Chapter 41

Peak-Oil and Ecological Economics

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Introduction

Peak-Oil as a concept was coined in 2002, when Collin Campbell and Kjell Aleklett founded the Association of the Study of Peak-Oil (ASPO).[2] Its early members used a curve-fitting method developed by fellow petroleum geologist K. Hubbert to forecast future oil production (e.g. Aleklett and Campbell, 2003; Campbell and Laherrère, 1998). In the mid-20th Century, Hubbert empirically discovered that the maximum extraction rate of crude oil from the wells of a region follows a bell shaped (Hubbert) curve, due to geological constraints. Hubbert applied his findings to forecast conventional oil extraction for the United States of America (USA) and globally.

The concept of peaking resources is now wide spread, but oil merits particular attention. Oil is the largest proportion of total global primary energy needs—33% in 2014 (BP, 2015)—being critical for key economic sectors of industrialised economies such as transportation, agriculture and the chemical industry (Kerschner et al., 2013; Murphy and Hall, 2011). It is also expected to be the first global energy supply constraint.

Public interest in Peak-Oil (based on web search statistics) has declined since 2005, with a short-lived comeback around the 2008 financial crisis when oil prices reached over $140 per barrel. Critics celebrated the “death” of the concept and the victory of human ingenuity in the form of fracking technology (e.g., Maugeri, 2012). Within Peak-Oil circles however, the declining interest is attributed to the lack of news worthiness assuming that most stories about ‘the problem’ have already been told, and the fragmentation of the Peak-Oil community which split into divergent camps when addressing potential solutions. Some Peak-Oilists argue for the inevitable collapse of the current industrial economies, some defend the feasibility of shifting to a 100% renewable energy system, while others favour nuclear power and/or the intensification of oil exploitation. Peak-Oil in academic publications (based on Web of Science) declined after 2008, but are now on the rise again. However, ecological

[1] Research supported by the Czech Science Foundation under the project Vulnerability and Energy-Economy Nexus at the Sector Level: A Historic, Input-Output and CGE Analysis (no. 16-17978S).
[2] The grammatically correct term would be oil peak; the change is like saying peak mountain as opposed to mountain peak. The reason for the incorrect usage was to change the acronym, because “A sop” is a derogatory term commonly used in the USA for drunkards or those easily bribed.

economists so far have shown limited interest. In the journal *Ecological Economics*, for example, only 6 per cent of all articles between 2002 and 2015 mentioned "peak oil", compared to 48 per cent that mentioned "climate change".

In this chapter we explain why Peak-Oil is a relevant and useful concept for ecological economists. The next section presents a definition based on the distinction between a quantity and a quality dimension of the phenomenon. We then turn to explanations of the evolution of oil prices and their role in indicating scarcity. We finish with some reflections on future directions and concluding remarks.

Defining Peak-Oil: Quality and quantity

Understanding Peak-Oil requires distinguishing between the available quantity and quality of existing oil (Kerschner, 2015, 2012; Murphy and Hall, 2011). The concept can then be defined as follows:

> "Peak-Oil is the maximum possible production of petroleum fuels per unit of time given external constraints. These constraints can be geologic, economic, environmental or social and determine its available quantity and quality to society."

The quantity dimension of Peak-Oil

The quantity dimension can be further divided into a stock (resource in the ground) and a flow (extraction rate of this resource) dimension.

Oil Stocks

A variety of metrics are used to describe the future availability of oil. The most common type of classification distinguishes between "resources" (amounts in the ground that might be exploitable in the future) and "reserves" (identified fraction of the resource-base estimated to be economically extractable at a given time). However, these estimates are affected by critical ambiguities and inconsistencies leading to considerable uncertainty as well as fluctuations over time. These are particularly problematic in long-term assessments, such as those required for the planning of an energy transition or the design of a sustainable economy (Capellán-Pérez et al., 2016; Miller and Sorrel, 2014).

