for barrel. The cost of transportation for pipelines is cheaper, 0.52 MJ per ton-mile.

5 Comparison of Global Alternative Energy Resources Based on EROI Values

The basic problem with alternative energy sources to fossil fuels is that none have the following ideal characteristics; high energy density, portability, and relatively high value of EROI. So, a wise combination of many energy sources should be employed based on local availability and efficiency. The massive substitution of fossil fuels by renewable energy sources is urgent because the time required to get such change requires around 55 years (Marchetti 1981, 1985). Now we present a brief summary and analysis of different global energy resources based on their EROI parameters making use of data found in the work of Dale et al. (2011) and data from other authors.

- **Oil**: The average EROI for conventional oil is 18 and its contribution to global consumption is 34 percent (Dale et al. 2011), or 32.6 percent (BP 2015). World reserves could last for 35 or 45 years at current consumption rates.
- **Coal**: The global EROI for coal has an average value of 40, and it contributes 27 percent (Dale et al. 2011), or 30 percent (BP 2015) to world energy consumption. World reserves will last for 50 and 100 years more. China is the largest consumer of coal in the world and pollution there is very high. It is well known that during coal combustion, there is production of carbon dioxide, an important greenhouse gas, and various oxides of sulfur. In addition, carbon and coal waste products release many other toxic-release chemicals.
- **Gas**: The EROI value for gas is 10 and it contributes 25 percent (Dale et al. 2011), or 23.7 percent (BP 2015) to world energy consumption. Main uses are in petrochemical industry, as fuel for industries that require high temperatures, and for the production of electricity. World reserves will last for 45 or 55 years.
- **Nuclear**: The global average value of EROI is 6.5. Its contribution to world energy consumption is 1.9 percent (Dale et al. 2011), or 2.0 percent (RESCCM 2012). The peak in world production of uranium will be reached by 2045. Well-known accidents are those of Chernobyl and Fukushima. It may not be feasible to spread nuclear power facilities around the world due to political or socially opposition.
- **Hydropower**: The global average value of EROI is 84. This energy source represents 2.3 percent (RESCCM 2012). Best sites for building dams are already occupied and are not likely to advance much more due to the damage that would be caused to the remaining wild ecosystems. Three Gorges Dam in China is the world's largest power station in terms of installed capacity (22,500 MW).

- **Wind power**: The average value of EROI is six, and its contribution to world energy consumption is around 0.2 percent (RESCCM 2012). Together with the photovoltaic solar energy this kind of energy is one of the world energy sources exhibiting higher increasing rates of production. For instance, between 2000 and 2007 global wind-power energy generation increased five-fold.
- **Photovoltaic solar energy**: The average value of EROI is six. This type of power is geographically limited and it is intermittent during 24-hour cycles, which requires the use of energy reservoirs, a fact that raises the overall cost of this type of energy. Its contribution to world energy consumption is around 0.06 percent (RESCCM 2012).
- **Biomass**: The global average value of EROI is 11, its contribution to world energy consumption is a little more than 7.5 percent (IEA 2006). Biomass energy is obtained from wood and other kinds of plants and animal waste. Part of this resource is considered elsewhere as biofuels. Around 3,500 million people use almost the total of this resource (7 percent of the total energy consumption) for cooking food and heating. According to Pimentel (1999), the use of biomass cannot be increased because already humans reap 50 percent of the energy produced by photosynthesis.
- **Energy from garbage**: The value of EROI for this case is not well known. Of course, we need to recover the maximum of nonrenewable waste to ensure that it can be reused and recycled. Food waste such as fruit and vegetables, as well as the waste of human digestion, should in principle be sent back to production sites of food to restore chemical balances in local food production sites.
- **Bioethanol and biodiesel**: The global value of EROI for bioethanol is less than 1. These resources are highly inefficient compared to other forms of exploitation of solar energy. According to extensive studies (Pimentel and Giampietro 1994), the production of ethanol from corn requires the use of 129 percent of fossil energy per unit of energy obtained, so no energy gain occurs. In countries with problems of water availability, is a bad idea to use scarce water to produce ethanol. The amount of corn required to produce the fuel for a car for a year of driving would imply the starvation of 51 human beings. Biofuel represents about 2.3 percent of the total fuel used in automobile transportation, according to Renewables (2014) Global Status Report; which means 0.5 percent of the total world energy consumption.
- **Energy from tides and waves**: EROI is six 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. In a similar manner to the case of the wind, the power is proportional to the cube of the water velocity. The facilities of this type of energy will be affected in its performance due to effects of global

warming. This type of power it is geographically limited. The total contribution of ocean energy is about 0.002 percent (RESCCM 2012).

