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Uncertainty in the availability of natural resources: Fossil fuels, critical metals and biomass

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HIGHLIGHTS

- Resource estimates are highly uncertain, frequently incommensurable, and regularly contested.
- Data limitations need to be overcome, and methodologies harmonised and improved.
- Sustainability and socio-political uncertainties are frequently neglected.
- Uncertainties are dynamic, but reducing uncertainties inevitably involves trade-offs.

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ABSTRACT

Energy policies are strongly influenced by resource availability and recoverability estimates. Yet these estimates are often highly uncertain, frequently incommensurable, and regularly contested. This paper explores how the uncertainties surrounding estimates of the availability of fossil fuels, biomass and critical metals are conceptualised and communicated. The contention is that a better understanding of the uncertainties surrounding resource estimates for both conventional and renewable energy resources can contribute to more effective policy decision making in the long term. Two complementary approaches for framing uncertainty are considered in detail: a descriptive typology of uncertainties and a framework that conceptualises uncertainty as alternative states of incomplete knowledge. Both have the potential to be useful analytical and communication tools. For the three resource types considered here we find that data limitations, inconsistent definitions and the use of incommensurable methodologies present a pervasive problem that impedes comparison. Many aspects of resource uncertainty are also not commonly captured in the conventional resource classification schemes. This highlights the need for considerable care when developing and comparing aggregate resource estimates and when using these to inform strategic energy policy decisions.

1. Introduction

The global energy system consumes vast quantities of natural resources. Some of these resources are finite (e.g. fossil fuels), some are renewable (e.g. biomass), and some, for example the metals required for permanent magnets in wind turbines, are finite but may be recycled. Scenarios for how the global energy system might evolve play an important role in informing the policy debate and are strongly influenced by resource availability and recoverability estimates (DTI, 2007). Yet these estimates are often highly uncertain, frequently incommensurable, and regularly contested. For example, fears over the availability of oil, have frequently led to statements that a transition to alternative energy sources will be necessary to avoid the socially disruptive effects of increasing prices (Helm, 2011, Maugeri, 2009).

Bioenergy is a renewable energy option that has arguably the greatest potential to substitute for oil, but here also there is uncertainty over its future availability. In particular, the interlinkages between biomass and food production have generated a high profile and divisive debate about whether large-scale adoption of bioenergy can be truly sustainable and the extent to which policy support can be justified (Slade et al., 2011b). In the case of other renewable energy infrastructure such as wind turbines and solar cells, these will only be able to make a significant contribution to global energy provision if large quantities of the critical metals[1]

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[1] The list of metals considered as *critical metals* is not fixed, but typically includes: Cobalt, Platinum Group Metals, Gallium, Rare Earth Elements (REEs), Germanium, Selenium, Indium, Silver, Lithium, and Tellurium (Speirs et al., 2013a).

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required for their production are available. The emergence of resource nationalism in response to real, or perceived, supply constraints could restrict access to these metals and this may ultimately limit the rate at which such technologies are adopted (Moss et al., 2011; Hayes-Labruto et al., 2013). Sources of uncertainty such as these provide the context in which strategic energy policy and resource management decisions must be made.

This paper explores how the uncertainties surrounding estimates of the availability of fossil fuels, biomass and critical metals are conceptualised and communicated. The nature of the uncertainties in these resource estimates has been examined by a number of analysts (see e.g. Sorrell, et al. (2010), Slade et al. (2011a), Mcglade et al. (2013a, 2013b)), yet the importance of understanding and quantifying uncertainty in resource estimates is often downplayed. Analysts also frequently fail to quantify or even acknowledge the uncertainty in the estimates they produce (IIASA, 2012, ARI, 2013). The result is a very wide range of estimates of 'available' resources that has the potential to cloud debate, confuse policy makers, impede effective action and foster further uncertainty and ambivalence (Lynd et al., 2011, Pearson et al., 2012). This is particularly the case for resources such as biomass and unconventional gas where the regulatory and policy incentive framework is less established.

The contention of this paper is that a better understanding of the uncertainties surrounding resource estimates for both conventional and renewable energy resources can contribute to more effective policy decision making in the long term. Our argument is presented as follows. Section 2 describes alternative approaches to conceptualising and categorising uncertainty in resource estimates. Section 3 introduces the dominant resource classification schemes currently used for energy resources. Sections 4, 5 and 6 discuss sources of uncertainty in fossil fuel, critical metal and biomass resource estimates respectively. Conclusions and policy implications are presented in Section 7.