For these reasons, Peak-Oil scholars have focused on the estimation of oil stocks in the light of the best available and transparent data, measured in terms of ultimately recoverable resources (URR). Table 41.1 compares the estimates of oil stocks available in terms of reserves and resources for conventional and unconventional oil according to three international agencies—the International Energy Agency (IEA), the German BGR and the Global Energy Assessment (GEA)—with a recent literature review of URR estimates (Mohr et al., 2015). The spread is in the range of around 1,300 Gigabarrels (Gb) for conventional oil and 2,350 Gb for unconventional oil. That is equivalent to approximately 40 and 75 years of current consumption, respectively (BP, 2015). The highest uncertainties relate to the potential of unconventional oils[3], with various claims of no peak being insight for 50 to 100 or more years (e.g. Maugeri, 2012).

Table 1: Global oil estimates from different sources (Gb)

Metric	Reference	Conventional oil	Unconventional oil
Resources + reserves	*GEA (Rogner et al 2012)*	1,590 - 2,410	2,630 - 3,570
	BGR (2013)	2,413	2,310
Remaining Recoverable Resources	*IEA (WEO 2014)*	2,715	3,296
RURR	*Mohr et al (2015) [Low; BG; High]*	(1,420; 1,490; 2,640)	(930; 1,810; 2,800)

Notes:1 Gigabarrel = 5.7 Exajoules. Source: Capellán-Pérez et al., (2016).

Oil Flows

As Laherrère (2010: 6) has stated what matters most for economic activity is not "the size of the tank" (stocks) but "the size of the tap" (flows). Geology imposes certain physical constraints on the extraction rate of non-renewable energy resource stocks. Oil deposits are not underground lakes but consist mostly of porous rock impregnated with oil. Usually water is injected to maintain underground pressure and bring the oil to the surface. Thus, technology can help regulate the extraction rate, but is bound by physical reality. Indeed innovation has so far failed to deliver substantial long-term increases in the flow rates of conventional oil wells without eventually damaging the well (Miller and Sorrell, 2014; Muggeridge et al., 2014). In addition, there are many factors (e.g. economic, political) "above the ground" that affect levels of investment in oil infrastructure (e.g. pipeline or refinery capacity) and so impact on flow rates.

Hence one key message of the Peak-Oil concept is that the most relevant limiting factor is not the remaining resource in-situ, but the constrained flow rates from deposits to consumers. Figure 41.1 illustrates the depletion over time of a non-renewable resource stock (grey dashed line) through flows (black solid line) in the absence of non-geologic restrictions. The maximum flow rate is reached much earlier than the full depletion of the stock. One of the reasons why mainstream economists struggle to grasp the concept of Peak-Oil is due to the fact that the notion of limits imposed by time is even more alien to them than absolute limits to materials and energy usage (Daly, 1992). In fact, they consider flow rates as technical details that can be changed at will.

[3] Unconventional oil (deep sea, heavy oils, tar sands, shale oil, oil shale and polar oil) is generally more technically difficult to extract, than conventional low-viscosity oils from subsurface reservoirs, requiring novel production technologies. Within the unconventional category there are several categories. Heavy or extra heavy oils are characterised by low flow and high viscosity. Shale oil (or light tight oil) is found in low permeability shale formations where flow requires stimulation via hydraulic fracturing or fracking. Tar sands (oil/bituminous sands, bitumen) is immobile in situ sometimes requiring mining.

