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Diffusion of nuclear energy in some developing countries

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A B S T R A C T

Electric power demand is increasing worldwide and, in the last years, energy policy has focused on expanding nuclear power, especially in developing countries. One of the key points surrounding this issue is the depletion time of uranium; further, forecasters had estimated that the use of nuclear reactors would come to a halt in 2020 by IAEA. It is apparent that we can no longer sustain the evolutionary model of energy consumption typical of the last century. The Fukushima disaster of 2011 reopened the debate about the use of nuclear energy to produce electricity. Japan, Switzerland and Germany decided to halt new nuclear projects. However, the question remains: would the world's uranium resources suffice to meet nuclear energy projects, especially those slated in the developing countries? This paper offers an analysis of nuclear energy diffusion of some graduated developing countries (the Slovak Republic and South Korea) and some developing countries (Ukraine, China, Bulgaria, and India); moreover, it estimates the depletion time of uranium using a Generalized Bass model and OECD forecasts, with the uranium requirements scheduled for 2035. This study concludes that, given the estimated depletion time of uranium, and considering 50 years as a reasonable lifetime for reactors, the present international nuclear energy policy, and in particular the nuclear projects of the developing countries are not sustainable.

1. Introduction

The diffusion of a life-style model that proposes western development in countries such as China and India, offers one of the reasons for the increase in the world's energy demand.

One of the most difficult challenges of the future will be to maintain a balance between energy demand for economic and social progress and the consequent environmental and social–political impacts deriving from this demand. Direct signals include, for instance, atmospheric changes, sweltering summers, and geological disasters that happen with unusual frequency.

The present economic system essentially grounded on energy deriving from fossil fuels, which strongly contributed to the greenhouse effect, now faces its imminent depletion era. To this end, nuclear energy offers one possible answer as a CO_2-free, safe, and cheap solution to the world's energy problems [1]. Starting in 1950, we can identify at least two important periods of nuclear energy expansion: the years from the 1980's to the 1990's, and from the 1990's to today. The first period shows a slowing down due to different factors, such as the fall of fossil fuel prices in 1983, the liberalization of the energy market first in the United States and then in Europe, and the accidents of Three Mile Island in 1979 and of Chernobyl in 1986. The second period, on the other hand, represents a sort of nuclear renaissance, but it came to a screeching halt after the Fukushima Dai-Ichi accident in March of 2011.

Governments worldwide are revising their nuclear policies in reaction to the Fukushima Dai-Ichi accident, but not in the same direction or with the same intensity. Some, predominantly developed, countries, like, for example Germany and Switzerland, have decided to gradually phase out the use of nuclear power, by exploiting operational nuclear reactors

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through their natural life cycles. Notably, relative to the concept of natural life cycle, in 2009 one half of US nuclear plants obtained a life extension license, from 40 to 60 years, by the Nuclear Regulatory Commission; after Fukushima, Germany and Switzerland extended the lifetime of reactors from 40 to 50 years, while Japan extended its to 60 years [2]. Italy, on the other hand, dropped a proposed project to return to the use of nuclear energy. At the same time, the uncomfortable perception of the unavoidability of safety and security questions brings countries, especially developed countries, to naturally invest in the use of renewable resources and new advanced technologies [3], that could lead to solutions, for instance, to the well-known storage problems in this field. On the other hand, developing countries, the principal followers of nuclear expansion before the Fukushima Dai-Ichi accident, are at present more focused on checking the safety of operational reactors, rather than dropping their challenging future nuclear projects.