2. Understanding uncertainty

Uncertainty in resource estimates stems from a variety of issues about which knowledge may be incomplete. Uncertainty, however, is a subtle concept used to mean different things in different contexts and disciplines (Thunnissen, 2003). In framing uncertainty for the discussion in this paper, two complementary approaches are presented. The first presents a typology of uncertainties and provides examples of how they might apply to fossil, metal and biomass resources. The second conceptualises uncertainty as alternative states of incomplete knowledge.

2.1. A typology of uncertainty

Uncertainties can be categorised according to their origin and impact. A typology frequently applied to fossil, metal and biomass resources estimates classifies gaps in knowledge as arising from either: physical, technical, economic, socio-political or sustainability uncertainties.

Physical uncertainties arise from imperfect data and imprecise measurement. The extent of an oil reservoir (or whether an oil reservoir exists), for example, may be based on a limited number of exploratory wells and seismic data. These techniques can only provide an imperfect estimate of the reservoir's area, volume and quality. In general, physical uncertainties may be reduced with improved sampling and repeated measurement, but this will normally entail additional cost.

Technical uncertainties relate to imperfect knowledge about the effectiveness of technologies used to extract resources. For example, the primary recovery phase of oil production only relies on the existing pressure of the reservoir. Once that pressure decreases and production slows, secondary and tertiary production techniques may be applied to artificially increase the well pressure, or influence the physical properties of the oil within the reservoir. This can significantly increase production rates in the short term and will influence the total volume of oil recovered. Estimating the potential impact of these interventions and the resulting recovery factor is difficult and varies across projects.

Economic uncertainties relate to assumptions about the future economic viability of resource extraction, including market prices, extraction costs and the availability of alternatives. If costs are high, and prices low, the quantity of recoverable commodity may be small as only the easiest and cheapest proportion of the commodity will be recoverable at a profit.

Socio-political uncertainties relate to the potential impact of current or future policy decisions or social interventions. Policy makers may change licensing rules, tax regimes, or the ownership structures of asset leases, changing the viability of affected projects. Similarly, public opposition or support for particular projects may influence the recoverability of a resource through legal, political or other channels.

Sustainability uncertainties relate predominately to the environmental and social implications of resource recovery. This might include the concerns over biomass production and its interactions with food production (the 'food vs. fuel' debate (Eide, 2008)), or the greenhouse gas implications of extracting and burning fossil fuel reserves (the so-called 'carbon bubble' debate (Leaton, 2011)). Sustainability uncertainties can influence the overall viability of individual projects either through policy or through the imposition of physical limits. For example, climate policy might dictate that fossil fuels should be left in the ground placing known fossil fuel reserves off limits. This type of uncertainty is intrinsically linked to the 'socio-political' and 'physical' dimensions, but is worth considering separately given its growing importance.

This typology is summarised in Fig. 1. Physical, economic and technical uncertainties are generally captured within the traditional resource classification schemes, although issues arise with consistency and transparency (discussed further in Section 3). In contrast, socio-political and sustainability uncertainties are typically not incorporated even though they may have significant impacts on the availability of resources.

2.2. Dimensions of incomplete knowledge

An alternative way of conceptualising uncertainty described by Stirling (2010) considers two dimensions of incomplete knowledge: the *extent of knowledge about a potential hazard or outcome*, and the *likelihood or probability of that outcome*. In the case where there are no significant gaps in knowledge an estimate of the impact of a known outcome can be combined with a discrete estimate of probability to provide an estimate of *risk*. In many cases, however, it may not be possible to know what the potential outcome will be, or its probability of occurrence. If knowledge about both these dimensions is complete or incomplete, then combining them gives rise to four contrasting states of incomplete knowledge, shown in Fig. 2, and characterised as: *Risk, Uncertainty, Ambiguity*, and *Ignorance* (Stirling, 2007, 2010).

There are a number of ways in which the axes in Fig. 2 could be interpreted with regard to estimating resource availability. However, the most straightforward is to interpret them in terms of *confidence about whether a resource exists and can be technically recovered* (*y*-axis: knowledge of probabilities) and *confidence about the social and political condition that will permit recovery* (*x*-axis: knowledge of outcomes). In this way, the *y*-axis takes into account many of the physical, technical and economic aspects of resource

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