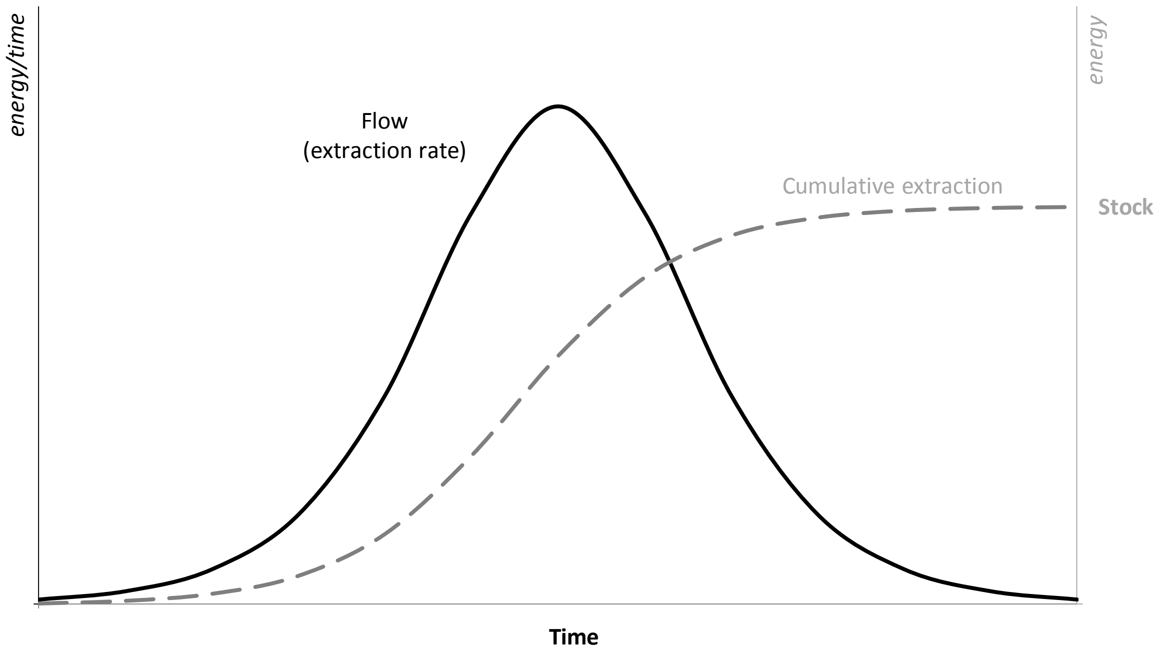

Figure 1: Simplified representation of the depletion of a non-renewable resource in the absence of non-geologic constraints. Stocks and flows of energy relative to time
Source: Own elaboration.

Peak-Oil for conventional deposits was reached in the early 2000s. Current extraction rates have remained at an undulating plateau since about 2005—levels projected by ASPO already in 2002 (~85 Mb/d). Since 2010 even the IEA—who previously ignored the work of ASPO and avoided even mentioning the term Peak-Oil—acknowledged the importance of supply constraints in its World Energy Outlooks (WEO). Extraction from operating conventional oil wells is declining at a global average rate of around 4% to 7% and 8 of the top 20 producing nations have already peaked (BP, 2015). Among them politically stable, advanced industrialised countries with the best available technology such as Norway in 1999 and United Kingdom in 2002. Offsetting this decline would require adding, every year, an amount of production capacities equivalent to all current shale oil rigs in the USA (~4.2 Mb/d), and if adjusting for quality (as discussed bellow) then an even greater amount.

Flow rates are also a key variable for unconventional deposits. For example, the oil stocks from tar sands in Alberta, Canada, are comparable to Saudi Arabia's (2nd largest oil producer after USA), but reaching just a fifth of its flow rate (~2 Mb/d), with substantial future increases being highly unlikely. In fact, Brecha (2012) argues that the rates of production of new unconventional are unable to make up for declines of conventional oil flows globally. Flows also matter for the oil industry as higher extraction rates promise faster payback of investments. Indeed high initial flow rates one of the main reasons why hydraulic fracturing has caused a gold rush among oil companies and investors.

Shale oil and gas operations are easier to upscale than those of tar sands (given the absence of public opposition). The recent steep increase of shale oil and gas production was initially not foreseen by Peak-Oilists. So far, however, what Maugeri (2012) called the “shale oil revolution” has remained mostly a USA phenomenon with around 50% of total current domestic oil production coming from shale (EIA, 2015). As a result, the USA became the world’s top producer of oil liquids as of 2014, surpassing Saudi Arabia (BP, 2015). However, after reaching their peak, shale oil wells show exorbitantly high extraction decline rates of up to 70% in the first year and between 55% and 22% thereafter, reaching their peak and being depleted much faster than conventional wells. In fact, total shale oil (and also shale gas) production in the USA is expected to peak by 2020 (Hughes, 2015, 2013). Meanwhile, the related environmental impacts are vast. Hence far from a revolution, the shale oil and gas phenomenon is more like “a dirty retirement party of the oil age”. In fact, in many other regions like Europe, fracking faces strong public opposition, and is not expected to reach a significant scale.

