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On the global economic potentials and marginal costs of non-renewable resources and the price of energy commodities

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HIGHLIGHTS

- Theoretical model to forecast marginal costs of non-renewable resources.
- Tracks the consumption and costs of non-renewable resources.
- For use in economic or technology models.

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ABSTRACT

A model is presented in this work for simulating endogenously the evolution of the marginal costs of production of energy carriers from non-renewable resources, their consumption, depletion pathways and timescales. Such marginal costs can be used to simulate the long term average price formation of energy commodities. Drawing on previous work where a global database of energy resource economic potentials was constructed, this work uses cost distributions of non-renewable resources in order to evaluate global flows of energy commodities. A mathematical framework is given to calculate endogenous flows of energy resources given an exogenous commodity price path. This framework can be used in reverse in order to calculate an endogenous marginal cost of production of energy carriers given an exogenous carrier demand. Using rigid price inelastic assumptions independent of the economy, these two approaches generate limiting scenarios that depict extreme use of natural resources. This is useful to characterise the current state and possible uses of remaining non-renewable resources such as fossil fuels and natural uranium. The theory is however designed for use within economic or technology models that allow technology substitutions. In this work, it is implemented in the global power sector model FTT:Power. Policy implications are given.

1. Introduction

1.1. Energy–Economic–Environmental interactions

The use of large scale models for exploring Energy–Economic–Environmental (E3) interactions is crucial for devising policy aimed at addressing coupled economic and environmental problems and achieve related policy goals. This is due to the fact that in such complex and highly correlated systems, while conceptual difficulties arise in attempting to understand the systems-wide influence of individual policies and regulations, significant complications arise in the potential mutual influence between several such policies (Barker et al., 2007). This includes for instance the strong interaction between government support for novel transportation technology and power sector or land use management, and their very uncertain effect on global emissions, which depend highly on their timing, technology diffusion timescales and energy conversion efficiencies (as examples of differences in estimations of potential emissions reductions for the transport sector, see van Vliet et al., 2010, 2011; Pasaoglu et al., 2011; Takeshita, 2011, 2012). It has been widely recognised that large expansions in modelling capacity are required in order to better predict the likely result of comprehensive policy portfolios, which should include combinations between top-down economic models and bottom-up technology models (see for instance Koehler et al., 2006a,b; Grubb et al., 2002). While common economic models can evaluate the global demand for energy, transport, materials, goods and services, they generally do not represent with much detail the way in which their supply is produced and at which costs, from lack of

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technology resolution, or none altogether. This generates for instance significant uncertainty over production efficiency, carbon intensity and greenhouse gas (GHG) emissions. Meanwhile, bottom-up technology models generally take demand values (energy, services, goods, etc.) as given and therefore, although they are able to generate prices and accurate efficiency values and emissions factors, they do not capture the interaction between prices and demand (for details on these aspects for several existing models, see Edenhofer et al., 2006, 2010). Coupling bottom-up and top-down models generates the most powerful method to capture systems-wide and economy-wide coupled interactions, which are currently strongly required for devising sensible climate change mitigation policy (Koehler et al., 2006a).

Energy flows, originating from natural resources, are a necessary component for all sectors of the world economy. Although the economic output of the energy sector accounts only for a small fraction of the world gross domestic product (GDP),[1] changes in the prices of energy carriers have pronounced consequences on the output of most other economic sectors (see for instance Jones et al., 2004).[2] Since the price of energy carriers is reflected in the prices of goods and services originating from energy intensive sectors, such changes can lead to increased inflation, decreases in economic output and reduced paces of economic development. Many attempts have been made to capture such interactions between energy, the economy and the environment in computer models (see for instance Edenhofer et al., 2006, 2010, and the various models reviewed). While many models of E3 interactions do not incorporate explicit representations of natural resource use and depletion, or the physical limits to available energy flows, very few feature endogenous exploitation costs of non-renewable resources and none of them to our knowledge features a particular emphasis on uncertainty in the economic or technical potentials of natural resources.[3] For this reason, in previous work we defined a theoretical framework and built an extensive database with a resolution of 190 countries for limiting and tracking the use of natural resources in models of global energy systems (Mercure and Salas, 2012), which, although adaptable to any energy systems modelling framework, was designed for use in the model Future Technology Transformations in the Power sector (FTT:Power) (Mercure, 2012b). FTT:Power is based on a theoretical framework for technology diffusion (Mercure, 2012a, 2013), integrated as a bottom-up component to the Energy–Economy–Environment model at the Global level (E3MG, for descriptions see Cambridge Econometrics, 2013; Barker et al., 2006, 2012; Barker and Scrieciu, 2010; Koehler et al., 2006a).

