The Oil Drum: Europe
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Should EROEI be the most important criterion our society uses to decide how it meets its energy needs?

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What is EROEI?

Energy returned on energy invested (EROEI or EROI) is a concept that mirrors the financial metric, return on investment (ROI). In order to make an energy gain or "profit", energy or work must be consumed or exerted (Cleveland, C.J., 2001, p.1[1]). The energy gain or profit often referred to as "net energy". EROEI is usually expressed as a ratio, or occasionally as a percentage. EROEI can also be represented diagrammatically in simplified form (Fig. 1).

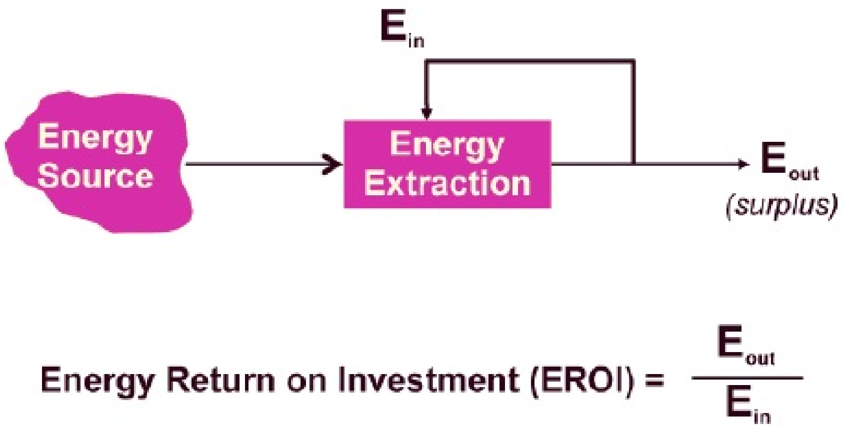


Figure 1: EROEI
(Charles Hall, Pradeep Tharakan, John Hallock, Wei Wu and Jae-Young Ko, Advances in Energy Studies Conference, Porto Venere, Italy, September 2002)[2]

The energy referred to in EROEI can be energy to run technology, such as liquid fuels for transport or electricity for lighting. It can however refer to energy in a form that can be taken in directly by living organisms: food.

How widely is EROEI-analysis currently used?

EROEI is understood by some of those campaigning on environmental issues, mostly those who focus on fossil fuel depletion issues. The concept of EROEI has been defined by Cleveland, Costanza, Hall & Kaufmann, (1984)[3] and Odum (1996)[4]. However, within society's key decision-making mainstream – financial markets, governments, parliamentarians and those advising them within the civil service and policy-making and lobbying bodies – there is little evidence that the concept and significance of EROEI is grasped or accepted. Instead they appraise different energy investment options applying financial, political and environmental criteria. Environmental criteria usually encompass climate change, local environmental effects and waste management. Where resource constraints are discussed, the financial ROI is implicitly seen as an adequate proxy for EROI: for example the remaining uranium reserve is usually described in remaining tonnes of uranium which can be economically extracted at a minimum uranium commodity price ($US per kg)[5] using current technologies. Implicit in this is the idea that the financial cost and technology are the key determiners of availability, rather than any physical constraints. Nate Hagens, a former Wall Street hedge fund manager, has observed that the financial markets do not understand net energy[6]. Peter Davies, Special Economics Advisor at BP, has also stated that the net energy of an energy source is an irrelevant criterion[7].

In addition, the decision-making mainstream has conducted energy policy on a predict-andprovide basis: “energy needs” must be met (BERR, White Paper, “Meeting the Energy Challenge”, May 2007)[8]. Energy efficiency has been encouraged since the oil crises of the 1970s and the industrialised economies now generate more wealth per unit of inputted energy now than in previous decades. However, total energy use has increased over time as the global economy has grown. Planned reduction in overall energy use, as a matter of public policy, is not yet accepted because of the impact this would have on future economic growth (Stern, 2003, p49)[9]. In the Department for Business Enterprise and Regulatory Reform’s (BERR’s) May 2007 White Paper, there are 15 references to need to sustain “economic growth”.

Measuring EROEI – system boundaries

While differences in philosophical outlook or ideological constraints may explain why EROEI has largely been ignored by mainstream decision-makers, use of EROEI as a metric to appraise energy investment options is also problematic for practical reasons.

Currently no established, globally agreed criteria exist to define the boundaries of an energy system. What inputs should be counted as “energy invested”? At what point is the “energy returned” considered to have been delivered as a useful output? The results of an EROEI analysis and the conclusions that can be drawn from them are influenced strongly by the boundaries used to define an energy system.