- **Tar Sands**: The average value for EROI of tar sands is four. Only ten percent of that amount is economically profitable with current technology. In the province of Alberta in Canada, mining operations are open, but according to Hansen (2012), the Canadian oil sands are dangerous since they contain twice the carbon dioxide, which humans have thrown into the atmosphere.
- **Shale Oil and Gas**: The EROI varies between 1.5 and 4, with an average value of 2.8. Shale oil is very similar to the tar sands; being both oil sources of very low quality. The shale gas revolution did not start because its exploitation was a very good idea; but because the most attractive economic opportunities were previously exploited and exhausted. Shortcomings? Serious damage to local ecosystems through different mechanisms such as segmentation of ecosystems and local water removal that is necessary for the development of wildlife. In addition, drinking water in areas near the gas wells gets contaminated by methane and various chemicals. It is known that many of such products used in the process of fracturing rocks (to obtain a productive gas well) are carcinogenic for human beings.
- **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. Until recently, geothermal power systems have exploited only resources where naturally occurring heat, water, and rock permeability are sufficient to generate energy by movement of turbines and thereby produce electricity. Its production can be divided in two types, depending on the process; 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 contribution of this source has been growing linearly with time since 1975. In 2013, 11.7 GW of geothermal power was generated worldwide and geothermal electricity generation is currently used in 24 countries, while geothermal heating is in use in 70 countries. The total contribution of wet geothermal energy is about 0.1 percent (RESCCM 2012). For instance, in Iceland there exist five major geothermal power plants, which produce more than one fourth of the nation's energy. In addition, geothermal heating meets the heating and hot water requirements of most of buildings in Iceland.

b) **Hot Dry Rock (HDR) or Enhanced Geothermal Energy (EGE)**: This energy source does not arise naturally from Earth to the surface. However, most of the geothermal energy within reach of conventional techniques could be obtained almost from anywhere from dry and impermeable rock from 6 to 10 kilometers deep in the Earth. Therefore, an important advantage of this type of geothermal power is the fact that it is not geographically limited, in contrast to WHR sources.

In order to extract geothermal energy from hot dry rocks deposits, first a well is drilled to the area of hot rocks, which exists to 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 stage the installation operates more or less as a wet rock geothermal plant. 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 hot WHR energy source is around nine (Hall 2014), and in the case of HDR or EGS goes from 1.9 to 13 or from 5.7 to 39 (Hall 2008). This author attributed the difference to the lack of a unified methodology to consider the border effect of thermodynamic systems, and 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 in the near future. 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 (Augustine 2006). So one of the main obstacles to the development of HDR or EGS is in the process of being solved.

We note that the annual contributions of different energy sources add up to 101.46 percent, due to rounding errors, which represents a relative error of less than 2 percent. We recall that our sources were BP (2015), RESCCM (2012), Renewables (2014) and IEA (2006).

6 Concluding Remarks

The worldwide burning of fossil fuels is far from ending. However, there exists strong opposition to its indiscriminate use. Let us recall that the massive substitution of fossil fuels by renewable energy sources is urgent because the time required to get such change requires 55 years (Marchetti 1980, 1985).

It is important to note that almost all investments and installations to produce electricity (from biomass, wind, sun, waves or tides, etc.) will be negatively affected by various effects of global climate change. Also, those sources of energy are intermittent in character and furthermore the contribution geothermal energy sources to global warming is much smaller than other energy sources. Therefore, in the long run we could expect renewed emphasis on geothermal energy sources obtained from Dry Hot Rocks energy sources, due to technological advances and the availability of this kind of energy source 365 days per year and 24 hours of a day.

Let us remember that we must increase the use of renewable energy sources and help prevent a humanitarian and ecosystem catastrophe on a planetary scale. It is necessary to accelerate our actions because humankind is working against time (Montemayor et al. 2015)!

Acknowledgements

We are grateful for the partial financial support provided by DGAPA-UNAM, Mexico, through Grant No. IN105814.

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