Figure 41.2 depicts the estimated projections of total oil production (conventional plus unconventional) found in the literature from analyses considering URR estimates (stock limits) and taking into account geological constraints of extraction rates (flow limits). Leaving aside variations due to a lack of standardisation, the general trend indicates a stagnation of production in the near future, followed by a decline during the rest of the century. Note also the substantial drop between IEA projections of 2004 and one decade later, from over 120 Mb/day by 2030 to below 100 Mb/day by 2040 (WEO, 2004, 2014).

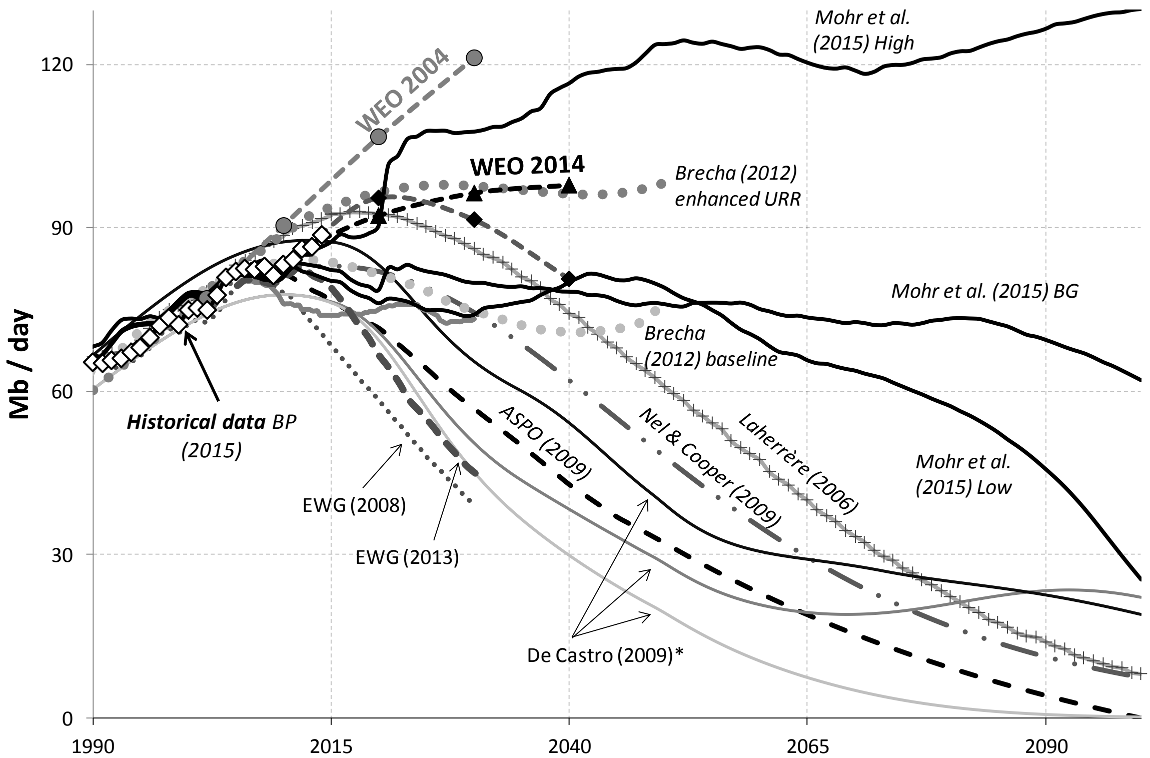

Figure 41.2 Estimations of total primary oil extraction (conventional and unconventional) by different authors (Mb/day). The estimation marked with an asterisk take into account resource quality i.e. its adjusted for net-energy via the EROI.
Source: figure updated from Capellan-Perez et al (2014).

Ahead of geology, the possible flow rate is determined by economic, social, political and environmental parameters. Many oil producing countries have, for example, substantially reduced oil exports due to increases in (usually subsidised) domestic demand. Geopolitics—as in the standoff between the USA, Saudi Arabia and Russia since about 2014— is another causal mechanism. However, in the medium to long run the critical factor determining flow rates is the quality dimension of Peak-Oil, as it essentially changes the social metabolic profile [Chapter 11] of our energy-economy system.

