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Net energy yield from production of conventional oil

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ABSTRACT

Historic profitability of bringing oil to market was profound, but most easy oil has been developed. Higher cost resources, such as tar sands and deep off-shore, are considered the best prospects for the future. Economic modelling is currently used to explore future price scenarios commensurate with delivering fuel to market. Energy policy requires modelling scenarios capturing the complexity of resource and extraction aspects as well as the economic profitability of different resources. Energy-return-on-investment (EROI) expresses the profitability of bringing energy products to the market. Net energy yield (NEY) is related to the EROI. NEY is the amount of energy less expenditures necessary to deliver a fuel to the market. This paper proposes a pattern for EROI of oil production, based on historic oil development trends. Methodology and data for EROI is not agreed upon. The proposed EROI function is explored in relation to the available data and used to attenuate the International Energy Agency (IEA) world oil production scenarios to understand the implications of future declining EROI on net energy yield. The results suggest that strategies for management and mitigation of deleterious effects of a peak in oil production are more urgent than might be suggested by analyses focussing only on gross production.

1. Background

Energy is fundamentally important to all of the processes that occur within our modern, (post)industrial society. Of all the energy resources in use, none is so vital as oil. It is an essential commodity that allows our transportation system to function, distributing much-needed food and resources among all corners of the globe.

The issue of the possibility, timing and mitigation strategies of the peak in global oil production has been discussed previously in this publication (Lloyd and Subbarao, 2009; Bentley et al., 2007; Greene et al., 2006; Alekett et al., 2010; Hirsch, 2008; Tsoskounoglou et al., 2008). Net energy analysis (NEA) and EROI have also been discussed (Chapman et al., 1974b; Leach, 1975; Bullard and Herendeen, 1975; Peet et al., 1987; Jefferson, 2008; Shaw et al., 2010; Lloyd and Forest, 2010; Sorrell et al., 2010).

Instead of focussing on total oil production, this paper looks at the net energy yield from oil production, i.e. the energy available to the economy from oil production, less the amount needed to deliver it. Consideration of this net energy perspective suggests that the implementation of peak oil mitigation and management strategies is more urgent than previously supposed.

1.1. Peak oil

Many of the oil resources currently in production were discovered decades ago. Discovery of new oil fields peaked in the sixties (Campbell and Laherrere, 1998). Production from an oil field has a very distinctive peaking shape with the peak in production, depending on the size of the field, occurring between 10% and 30% of the initial proved and probable (2P) reserves have been produced (IEA, 2008). The combined output of many such fields also has a peaking shape which could represent the production from a particular basin, country, region or even total global production. A number of major oil producing countries have already passed their peak in oil production. These include the USA (1972), Iran (1974), Russia (1987), the UK (1999) and Norway (2001) (BP, 2008). The issue of a peak in global oil production—peak oil—has been gaining greater attention in recent years since, thereafter, the availability of oil may become a serious constraint to economic opportunity and even continued well-being of countries currently dependent on such supplies.

A number of organisations, such as the International Energy Agency (IEA), Intergovernmental Panel on Climate Change (IPCC) and the UK Energy Research Council (UKERC), have made projections of future oil production. These are often based on economic

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models, such as MESSAGE (Messner and Strubegger, 1995), MARKAL (Seebregts et al., 2001) and the IEA's WEM (OECD/IEA, 2009). The IEA's projections for conventional oil production from the World Energy Outlook (WEO) 2008 and 2010 are plotted in Fig. 11. These predict a continued increase in production over the period to 2035, however the predicted increase is somewhat diminished between the WEO 2008 and WEO 2010 projections.

Hirsch (2008) distinguishes three scenarios for peak oil mitigation strategies:

1. Best case scenario: Maximum world oil production is followed by a period of relatively flat production (a plateau) before the onset of a decline rate of 2.5% per year.
2. Middling case scenario: World oil production grows to a relatively sharp break maximum, after which it goes into a monotonic decline (2.5% per year).
3. Worst case scenario: A sharp break worsened by oil exporter withholding, leading to rapid declining world oil production (potentially greater than 2.5% per year). The timing of withholding is not predictable, but it could easily occur before the peak in the middling case.

He goes on to say that, 'early mitigation will almost certainly be less expensive and less damaging than delayed mitigation,' since, 'it requires a very long time to build a substantial number of substitute liquid fuel production facilities and/or generators of alternate energy forms.'

