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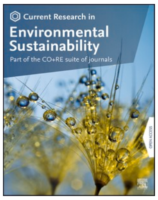

Global oil reserve estimates and the implications for sustainability

Ecosystems and socio-ecological systems are complex, hierarchical, and adaptive with the ability to use available energy flows to construct and maintain structures. Doing this, they are essentially boot-strapping, self-organization through controlled positive feedback (an important form of autocatalysis) (Levin, 2002; Patten et al., 2002). Sustainability is predicated on having this constant (or constantly pulsing) supply of energy input. Therefore, reliable input is the most fundamental test of whether a system even has the potential or not to be sustainable for without reliable energy one can unequivocally state that the system is not sustainable (Fath, 2017).

In nature, the flows of energy are solar-based, and ecosystems have emerged in place over time to capture them and transform them into exceedingly complex, diverse, intricate, information-packed networks of exchange, substance, mutualism, and competition. In socio-ecological systems, input flows were also solar-based until the recent, ecologically-speaking, two-hundred-year-old fossil fuel revolution. Of course, one could refer to fossil fuels—coal, petroleum, and natural gas—as solar-originated, but given they are formed from the photosynthetic capture of ancient sunrays (at a time when the earth was very different than it is now), they are better considered as stocks rather than flows. In the early days of fossil fuel exploitation, new sources were being found more quickly than supply diminished, prices dropped, and new applications were found. The more they were used, the more uses were found for them, driving, for the first time, a truly growing economy. But the growth was not due to a fundamental shift within the socio-ecological system itself, but rather due to the ever-increasing amounts of energy input pushing into and through the economy and society. Previously, land was the primary resource needed for capturing solar energy, it was the basis for life and economy. Now, economy could be decoupled from land unleashing new niches, activities, and specializations, but also building strong dependencies on those energy inputs. Fossil fuels penetrated all walks of human society, from heating and cooking, industrial applications, electricity generation, and notably as a transportation fuel first with coal-powered steam locomotives and eventually the ubiquitous gasoline-powered internal combustion engine. Currently, for a human population approaching 8 billion, there are around 1.4 billion cars. In the United States, there is near parity with the number of cars and humans. Overall, the number of cars nears the global human population (~2 billion) that lived during the start of the fossil-age in 1800. That is a lot of gas tanks to feed.

Fossil fuels are non-renewable resources. Warning signs about supply shortages have been raised many times, notably by the geologist and geophysicist, M. Hubbert (1956). The Hubbard Peak is the phrase given to the concept that extraction and depletion of a non-renewable resource can be reasonably modeled using a bell-shaped curve: production rises quickly in the early stages, reaches an inflection when supply is one-half consumed, and tails off symmetrically until the resource is exhausted. Hubbard used the model to forecast anthracite coal production, US oil production, and global oil production, among others. The peak is often confused as the point when the non-renewable resource becomes unavailable, but rather it is the point when one-half of the of the resource is gone, meaning one-half still remains. Therefore, while a peak does not indicate the end of supply, it does usher in a hard growth constraint – no more input to grow the system and shrinking supplies drive up prices. The peak represents the end of cheap resources, which could lead to innovation in terms of fuel switching and novel technologies, but it could lead to constriction and collapse of the dependent structures. In the transportation sector there is so much inertia and invested capital in petroleum-based engines and distribution sector, the switch away from fossil-fuels experiences a strong hysteresis, pathologically resilient to change, and locked in an unsustainable state (Kharrazi et al., 2020). Another reason petroleum is the preferred fuel choice for transportation is its high energy density (higher than other fossil fuels and biomass), meaning one has to carry less of it for the same level of performance, and there is a clear trade-off in weight of the transportation vehicle and the fuel needed for motion. In fact, if one considers a second order energy efficiency, then it is clear how immensely inefficient automobiles are as an overwhelming majority of the fuel is used to push the vehicle itself and not the passengers or cargo. US EPA reports the average weight of a car at 4156 lbs. (1885 kg) compared to weight of average person of 165 lbs. (75 kg), with a weight ratio of 96–4. All that fuel you are buying and using is almost entirely to move your car from place-to-place!

Aside: a personal anecdote is that my first foray into environmental science was in the early 1990s applying Hubbert Curve modelling to fossil fuel resources of countries of the former Soviet Union, which was the topic of my M.S. thesis from Ohio State University (Fath, 1993). While not continuing directly in that line of research, I have taken the foundational aspects of energy into other areas of ecological and socio-ecological research.

The Hubbard Peak has been applied to many non-renewable resources notably, peak oil, a concept that reached peak attention in the early 2000s (including a *National Geographic* cover story in June 2004) (some say the financial crash of the 2007–08 was a reaction to the oil prices that immediately preceded it, but that is another story). To calculate when the peak will occur, one needs data on extraction rates and also reasonable estimates on the total energy reserve. Given the current world oil markets, there are many incentives not to be honest about reserve numbers.

The current paper by energy experts Laherrère et al. (2022) investigates alternative methods to calculate global oil reserves.

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Importantly, they show that commonly published data by leading national and non-governmental sources over-estimate the reserves by significant factors. Employing an approach based on private company consultancy data and Hubbert linearization, they estimate the global ultimate recoverable resource ranges from 2500 Gb for conventional oil to 5000 Gb for 'all-liquids', which is about one-half global reserve estimates of the Energy Information Administration. These corrected values correspond to peak oil estimates of 2019 (i.e., already past) for conventional oil to around 2040 for "all-liquids". While rising prices and supply shortages will play havoc on the global economy, it will spur a faster transition to alternative transportation options (including lowering transportation demand through more compact land use design, i.e., walkable cities, also a topic for another discussion). If there is another silver lining, then lower oil reserve estimates mean there is less carbon in the lithosphere to release into the atmosphere making some of the high-end carbon dioxide emission scenarios unlikely. Still, there is more than enough remaining fossil fuels to jump past many climate change triggering thresholds at 1.5 °C, 2 °C, and beyond. Therefore, whatever the total ultimate recoverable resources of oil are in the ground, a good fraction of it needs to remain there.

In any case, I encourage readers to study the paper by Laherrere et al. closely and consider the implications that this has on all aspects of sustainability research.

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