The quality dimension of Peak-Oil

According to resource economists, those resources with the highest quality will be extracted first—the 'best first principle'—in order to minimise costs and maximise profits. For the case of oil, the highest quality deposits are conventional giant fields (over 0.5 Gb of sweet light crude oil) situated on land, ideally in a desert with low population density and low environmental impacts and in a politically stable country willing to sell freely to global markets. Any deviation from this ideal case tends to increase economic, social, political and environmental costs and therefore reduces its 'quality'.

One parameter of resource quality is the net energy obtained. That is the available primary energy after subtracting the amount necessary to explore, extract and refine an energy resource. This is called the energy return on investment (EROI). If the EROI is 1, then as much energy is invested as it is finally obtained; and if less than 1 more energy is invested than obtained (being an energy sink instead of a resource). According to Hall et al., (2014), the global EROI of oil has declined from 30 in the 1995, and to about 18 in 2006, while unconventional oil (e.g. tar sands, shale oil) are between 1-5. As the EROI of energy resources declines less net energy is available for our economic system (Dale et al., 2012). Similar to natural systems, our socio-economic systems have been conditioned by some key (energy) resources which have been accessible to us in a certain *quality* and *quantity*—they might be regarded as having co-evolved [Chapter 13]. The decline in EROI equates to a regime shift or metabolic change in our energy system (Murphy and Hall, 2011; Sorman and Giampietro, 2013), and Peak-Oil is such a change being actualised (Kerschner, 2015, 2012).

Most current energy-economy models ignore the "net energy" approach and thus are unable to detect or analyse its implications (Dale et al., 2012). For mainstream economists, natural resources are only scarce relative to another resource or the same resource of a different quality (Daly, 1992). They assume that the price mechanism will bring about new technological advances (like fracking) that will solve eventual scarcities (e.g. Barnett and Morse, 1963; Solow, 1974). Thus, Peak-Oil may occur sooner or later, but will not substantially affect world economies because oil can be replaced by perfect substitutes.

In contrast, the ontology of ecological economics incorporates biophysical reality (Spash, 2012). This includes the Laws of Thermodynamics and the absolute scarcity of low entropy matter and energy (Georgescu-Roegen, 1971). Low entropy materials (e.g. concentrated iron ore) and energy resources (e.g., light sweet crude oil) are the ultimate means of economic activity. In fact entropy could be seen as an indicator of quality of resources in general (Valero and Valero, 2014), however attempts to measure entropy have proven elusive and any claims of success have been highly misleading [Chapter 9].

Other physical properties also make oil a high quality resource. It is a liquid fuel with very high power density, of relatively little toxicity or explosiveness, and that can easily be transported (e.g. via pipelines or tankers). Hence Peak-Oil is also often seen as a liquid fuel problem rather than a general energy problem. This however does not reduce its relevance, on the contrary our globalised economy requires cheap transport 95% of which currently depends upon oil. These qualities make oil very difficult to substitute (Capellán-Pérez et al., 2014; Miller and Sorrel, 2014). Substitution often depends on using alternative low entropy energy and/or materials which are subject to their own peaks (Valero and Valero, 2014). Moreover, leaving aside past dreams about a future hydrogen economy, only biofuels could currently be seen as relevant substitutes for liquid oil. However, they compete with food production, have low power density and an EROI of 2 or less depending on end use (Hall et al., 2014).

Economic Costs

Unconventional oil, which accounts for most of the latest additions to global oil flows, currently becomes profitable at oil prices between 60-80$/barrel (Hughes, 2013). This seems very high considering that our present economic system has been built on oil prices oscillating between 10-40$/barrel from 1880-2000 (except for the two oil crises). Murphy and Hall (2011) have estimated that a 'real' price of around 60$/barrel is the threshold of how much global economy was able to take in the past before entering recession. Tverberg (2015) on the other hand emphasises the role of average wages. They tend to rise with low oil prices because this leads to high labour productivity and decrease with high prices that lead to low labour productivity. The threshold for the USA seems to be around 40$/b. From that point wages start to decline, reducing peoples' discretional spending power and ability to pay mortgages, as during the 2008 financial crisis (Tverberg, 2012).