Modelling energy systems realistically requires the representation of many complex interactions between different types of systems, which must respond to the economic climate and natural environment at every point in time. This involves modelling the behaviour of actors who influence the working and composition of the technological mix within the system. Once this mix is defined, the requirements in terms of energy resources are straightforward to evaluate. Global energy demand is strongly influenced by the price of energy carriers,[4] generating a feedback interaction between the economy and the global energy system through demand and prices (Mercure et al., in preparation). Meanwhile, the cost of energy resources influences the choice of investors in energy systems and thus the technology composition, as well as the cost of producing energy carriers. Therefore, a second strong feedback interaction exists between the global energy system and the natural environment through the exploitation of resources through demand and prices. As described earlier by one of us (Mercure, 2012a,b, 2013), the evolution of technology in most sectors, including the power sector, is well described by a coupled family of non-linear differential equations that simulates transitions between energy technology systems, changes that are driven by the trend of investor decisions, an approach supported by an extensive empirical literature (see for instance Grübler, 2012; Marchetti and Nakicenovic, 1978; Grübler et al., 1999; Wilson, 2009; Bass, 1969; Sharif and Kabir, 1976; Bhargava, 1989; Morris and Pratt, 2003; Grübler, 1990). Meanwhile, the cost of producing energy carriers is influenced by that of natural resources, as well as and through components such as investment, maintenance, capacity factors and taxes or carbon costs, all of which should be considered when calculating the cost of electricity production, for which for instance the Levelised Cost of Electricity (the LCOE, see for instance IEA, 2010a), in the case of the power sector, is a good representation of the way investors evaluate technology costs (and in a similar construction for other sectors of technology). As argued in our previous work (Mercure, 2012b; Mercure and Salas, 2012), the limitation of the expansion of certain types of energy systems is well reproduced by cost–supply curves, which track the increasing marginal cost of production of energy with increasing demand, through its influence into certain components of the LCOE (e.g. fuel costs, capacity factors, investment costs, etc.).

Modelling energy flows from renewables and non-renewable resources entails large conceptual differences. Cost–supply curves have been generated for different types of renewable resources in works by Hoogwijk (2004), Hoogwijk et al. (2004, 2005), de Vries et al. (2007), and van Vuuren et al. (2009), using the cumulative sum of cost rankings of the global number of potential sites for energy production by type (wind, solar and biomass energy). This involves the assumption that these renewable resources are chosen and exploited in order of cost, starting with the most profitable development ventures. The cost–quantity availability of non-renewable resources such as oil and gas can also be expressed using a cost–quantity curve (as in Rogner, 1997; Mercure and Salas, 2012), which expresses a quantity available at a certain exploitation cost rather than a flow. Such a curve, however, is much more difficult to interpret in order to derive marginal costs, since taking the assumption that consumption progresses in perfect order of exploitation cost is not reliable, and the gradual depletion of fixed amounts of resource means that the cost–quantity curve changes with time. In contrast, as apparent in the oil industry for instance, the exploitation costs of existing projects cover a wide range rather than a single competitive value, depending on the nature and quality of resource occurrences (ETSAP, 2010a,b). This range is determined by the price of oil. There is thus a connection between the supply and the price of energy commodities, where higher prices enable production at higher costs, and therefore the accession of larger amounts of resource at such costs. Meanwhile, the demand for energy commodities may justify increases of prices, in order to enable production at higher costs, such that the demand is met by the supply, using ever more difficult and expensive methods, locations and types of resources (ultra-deep offshore drilling, arctic sites, tar sands, oil shales, etc.). However, high prices, as for instance generated by depletion and scarcity, may also be avoided by simply phasing out the use of certain types of high price commodities, replacing them by other types. Such substitutions actually stem from technology substitutions, which can become economical in the event of the price of some

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[1] The global output of the energy and fuel supply industries makes 2–3% of global GDP and decreasing, values obtained from our own E3MG-FTT calculations (Mercure et al., in preparation).

[2] This is also a pronounced effect in E3MG-FTT results.

[3] Most models rely on outdated and fixed (i.e. not time dependent) cost–supply curves from Rogner (1997).

[4] As can readily be observed using E3MG-FTT with different scenarios of energy prices. E3MG-FTT is an econometric model that extrapolates such trends from data (Mercure et al., in preparation).