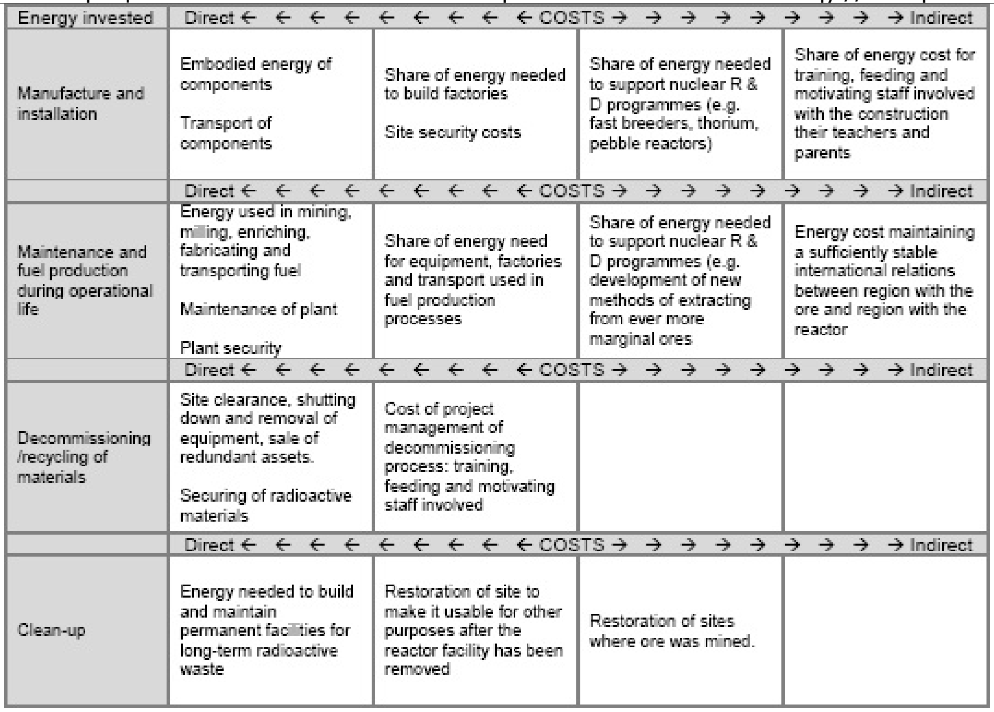
Energy returned

Where should the “energy returned” system boundary be drawn? How this question is answered depends on the scope of the energy investment option appraisal. If the EROEI analysis is limited to alternative methods of generating electricity for the national grid, the “energy returned” should be in the form of electricity delivered to the consumer. If the comparison is between methods of fuelling vehicles, the energy return should be in the form of mechanical energy delivered to turn the vehicle’s wheels.

Energy invested

Energy has to be invested at all stages in the life cycle of an energy system. As with financial accounting, some costs are directly associated with the activity. Others are overheads, which are allocated pro-rata. Some of the costs may have no connection to the energy system but have been incurred somewhere in wider society.

Example: a nuclear reactor (with examples of the energy costs that could be included)



Energy invested	Direct ← ← ← ← ← ← ← ← ← COSTS → → → → → → → → → Indirect			
Manufacture and installation	Embodied energy of components Transport of components	Share of energy needed to build factories Site security costs	Share of energy needed to support nuclear R & D programmes (e.g. fast breeders, thorium, pebble reactors)	Share of energy cost for training, feeding and motivating staff involved with the construction their teachers and parents
	Direct ← ← ← ← ← ← ← ← ← COSTS → → → → → → → → → Indirect			
Maintenance and fuel production during operational life	Energy used in mining, milling, enriching, fabricating and transporting fuel Maintenance of plant Plant security	Share of energy need for equipment, factories and transport used in fuel production processes	Share of energy needed to support nuclear R & D programmes (e.g. development of new methods of extracting from ever more marginal ores	Energy cost maintaining a sufficiently stable international relations between region with the ore and region with the reactor
	Direct ← ← ← ← ← ← ← ← ← COSTS → → → → → → → → → Indirect			
Decommissioning /recycling of materials	Site clearance, shutting down and removal of equipment, sale of redundant assets. Securing of radioactive materials	Cost of project management of decommissioning process: training, feeding and motivating staff involved		
	Direct ← ← ← ← ← ← ← ← ← COSTS → → → → → → → → → Indirect			
Clean-up	Energy needed to build and maintain permanent facilities for long-term radioactive waste	Restoration of site to make it usable for other purposes after the reactor facility has been removed	Restoration of sites where ore was mined.	