1.2. Energy analysis

Energy analysis is the process of measuring the energy flows through the process or system under investigation. According to Boustead and Hancock (1979), 'Energy analysis is a technique for examining the way in which energy sources are harnessed to perform useful functions' Peet (1992) classifies energy analysis as, 'determination of the amount of primary energy, direct and indirect. That is dissipated in producing a good or service and delivering it to the market' reflecting the current focus of energy analyses on economic activities. Energy analysis is important for a number of reasons:

- firstly, because of the adverse environmental impacts linked with energy transformation processes, especially of concern recently being the emission of greenhouse gases associated with the combustion of fossil fuels;
- secondly, because of the finite availability of fuels and other energy resources and;
- thirdly, because of the strong link between net energy and the material standard of living and economic opportunity offered by a society (Hall et al., 1986).

There is an evidence that the quality (i.e. net energy returns) of the major energy sources used by modern, industrial society are declining (Cleveland, 2005).

1.3. Net energy and EROI

Energy production processes in particular and the energy sector in general serve society by producing surplus energy yields over and above the energy required to provide those services. An energy sector that requires all of the energy that it produces to fuel its own processes is of little use to society.

Whereas standard econometric energy models, such as MESSAGE, MARKAL and the IEA's WEM (OECD/IEA, 2009), account only for gross production by the energy sector, P, net energy analysis (NEA) considers all energy flows between the energy sector and the rest of the economy, as depicted in Fig. 1.

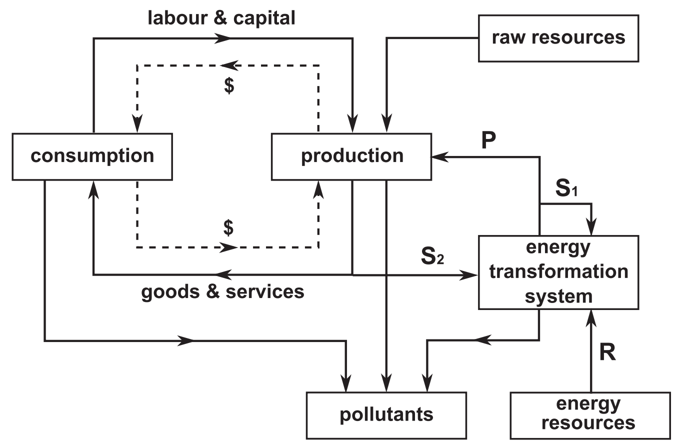

Fig. 1. Energy and material flows between the energy sector and the main economy based on diagram from Gilliland (1975).

The energy sector receives two 'inputs' from the rest of the economy in order to produce energy. Inputs in the form of energy, S_1 enable the energy sector to run its equipment, i.e. process energy. Inputs in the form of human-made-capital (HMC), S_2, are the physical plant that must be put in place in order to extract energy from the environment, e.g. oil wells, wind turbines, hydro dams, etc.

The net energy yield or benefit, the gross energy production less energy needs for extraction and processing, is $P-(S_1+S_2)$. The ratio of energy yield to the energy needed to obtain this yield, $P/(S_1+S_2)$, is known as the net energy ratio (NER) or energy-return-on-investment (EROI) (Baines and Peet, 1983; Hall et al., 1986).

A reduction in net energy yield may occur for one of three reasons:

1. the energy flow rate of the resource is declining, such as an increase in the water production of an oil field;
2. more energy is required to extract the resource, such as oil extraction by pumping down steam or gas during enhanced oil recovery (EOR) or;
3. both 1 and 2 are occurring simultaneously.

In all cases, the amount of energy required to produce a unit of energy output increases. This greater energy requirement will either be made up by utilising energy flows from within the same energy production process (internal), such as an oil producer using oil from the field to produce steam for EOR, or from energy flows originating outside of the process (external), such as an oil producer using coal or natural gas for the same purpose. In the latter case, the oil production process may be competing directly with other end-uses for the energy. Many authors have begun investigating the effects that declining EROI values will have on the economy (Hall et al., 1986; Gever et al., 1991; Peet, 1992; Cleveland, 1993, 2005; Hall et al., 2008).

Most estimates of EROI are made as static estimates of a resource at a particular moment in time. The authors have located over 500 such estimates for all of the energy resources currently under development, as well as some still under R&D. However some dynamic estimates have been made which track the EROI of a particular resource as it changes over time. A number of such studies track the EROI of oil production from various resources (Cleveland et al., 1984, 2000; Cleveland, 2005; Hall et al., 1986; Leach, 1976; Chapman et al. 1974a,b). These studies conclude that the EROI of most fossil fuel resources has been either (relatively) stable at an EROI of between 20 and 40 or decreasing over time,