Environmental, social and political costs and impacts

Non-economic costs resulting from resource scarcities have been neglected in the Peak-Oil literature. The exception being a geo-political discourse emphasising the potential for direct conflicts over resources, both nationally and internationally. Klare (2004) for example warns about a future intensification of wars over oil and other resources. Thus, the armed forces of the USA and Germany consider Peak-Oil in their planning while other public agencies ignore the issue. Securitisation and survivalism are emphasising domestic, national and individual resilience in the face of Peak-Oil achieved through eco-modernisation, securing international supply chains and by taking up a position of all-round defence. In contrast, a recent Austrian project concluded that areas with better social structures and networks would be more resilient to the inevitable energy crises (Exner, 2015).

An overall decline in the quality of a resource also causes increasing environmental costs, because declining ore grades increase the overburden (unwanted material) in both quantity and toxicity. In addition, the necessary extraction and refining activities are carbon intensive (e.g. natural gas is necessary for processing tar sands). In fact, some researchers have recently argued that at least a third of all oil reserves are unburnable if the international limit on climate forcing of 2°C is to be met with a 50% chance. Thus, the development of unconventional fuels is totally inconsistent with such a climate goal (McGlade and Ekins, 2015). Others have argued these estimates are themselves serious underestimates, and that the actual excess of reserves is more likely 80% and fossil fuel assets on company and State balance sheets are toxic (Anderson, 2015; Spash, 2016). Some policy-makers have challenged fossil fuel businesses to declare such stranded assets. Meanwhile activists have initiated a 'fossil fuel divestment' campaign. However, most fossil fuel companies are State owned (e.g. Petróleos de Venezuela SA, Saudi Arabian Oil, Statoil Norway) and shares are not traded publicly: for oil and gas 90% of the world's reserves and 75% of production (Tordo et al., 2011).

Phases of high oil prices also lead to the advancement of 'commodity frontiers', a concept that has been developed in ecological economics [Chapter 16, 38 and 40]. It means that resource extraction expands into industrially untouched/pristine ecosystems, biodiversity hotspots and remote communities. Extractive activities carried out in such areas can be disastrous for the environment and local inhabitants. This is exacerbated by accidents, e.g. the 2010 Gulf of Mexico oil spill. Social struggles in this context include the Inuit's fight against tar sand operations in Alberta, Ecuadorian tribes opposing the Yasuni-ITT project in the Amazon, and public opposition to fracking. Civil resistance to the advancement of commodity frontiers can bring about an earlier oil climax. This might restrict supply as well as induce environmentally motivated voluntary reductions that could lead directly to a demand decrease, in advance of the supply peak projections shown in Figure 41.2. Taxes or direct regulation would either increase production costs or decrease available quantity by restricting access (e.g. to the Arctic or to Amazonian biodiversity hot spots). The former is advancing a demand peak (unwanted oil), the latter a supply peak (unavailable oil).

Peak-Oil and oil prices

Oil demand and supply as well as its quality and quantity dimensions interact with prices in often complex and counter-intuitive ways. Interest in Peak-Oil as an explanatory concept tends to rise with high oil prices and fade with low ones. However, when entering the Peak and post-Peak-Oil era, it is rather price volatility that can be expected. Oil prices start rising as decreasing quality raises multidimensional costs (either directly via production costs or indirectly via attempts to govern non-economic costs) and decreasing quantity reduces market supply. As potential substitutes fail to achieve the necessary quantity and quality, oil prices rise far higher than the historical level upon which industrialised economies were built, causing widespread recession. Demand for oil falls and prices collapse again, which if combined with Keynesian expansionary policies may lead to a temporary recovery of the economy. However such policies only work if debts can be repaid by expanding economic activity fuelled by an expanding resource base, which is not the case after Peak-Oil (Douthwaite, 2012). Hence a new cycle starts with demand recovering and prices rising until hitting a ceiling again (e.g. Tverberg, 2012). The result is a business cycle wave-like development. Volatility in (and not consistently high) oil prices, happening over ever shorter intervals, are then to be expected (Murphy and Hall, 2011). This volatility creates uncertainty that is more difficult to handle economically than permanent high oil prices, hampering also the planning of an energy transition.