Figure 2, click to enlarge

Even if a technologically simpler energy system were to be analysed, such as a series of wind farms that generated the same net energy as the nuclear reactor, identifying and quantifying the all of the most tenuous, indirect costs would soon become impractical.

It is clearly more feasible to identify and quantify direct energy expenditure: for example, the energy cost of forging steel for a wind turbine tower, or the energy needed to transport it from the factory to its operational location. When does an energy cost become an indirect overhead? Perhaps, a portion of the energy needed to build and run the foundry and its equipment; and maybe also a portion of the energy needed to train, feed, entertain and motivate the foundry workers? The calculation would rapidly become very time-consuming and prone to error. Ultimately, a slice of the entirety of the remainder of society's activities could notionally be apportioned to each energy gathering activity, giving all energy sources an EROEI of 1:110. Clearly an EROEI which included all indirect costs, however tenuous their association to the energy system, would not be a helpful tool for assessing how best to meet society's "energy needs".

EROEI and the complexity of a society

So, if all the most tenuous, indirect energy costs of our global energy system were to be included in an EROEI analysis, the global energy system would have an EROEI of 1:1. Does this point to a more fundamental impact of EROEI on the nature of a society? Although EROEI had not been codified until recent decades, from its first beginnings all life has had to expend energy in order to capture energy from its environment: if a fox does not obtain more energy from eating rabbits that it consumes catching them, it will not survive long; similarly tulips, bacteria and humans. From the days of the earliest hunter-gatherers, the nature of human societies has been governed by their success in capturing energy (primarily food energy) at an energy profit[11].

The question of which factors determine the fate of different societies throughout history has been addressed by Joseph Tainter and Jared Diamond. In The Collapse of Complex Societies (Tainter, 1988)[12] and Collapse (Diamond, 2005)[13] the authors examine the reasons why societies of all sizes, from small isolated settlements up to the Roman Empire, collapsed. Diamond identifies four reasons why societies collapse: resource depletion; climate change; hostile neighbours;

friendly neighbours. Tainter focuses on "energy gain". Societies that manage to achieve high energy gains from their energy systems develop complexity, which have been characterised by large population densities; high levels of occupational specialisation; steeper social hierarchies and increased inequality[14] (Illich, 1974). As population densities and specialisation increase, the energy systems that sustain them have to deliver more net energy. In doing so, they allow the population to growth further and a still greater percentage of that growing population to become "non-productive" specialists.

The EROEI of fossil fuels, which represented more than 80% of our total primary energy use in 2004 (IEA, WEO 2006, p492)[15], is declining[16] (Cleveland, J., 2005, p.781) down to the lower levels typically achieved by current renewable energy technologies. If, as appears likely, we are moving to a lower EROEI or lower gain energy systems, the implications for our society will be most profound.

Other physical criteria for assessing the practicability of energy systems

As we have seen above, EROEI is a metric that can describe much more than the technical feasibility of an energy system. However, in a real world study or technical option appraisal, there are several physical factors that would need to be considered in addition to EROEI:

1. ***Infrastructural requirements*** – the world is not a blank sheet in terms of energy systems. There is a lot of existing energy infrastructure. If a new energy system requires significant changes to the existing infrastructure, it means there will be a longer lead-in time, decades in some cases (Hirsch, R. et al, 2005)[17], before the new technology starts to make significant contribution to the energy mix. For example, if the current energy system delivers liquid fuel to feed billions of internal combustion engines, a new energy system that delivers electricity for electric vehicles will only be able to replace the old system as quickly as existing liquid-fuel vehicles can be replaced or retro-fitted – a necessarily slow and costly process (financially and energetically). The energy costs of the infrastructural changes could be included as part of an EROEI analysis but the EROEI analysis would not be able to quantify the long lead-in times needed to adapt or replace energy infrastructure.

2. ***Energy density*** – the ability to store energy where space and weight constraints apply. Most energy for transport, particularly air transport needs an on-board energy store. The new energy system needs to produce energy in a form that can be stored with existing technology. The storage technology will probably require conversion of the energy, with consequent losses. This criterion could be incorporated into an EROEI analysis, if the storage process is included within the system boundary.

3. ***Location of resource*** (in relation to demand) – if the energy source is far from where it is needed, it may be impractical. This criterion could be incorporated in an EROEI analysis, if the transport process is included within the system boundary.