Developing countries have scarce other opportunities to confront their greatly increasing energy demands, chiefly because of a set of common political and economical backgrounds shared by all these countries. In general, the developing countries lack energy resources for geological reasons and others, such as having experienced wars that have destroyed industrial facilities [4]. Moreover, a lack of private investment money strongly restricts free enterprise leveling off living standards of the populations, as also Mallah [5] highlights in an analysis of energy options in India. In addition, an ever-increasing population density and the presence of weak, uncertain, and naive governments limit the opportunities. These remarks automatically lead us to consider unworkable any clean energy technologies. As a matter of fact Chow et al. [6] remarked that investment in renewable resources requires economical efforts that are not perceived as effective and fully convenient, also considering critical electrical grid conditions. China represents an exception, since it is the world's leading investor in renewable energy technologies and it has become the largest market for wind power; by 2009, China derived over 17% of its energy from renewable sources, most notably from hydroelectric power plants [7]. At the same time, nuclear energy is seen as a reliable, clean (at least in terms of CO_2 emissions), and abundant energy source like no other. China itself has the most challenging nuclear projects in the world (see Subsection 3.3). For South Korea, Lee and Jung [8] compared coal and nuclear as major electricity sources and concluded that the latter offers a unique solution from economic, environmental, and sustainability points of view. Choi et al. [4] see the success of South Korea's nuclear program as a symbol of the planning and organizational skill of a country that has chosen to bet on nuclear power. These considerations are not directly connected to the presence of energy reserves in the region, because they are not necessary for full economic development; in fact many energy-bereft countries have become highly developed and others countries that conversely had substantial reserves still remain among the poorest countries. In this sense, the aspect that seems particularly relevant for energy development of a country is the presence of a well-functioning socio-economic system able to control the energy resources for its full social benefit [6].

The paper first focuses on the expansion of nuclear power demand in those developing countries that now represent the most important supporters of nuclear projects. In particular, we analyze the production of electric power (TWh) coming from operational nuclear reactors of the developing countries of Ukraine, China, Bulgaria, India, and also the graduated developing countries of the Slovak Republic and South Korea, considered developing countries until recently.[1]

Later, this paper discusses the availability of uranium which plays a central role in international nuclear policies. Some countries, such as China, have very challenging projects planned for the near future, all of them depending on uranium availability. Providing an estimate of this latter represents a great challenge itself, such as predicting how long it will last. In fact, reactor technology is focusing on fuel efficiency utilization, but testing nuclear technical progresses is far from easy, due to environmental and worker safety issues. The literature has widely discussed the total amount of uranium available on Earth. At present, forecasts of uranium availability are mainly given by OECD [9] through Reasonably Assured Resources (RAR) and through IDentified Resources (IDR, that is RAR plus Inferred Resources). Based on geological certainties and costs of production, these estimates refer to direct measurements of uranium deposits and sometimes on feasibility studies, with a different degree of confidence between RAR and Inferred Resources.

In this paper, considering uranium as a finite resource [10] and following the theory about diffusion models [11,12], we adopt a quantitative method based upon the Generalized Bass Model (GBM) that uses only world uranium production data (tons) from 1945 to 2009 (source: IAEA PRIS). In this way we avoid the problem of uncertainty based on measurements of reserves and geological resources, which have different degrees of reliability, estimating directly from production data the whole life cycle of uranium, as Guseo et al. [13] did for oil. Moreover, in the GBM, the inclusion of exogenous variables that capture interventions of economic and political nature gives back a more dynamic and flexible model able to interpret the complex factors that contribute to determining the life cycle of energy resources. So, we perform GBM modeling for both the cross-country analyses of the production of electric power (TWh) and the uranium life cycle. We compare GBM estimates with those provided by OECD [9], focusing the debate on the feasibility of the nuclear energy projects of the countries studied for the future. In addition, we discuss the estimate disparities, taking also into account the depletion time of uranium and the growth of uranium requirements as estimated by OECD [9].

The remainder of the paper is structured as follows. Section 2 presents the basics of the GBM; Section 3 shows the diffusion of nuclear energy in the developing countries, and Section 4 exhibits the analysis of the life cycle of uranium, in both cases through GBMs. Section 4 also includes a debate on the feasibility of the nuclear projects, while conclusions are given in Section 5.

2. The model

In this section we present some basic concepts of the Bass model and the GBM, after a brief introduction about other most popular diffusion models. The literature about diffusion

[1] In the following, for brevity, we refer to all of these countries using the term "*developing*" countries.