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Carbon free energy development and the role of small modular reactors: A review and decision framework for deployment in developing countries

Geoffrey Black [a,*,†], Meredith A. Taylor Black [b], David Solan [c], David Shropshire [d]

[a] Department of Economics, College of Business & Economics, Boise State University, Boise, ID, USA
[b] International Business Programs, College of Business & Economics, Boise State University, Boise, ID, USA
[c] Energy Policy Institute, Boise State University, Boise, ID, USA
[d] Department of Nuclear Energy, International Atomic Energy Agency, Vienna, Austria

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ABSTRACT

Global energy demand is projected to continue to grow over the next two decades, especially in developing economies. An emerging energy technology with distinct advantages for growing economies is small modular nuclear reactors (SMRs). Their smaller size makes them suitable for areas with limited grid capacities and dispersed populations while enabling flexibility in generating capacity and fuel sources. They have the ability to pair well with renewable energy sources, the major source of increased energy capacity for many developing economies. Further advantages include their passive safety features, lower capital requirements, and reduced construction times. As a result, SMRs have potential for overcoming energy poverty issues for growing economies without increasing carbon emissions.

This study reviews the features and viability of SMRs to meet increasing energy capacity needs and develops a decision support framework to evaluate the market conditions for SMR deployment to emerging economies. The focus is on identifying countries best suited for domestic deployment of SMRs rather than vendor countries with ongoing or future SMR development programs for export. We begin by examining the characteristics of over two hundred countries and identifying those that satisfy several necessary economic, electrical grid capacity, and nuclear security conditions. Countries satisfying these necessary conditions are then evaluated using the Analytical Hierarchy Process (AHP) using criteria related to the economic and financial conditions, infrastructure and technological framework, and governmental policies within each country. The results find that countries with increasing GDP and energy demand that possess a robust infrastructure, energy production from high GHG sources, and governmental policies favorable to foreign investment are well-suited for future SMR deployment.

Contents

* Correspondence to: Department of Economics, College of Business & Economics, Boise State University, Boise, ID 83725-1620, USA. Tel.: +1 208 426 1359.
† The authors would like to recognize graduate students, Timothy Montoya and Wesley Labor, for their contributions to this research.
E-mail address: gblack@boisestate.edu (G. Black).

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1. Introduction

Global energy demand is growing and projected to rise by more than fifty percent by 2040, with most of this growth occurring in developing economies [1,2]. Recent projections forecast a ninety percent increase in energy use in countries outside the Organization for Economic Cooperation and Development (OECD); while energy use in OECD countries is expected to rise by only seventeen percent over this time frame [2]. The use of fossil fuels as the primary sources of energy production is projected to continue into the foreseeable future, especially in China and India which are projected to account for seventy-five percent of increased coal usage [3]. However, there are likely to be significant changes in the supply mix. Given that electricity production is the largest source of greenhouse gas (GHG) emissions globally, and especially in developing economies [4–6], increasing concerns with climate change will result in growing demand for low-carbon and renewable energy sources. This is already evident in the dramatic growth in energy production from renewable energy sources over the past several years with ongoing increases projected through 2040 [1,7]. In addition to renewable energy sources such as solar, wind, hydroelectric, biomass, and geothermal, the growing demand for low-GHG energy sources will likely increase the demand for nuclear energy. A recent article in this journal by Amponsah et al. [8] notes that, on a life-cycle basis, nuclear ranks second behind offshore wind as the lowest source of GHG emissions of electricity generation methods, with about one-third of the GHG emissions from hydroelectric, less than twenty percent of GHG emissions from solar and onshore wind production and less than five percent of GHG emissions from biomass and natural gas energy production. Indeed, the recently released International Energy Outlook states that renewables and nuclear power are the fastest growing sources of global energy [9].

Although the projected demand for new energy is greatest in developing countries, the use of large nuclear power plants (NPPs) is not often a viable option for many emerging economies given the large grid sizes, concentrated populations, and high capital costs required for NPPs. A new technology currently being developed with the potential to make significant contributions to meeting both future energy demands and carbon reduction targets is small modular nuclear reactors (SMR). As former U.S. Secretary of Energy Steven Chu stated in 2010:

> If we are serious about cutting carbon pollution, then nuclear power must be part of the solution. Countries such as China, South Korea and India have recognized this and are making investments in nuclear power that are driving demand for nuclear technologies. Our choice is clear: Develop these technologies today or import them tomorrow…..one of the most promising areas is small modular reactors (SMRs). [10]

One question, raised in several recent articles in this journal and elsewhere, is the relationship between carbon reduction, through the increased use of renewable energy sources, and economic growth. Farhani and Shabaz [11], for example, find that reductions in CO_2 emissions may be associated with slower economic growth in some developing regions. Park and Hong [12] find similar results for South Korea. Halkos and Tzermes [13] find a negative correlation between electricity consumption from renewable sources and economic growth in developing countries, but they note that the relationship is positive for developed economies. At the same time, Terrapon-Pfaff [14] find access to energy to be a crucial element in reducing poverty in developing nations and that small-scale renewable energy projects can lead to sustainable economic growth in emerging economies.

In order to foster economic development while addressing carbon reduction concerns, the adoption of SMRs is a viable policy option. This emerging energy technology has distinct advantages for growing economies. They are able to pair with renewable energy sources, have significantly lower capital costs compared to large nuclear power plants (NPPs) or coal facilities, and are better able to match the lower energy outputs and less developed energy infrastructures of emerging economies. In addition, SMR designs incorporate high levels of passive safety systems and security features and offer the flexibility to support electrical generation as well as cogeneration, industrial heat, desalinization, and other uses particularly important to developing countries. SMRs are of particular interest to government officials, industry, international organizations, and environmental groups because of their potential impacts on economic growth, climate change mitigation, nonproliferation efforts, and waste disposal. In short, SMRs have significant potential for supplying a meaningful portion of rising energy demand over the coming decades, especially in emerging economies, while reducing the demand for fossil-fueled sources of energy production.

This study addresses the suitability of SMRs to meet part of the growing demand for carbon-free energy. It begins by reviewing the features of SMRs as described in a small, but growing, literature on this new technology. SMRs are less than one-third the size of conventional NPPs and are designed to be modular in construction, thus enabling them to be transported by truck, rail, or ship. Their modular components are assembled on-site. These features make them suitable for locations with smaller grid size and lower capacity needs than those where larger nuclear, coal, or other conventional power sources are appropriate. Similarly, their smaller size and modularity allow for increased flexibility to accommodate gradual increases in demand and require lower capital costs and construction times than large conventional power plants. SMR designs incorporate passive safety features that, along with their modularity, require fewer trained personnel for on-site deployment and operation. Further, most SMR designs have the ability to pair with renewable energy sources, such as wind and solar, where the ability to load-follow promotes both energy production and grid stability. In addition to these advantages for electricity production, some SMR designs are suitable where cogeneration and non-electrical industrial applications are needed.

Given these features and advantages, SMRs are well poised to meet part of the future demand for carbon-free energy production not only in developed economies but also, especially, in developing nations. However, very little research has taken