4. ***Scalability & rate of extraction*** – the rate at which the resource (whether renewable or finite) can be harvested will determine the maximum flow rate of energy that the energy system can deliver. Similarly, the size of the resource, together with the maximum flow rate, together will determine how big a contribution the energy system can make and, if the source is non-renewable, for how long.

5. ***Environmental impact*** – the extent to which an energy system impacts on the global and local environment has to be taken into account; this is seen most clearly in our use of fossil fuels and the effect it is having on the global climate. An EROEI analysis would not normally incorporate this factor, unless the energy costs of correcting the environmental

impact was incorporated under energy invested but this would not be a very useful analytical approach.

6. ***Complexity and resilience*** – as discussed above, there is a direct link between the EROEI of society's energy systems and the complexity of the society that can be sustained by it. Homer-Dixon (2006)[18] refers to Tainter's work and links it with the work of Crawford S. Holling on ecological systems. All systems, including those that make up a human society, go through "adaptive cycles" of growth, collapse and regeneration (Homer-Dixon, 2006, p.226). As a system grows, it not only becomes more complex, it also develops greater connectedness, as each part becomes dependent on the part before it. As the human actors in the system seek the ever greater EROEI needed to support their by now very complex society, they use their ingenuity to improve the efficiency of each part of the system. Doing so makes the relationship between the parts more tightly coupled. That efficiency gain is at the expense of system resilience. As the system loses resilience, it develops "brittleness" and it becomes less able to cope with interruptions in inputs to the system. One example of this is our modern global economic system, with the development of justin- time logistics, facilitated by IT and the internet.

   In making choices about what energy systems to build, if a complex and brittle one is chosen over a less complex and more resilient one, if and when they fail, they will be less likely to cause a much more widespread failure in the other systems that society relies on. Also, a more complex and brittle energy system requires that high levels of complexity in the wider society are maintained. This could be seen as a risk in an era when the extraction rates of society's main sources of energy, fossil fuels, are finite and are expected to go into decline during the next two or three decades and where the timing of some of the declines, particularly coal (Energy Watch Group, 2007, p4)[19], is not known with great certainty.

7. ***Managing supply & demand*** (storage issues) – energy provision could be compared with performing a theatre play: one that never ends! The show has to go on: day after day, night after night, following demand. This issue needs to be examined carefully when appraising options for electricity generation systems from renewable sources, such as wind, tides or solar.

Conclusions and limitations of this essay

EROEI is, or should be, the most important physical criterion used to assess the practicability of a proposed energy system for two reasons:

> First, if the EROEI of an energy system is 1:1 or lower, it is no longer an energy source. As the EROEI drops below 1:1, it becomes an energy sink. This is important now, because society currently benefits from such high EROEI from fossil fuels that the low EROEI of alternatives may not be as obvious as it would otherwise be. The growth in use of corn-based ethanol as a substitute for fossil fuel in the US vehicle fleet is an example where it is uncertain that the biofuel-based energy system delivers any net energy (Cleveland et al, 2006)[20].
>
> Second, the energy choices made now, if they are not made with a grasp of the wider implications of a reduction in our energy systems' overall EROEI, will cause a profound, painful and largely unexpected and apparently inexplicable reduction in the complexity of society: in other words, an unmanaged and protracted collapse.

Despite the centrality of EROEI, the other physical criteria referred to above must also be taken into account in an appraisal of energy system options; although energy density, location of resource and (to a certain extent) infrastructural requirements could all be incorporated into an EROEI analysis.

In examining EROEI, this essay has assumed that the analyses would be of different energy supply alternatives. An EROEI analysis could equally usefully be applied to different conservation and demand reduction alternatives. In this case, the other physical criteria may be different. Appraising the effect of psychological factors and behaviour change may require a different analytical approach.

This essay has not discussed the non-physical factors that also influence an energy system option appraisal: financing constraints, psychological and behavioural factors, political and security issues, macro economic implications. These remain important but, if an appraisal is to be meaningful, the physical criteria, particularly EROEI, must be fulfilled, or the extent to which they act as constraints must be understood, before the non-physical factors are considered. Most important to avoid is to see non-physical factors as key whilst ignoring or seeing as peripheral the physical criteria. Richard Heinberg[21] has said we must make our energy choices “carefully, intelligently and co-operatively”. In providing an overview of the physical criteria which determine how useful an energy system can be, this essay has illustrated why EROEI is the most important but not the sole criterion in deciding how to meet society’s energy needs.

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