In recent years, such volatility seems particularly evident. After the historic spike in oil prices of 140 US$/barrel in 2008, the global economy entered a deep recession and oil prices declined to below 40 US$/barrel. Countries like the USA and China put together emergency Keynesian stimulus packages of historical dimensions. Oil prices recovered and rose to a record annual average of around 100$/barrel between 2011-2014 and Wall Street was flooded with money from investors seeking safety in commodities (Rogers, 2013). Hence not only technological advances and lax environmental legislation, but also, and most importantly, the combined situation of low interest rates and high oil prices brought about the shale 'revolution' and economic recovery in the USA with annual Gross Domestic Product growth rates of +2.2% since 2009.

However, the rest of the world only partly shared this recovery and government debts have been increasing substantially everywhere. Even China's period of relentless growth appeared to have ground to a halt amid the detrimental effects of its stimulus package i.e. rising debts and a housing bubble (Wigglesworth, 2015). Meanwhile oil prices have once again collapsed to levels just above 40$/b, because of a short to medium term oversupply of oil and decreasing demand due to a weakening global economy. Such low prices mean that most producers of expensive oil are making losses (e.g. from shale). Hence many analysts talk of a shale oil investment bubble that is bound to burst at any time, possibly causing a renewed financial crisis, recession or depression (Hughes, 2013).

Future directions

Uncertainty surround how our social economic system will respond to Peak-Oil and whether price volatility, conflicts and economic turmoil are already the first signs of the post-Peak-Oil era. In fact, relatively little is still known about the economy-energy nexus (Sorman and Giampietro, 2013). Hence vulnerability and impact analysis, as well as progressive energy-economy models are regarded as essential for designing effective policy responses (Capellán-Pérez et al., 2014; Kerschner et al., 2017). Special analytical attention is needed at the sectorial economic level such as transport (Kerschner et al., 2013).

To date, most of the empirical research related to Peak-Oil has focused on estimating future oil extraction consistent with geological constraints (Figure 41.2). However, these studies have usually applied simple models (often built ad hoc) without a full representation of the economy-energy interactions. They are incapable of consistently accounting for potential technology and fuel substitutions. Thus, future work could (i) expand these models to include these features, or (ii) introduce Peak-Oil assumptions into current energy-economy models. However due to the urgency of the situation, these efforts can only go hand in hand with attempts to study, design and implement biophysical degrowth strategies such as legislated resource limits and carbon taxes. Moreover experiments should be undertaken to explore alternative social ecological economic systems that are fossil fuel independent.

Concluding remarks

Reaching Peak-Oil is not the same as running out of oil. Neither does this imply long-term sustained and exorbitantly high oil prices, as is sometimes claimed. Instead, the concept of Peak-Oil refers to a complex energy phenomenon framed by the interaction of a diversity of constraints that limit flow rates of oil to society both in quantity as well as in quality. The same concept is applicable to other non-renewable and renewable resources e.g. gas and water peaks.

Ecological economic theory is essential for understanding the relevance of resource peaks, because substitution of low entropy matter and energy is limited. Key resources like oil create use dependencies and as a result become difficult or impossible to replace in the quantity and quality required by our current industrial economic system. Moreover social ecological economics, with its concept of expanding commodity frontiers and environmental conflicts, directs the research to analyse the usually neglected environmental and social costs of resource peaks.

In response to Peak-Oil and other social and environmental factors, social ecological economists and the degrowth community [Chapter 44] argue in favour of a conscious downscaling of the economy, with some arguing in favour of a biophysical steady state [Chapter 45] (e.g. Kerschner, 2010). This goal could be seen as identical to that of a post-carbon transformation of our society. In terms of Peak-Oil it implies voluntarily bringing about an early peak or adapting to the post-Peak-Oil era quickly and proactively. As we have outlined, there are indications that our society has already entered into this era because of persistent and substantial oil price volatility, economic turmoil and conflicts.

A radical post-carbon transformation provides the only long term exit route out of Peak-Oil enhanced boom and bust cycles. Ill-conceived Keynesian stimulus packages for saving banks and the automobile industry or for feeding housing and infrastructure bubbles only postpone the peak and steepen the inevitable decline. Moreover, this transformation, which also means a reshuffling of the cards of global power relations should be seen as an opportunity for creating a more equal and just society as envisioned by the degrowth movement.

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